THE WORLD'S WATER

Volume 7

The Biennial Report on Freshwater Resources

Peter H. Gleick

Lucy Allen

Juliet Christian-Smith

Michael J. Cohen

Heather Cooley

Matthew Heberger

Jason Morrison

Meena Palaniappan

Peter Schulte

- U.S. Water Policy
- Water and Fossil Fuels
- International Water Quality
- Transboundary Water and Climate Change
- Corporate Water Management
- Drought and Water Management in Australia
- China and Dams

About the Pacific Institute for Studies in Development, Environment, and Security

The Pacific Institute is one of the world's leading research and policy nonprofits working to create a healthier planet and sustainable communities. Based in Oakland, California, we conduct interdisciplinary research and partner with stakeholders to produce solutions that advance environmental protection, economic development, international security, and social equity—nationally and internationally. Since the Institute's founding in 1987, we have worked to change policy and find real-world solutions to problems like water shortages, habitat destruction, global warming, and environmental injustice, with the fundamental idea that adequate, safe, clean water are closely connected to every vital resource issue of our time. We have moved the focus of water thinking away from narrow approaches and toward more integrated and sustainable water practices and concepts through rigorous independent research, extensive policy engagement, and intensive outreach to the public. The Pacific Institute has formulated a new vision for long-term water planning in California and internationally, developed a new approach for valuing well-being in local communities, worked on transborder environment and trade issues in North America and beyond, analyzed standards in global environmental protection, clarified key concepts and criteria for sustainable water use, offered recommendations for reducing conflicts over water in the Middle East, Latin America, and Central Asia, championed the human right to water, assessed the impacts of global warming on freshwater resources, and created programs to address environmental justice concerns in low-income communities and communities of color. Our research has reached tens of millions of people through reports, projects, speeches, testimony, and media; more than 100 research papers, reports, and testimonies are available free on the Pacific Institute websites at www.pacinst.org and www.worldwater.org.

THE WORLD'S WATER

Volume 7

The Biennial Report on Freshwater Resources

Peter H. Gleick
with Lucy Allen, Michael J. Cohen, Heather Cooley, Juliet Christian-Smith, Matthew Heberger, Jason Morrison, Meena Palaniappan, and Peter Schulte

ISLANDPRESS
Washington | Covelo | London

ISBN 978-1-59726-998-8 (cloth)
ISBN 978-1-59726-999-5 (paper)

ISSN 15287-7165

Printed on recycled, acid-free paper

Manufactured in the United States of America
10 9 8 7 6 5 4 3 2 1

Contents

DATA SECTION

Foreword

The hydrologic cycle teaches that we can neither make nor destroy water. We're drinking the same H_2O as the dinosaurs did. But if that's true, how can there be a water crisis? There are two reasons. First, Mother Nature can be cruel; the worldwide distribution and management of water is very uneven, which partly explains why more than one billion people lack access to safe drinking water. Second, we're using water faster than Mother Nature replenishes it. Diversions from rivers, pumping from wells, and pollution by farms, cities, and industry all compromise the supply of water. Each of these activities has contributed, over the span of many years, to the current crisis. And each has been documented, and expertly analyzed, in the pages of *The World's Water* since the first volume appeared in 1999.

Now, as Peter Gleick and his colleagues at the Pacific Institute release Volume 7 in the series, global climate change has upped the ante—increasing the threat to our water supply. Air and ocean temperatures continue to reach record highs, glaciers and polar ice-caps are rapidly melting, and extreme events—floods, droughts, hurricanes, and typhoons—are increasing. In the United States, ominous predictions about flows in western rivers presage frightening shortages. Chapter 1 in this volume tackles the challenges facing transboundary water resources in the face of climate changes.

On the demand side, population growth and rising energy use drive the need for more water, even in a relatively water-rich country like the United States. At long last, we are recognizing the connection between water and energy production—a link explored in Chapter 4 of this volume. Gleick and his colleagues give us a frightening statistic: 22 percent of all water used is for industrial purposes, including fossil-fuel extraction and power generation. As the demand for energy worldwide spirals upward, it will take even more immense quantities of water to satisfy the demand for power. Even the Internet is fueling this upsurge, with companies such as Intel and Google using large volumes of water to produce their semiconductor chips and to run their "server farms."

This last point illustrates a profound reality: water is not only a necessity of life and an environmental amenity; it also drives economies. Water is a critical input not just for obvious companies, such as Coca-Cola and other food producers, but also for industrial concerns, ranging from the steel industry to high-tech companies. Gleick and his coauthors argue that shortages have finally begun to force businesses to manage water more responsibility. If they don't, it is not just a moral stain or a public relations problem but a real threat to their bottom lines. Chapter 2 examines the risks that water poses for companies and explains how better management can reduce those risks.

In addition to corporate responsibility, how else can we prevent the water crisis from becoming a catastrophe? We have a menu of options, but the status quo is not one of them. In the United States, the usual response to water shortages is to divert more water from rivers, build more dams, and drill more groundwater wells. These traditional alternatives are not viable solutions. Other ideas—surreal ones—include towing icebergs from the Arctic, importing water from British Columbia, and seeding clouds. These ideas reflect a misguided hope that there is a new oasis out there, somewhere, that will obviate the need to examine carefully how and for what we use water. More sensible approaches include conservation, desalination, and reuse of treated municipal effluent. Yet even communities that have embraced these measures still face ominous water futures.

As the final chapter in this volume argues, what we in the United States desperately need is a "21st century water policy." Rather than foolishly trying to create new supplies of water, we must use the resources we have more effectively. And that means using (1) price signals to encourage water conservation and (2) market forces to encourage the reallocation of water from lower-value to higher-value uses. In addition to economic tools, Gleick and his coauthors throughout this volume examine what we can learn about water management reform from other countries (from Australia to South Africa to Russia and beyond), and how the U.S. government can play a more constructive role in protecting our water supply.

In short, we have options to prevent the crisis from turning into a catastrophe. Now, we need the moral courage and political will to act. And—as always—we need reliable data and expert analysis to guide our reform efforts. For more than a decade, *The World's Water* has provided those critical insights. Readers who regularly anticipate the biennial release of the series will find Volume 7 a treasure trove. It includes not only amazingly comprehensive data, with detailed charts and graphs about the world's freshwater resources, but also provocative and original essays. This book is a resource in itself.

Robert Glennon
Author of Unquenchable *and* Water Follies
Morris K. Udall Professor of Law and Public Policy
University of Arizona

Introduction

Welcome to the latest volume of *The World's Water*. With this volume, we are modestly changing how we name and number the series, moving away from the "year" identifiers and renaming them by volume. This book is thus Volume 7—the seventh in the series produced since 1999. Our goals remain the same: to help improve global understanding of the water challenges and the availability of solutions. Alas, the world water crisis remains: basic human needs for water and sanitation remain unmet for far too many, with serious adverse health and community impacts. Climate change has become increasingly apparent, with growing evidence of impacts on hydrology and our built water systems. Ecosystems continue to deteriorate in many parts of the world. And tensions over water allocations and use are growing, not diminishing. But if there is any good news, it is that these crises in water are also receiving more attention from policy makers, scientists, the media, and members of the public, and that there are effective solutions to these problems. So, I believe that the need for *The World's Water* remains. New thinking about solutions and sustainable water planning and management, better data, case studies, and efforts to raise awareness, are all needed. As with the first six volumes, I and my colleagues explore a subset of the many pressing water issues based on timeliness, urgency, and our own experience and priorities. There is no shortage of topics to address, and as always, it is a challenge to try to choose among them for inclusion in the books. In Volume 7, we tackle some new topics and revisit and update some older ones. We provide a Comprehensive Table of Contents and an integrated index across all seven volumes, to help readers find information in other volumes that might be useful for their research or other efforts.

Chapter 1 offers an overview of the rapidly unfolding connections between climate change and transboundary water resources, including both surface and groundwater. This chapter summarizes work the Pacific Institute recently completed for the United Nations Environment Programme and expands the long line of studies produced at the Institute on the links between climate and water. Chapter 2 summarizes major new work on understanding and classifying water-related risks for the corporate sector and how to define responsible and sustainable corporate water management. This work exemplifies our belief that the corporate sector must develop improved standards around water management and use more rapidly and work with affected communities far more closely than has been the case in the past. This volume also offers a comprehensive overview and perspective on water-quality challenges globally (Chapter 3), also based on work done for the United Nations Environment Programme. Water quality is often the lonely stepchild of more extensive work on water quantity and availability, yet some of the most serious water challenges are related to contamination. Indeed, many water-availability problems have, at their root, water-quality origins. We also offer some suggestions about new approaches for more quickly and comprehensively addressing water-quality problems. Chapter 4 expands on the issues of water quality in the specific context of producing fossil fuels. We have previously written about the links between water and energy (in Volumes 1 and 2 related to hydroelectric dams, in Volume 5 in a chapter on desalination, and elsewhere). This new chapter expands that work to address a serious water-quality threat related to energy policies and activities, including the new and increasingly worrisome implications associated with "fracking" natural gas formations. Chapter 5 explores the dramatic consequences of the long, severe drought recently experienced by the people and ecosystems of Australia. The responses of that nation offer insights into how difficult long-term climatic changes may be to address, the complications of developing water markets and policies for reallocating water, and the kinds of institutional changes that serious disruptions of expected water availability can cause. Chapter 6 expands on a topic touched on in earlier volumes: the water catastrophe rapidly unfolding in China. Chinese water challenges have often been a topic in these books: the first volume included a comprehensive assessment of the Three Gorges Dam project, then under construction, and the status and implications of that project were reevaluated in the most recent book, Volume 6. Volume 6 also included a comprehensive chapter on China's water crisis. Chapter 6 in the current volume focuses on China's dam policies, both within the country and outside its borders where massive Chinese investments and construction projects are under way, with controversial impacts. The final chapter looks at the need for a comprehensive reform of United States water policy at the federal level, drawing on lessons from recent international experience with water policy. This chapter is an advanced look at some of the work being done at the Pacific Institute to redefine U.S. water policy in a more comprehensive way.

As in the previous volumes, the major chapters are supplemented with shorter "Water Brief" reports on items of interest. Heather Cooley and I offer a summary of the energy implications of bottled water—reporting on our research into the overall energy costs of producing, transporting, and using bottled water. Peter Schulte provides an overview of the new Great Lakes water agreements as a good example of both the need for and the value of international cooperation over shared water resources. The third Water Brief offers some fun reading—for readers interested in how water is portrayed in the movies, I provide a summary of diverse dramas, comedies, action films, and more where water is a fundamental component of the plot. Some of the earliest movies ever made portray conflicts over water in the western United States; more recently, water has appeared regularly in science fiction, comedies, and post-apocalyptic movies where themes include access to water, attacks on water systems, or evil corporate world dominators bent on controlling water or the world economy. Add some of these to your Netflix list! And send us examples we have missed. We also bring to the readers, again, our tremendously popular Water Conflict Chronology, with many new historical examples of conflicts related to water going back millennia. This chronology is now available in a wonderful new format online at www.worldwater.org, where readers can sort water conflicts by time, location, type of conflict, and more, and see the results in active maps.

Finally, Volume 7 of *The World's Water* again offers a wide variety of important, useful, and popular data on water in a series of Data Tables. In this volume, we present updated data on access to water and sanitation around the world, water availability and demand, the mortality rate in children under five years of age from water-related diseases, progress toward the Millennium Development Goals for water, a dataset on trends in overseas development assistance for water, insights into public opinion on critical water issues based on polls from a diverse set of organizations, information on water quality, and far more. We also provide a sobering look at the list of freshwater animals now considered to be extinct—a measure of the serious impacts humans have on our aquatic environments.

Special thanks to all of the coauthors, especially to Lucy Allen. Lucy contributed serious substance to several of the chapters, and she did a remarkable job of collecting, vetting, correcting, and writing up most of the data tables. Finally, this project has always benefited from the enthusiastic support of Todd Baldwin, my editor at Island Press. Todd has now moved on to different professional pastures, and I miss our regular interactions, his thoughtful comments and insights, and his help, but I look forward to continuing to work on *The World's Water* with Emily Davis at Island Press.

Peter H. Gleick
Oakland, California, 2011

CHAPTER 1

Climate Change and Transboundary Waters

Heather Cooley, Juliet Christian-Smith, Peter H. Gleick, Lucy Allen, and Michael J. Cohen

Freshwater is a fundamental resource, integral to all ecological and societal activities, including food and energy production, transportation, waste disposal, industrial development, habitat for fish species, and human health. Yet freshwater resources are unevenly and irregularly distributed, with some regions of the world extremely short of water. Political borders and boundaries rarely coincide with borders of watersheds, ensuring that politics inevitably intrude on water policy. Indeed, over 260 river basins are shared by two or more nations. Just as oil creates disputes between states, water also plays a role in international conflicts. Inequities in the distribution, use, and consequences of water management have been a source of tension and dispute. In addition, as previous volumes of *The World's Water* have explored (see, for example, Gleick 1998), water resources have been used to achieve military and political goals, and water systems and infrastructure, such as dams and supply canals, have long been military targets.

In 1994, the Pacific Institute created the Water Conflict Chronology, which summarizes historical disputes over water resources (Gleick 1994, Hatami and Gleick 1994). Each volume of *The World's Water*, including this one, contains detailed chronologies of water-related disputes, and an updated online version of the complete Water Conflict Chronology was released in December 2009. The online version links historical information with Google Earth and an interactive timeline (see www.worldwater.org). This chronology suggests that one of the most important changes in the nature of conflicts over the past several decades has been the growing severity and intensity of local and sub-national conflicts and the relative de-emphasis of conflicts at the international level. A growing number of disputes over allocations of water across local borders, ethnic boundaries, or between economic groups have also led to conflict.

The good news is that water disputes are generally resolved diplomatically, and shared water resources are often a source of cooperation and negotiation. An estimated 300 agreements have been developed between riparian states—those states with territory within a shared river basin. But the long history of violence associated with transboundary water resources highlights the challenges associated with managing shared water resources (see, for example, the growing disputes between China and its neighbors in Chapter 6 in this volume).

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_1,

Future pressures, such as population and economic growth and climate change, could increase tensions, even in areas that in the past have been characterized by cooperation. Global climate change will pose new challenges for freshwater management as a result of changes in water quantity, water quality, water-system operations, and more. For countries whose watersheds and river basins lie wholly within their own political boundaries, adapting to increasingly severe climate changes will be difficult enough. When those water resources cross borders, bringing in multiple political entities and actors, sustainable management of shared water resources in a changing climate will be especially challenging.

To what degree can existing transboundary agreements or international principles for sharing water handle the strain of future pressures, particularly climate change? Climate changes will inevitably alter the form, intensity, and timing of water demand, precipitation, and runoff, meaning past climate conditions are no longer an adequate predictor of the future. At the same time, new disputes are arising in transboundary watersheds and are likely to become more common with increasing pressures. Thus, transboundary agreements are needed now more than ever, but new forms or arrangements for such agreements may be necessary and old agreements may need to be renegotiated in the context of a changing climate. As Goldenman noted in 1990: "One of the major challenges ahead for the international community will be to develop the principles, procedures, and institutions for managing and protecting shared resources, such as watercourse systems, at the same time that the Earth adapts to climate change."

Little progress has been made in this area in the subsequent two decades. This chapter outlines some of the risks that climate change poses to transboundary water agreements, drawing from a larger report on the topic released in December 2009 (Cooley et al. 2009). In the following sections, we define the extent and general characteristics of transboundary rivers and aquifers and describe some of the institutional structures that have developed to manage them, including both international guidelines and specific transboundary agreements. We then provide a brief overview of the current understanding of climate change, focusing on potential impacts on water resources in order to analyze how transboundary water management could better adapt to and incorporate climate change impacts. We provide three case studies to demonstrate the range of potential impacts of climate change and degree of integration into transboundary water management and conclude with a series of recommendations to reduce the risks that climate change poses to transboundary water resources.

Transboundary Rivers and Aquifers

Many rivers, lakes, and groundwater aquifers are shared by two or more nations, and most of the available freshwater of the Earth crosses political borders. International basins cover about half of the earth's land surface, and about 40 percent of the world's population relies on these shared water sources (Wolf et al. 1999). In 1958, the United Nations published the first comprehensive collection of information on shared international rivers of the world (UN 1958). This early assessment identified 166 major international river basins. In 1978, the United Nations published an updated assessment (UN 1978) identifying 214 such basins. By today's standards, the analysis and mapping of these river basins were crude and subject to large errors. Measurements were based on regional maps and taken by hand with a planimeter—a tool today's generation of digital mappers has never used. In the 1978 assessment, only "first order" basins, or those that drain directly to the final water body (the ocean or a closed inland sea or lake), were included to distinguish them from tributary basins.

This approach is still used today, even though some second- or even third-order tributaries of major rivers may be substantially larger in size than most first-order coastal basins. Many tributary basins may also be more important politically and economically. Thus, the scale of analysis is vitally important, and one should not presume that river basins excluded here are unimportant or irrelevant for regional or even international politics. For example, the Cauvery River basin is entirely contained within one nation—India—and hence is not included in international registries. Yet the Cauvery River has been the source of intense interstate rivalry, and even violent conflict, between the Indian states of Karnataka and Tamil Nadu (Gleick 1993).

The world has changed significantly since the 1978 assessment. The current registry, prepared by Aaron Wolf and several colleagues (Wolf et al. 1999) and updated in 2002, now identifies 263 major transboundary river basins, covering nearly half of the ice-free land surface of the Earth (Table 1.1). The increase in the number of basins since the last comprehensive survey reflects changes in the political landscape, improvements in mapping technology, and the inclusion of river basins on island nations. Our abilities to precisely measure topography, identify geographical characteristics in flat terrain, and accurately map both geophysical and geopolitical borders have dramatically improved. The most important of these changes has been the disintegration of the Soviet Union—once the largest single county in the world—into 15 separate nations. Many of the world's largest rivers flow in the territories of these nations, and the breakup of the Soviet Union has resulted in many new international rivers.

Until recently, little information was available at the global level on shared groundwater basins. Yet, an estimated 99 percent of the Earth's accessible freshwater is found in aquifers, and about two billion people rely on aquifers as the sole source of their water (UNESCO 2009). In October 2009, UNESCO released the *Atlas of Transboundary Aquifers*, which identified 269 shared groundwater basins. Thus, while groundwater is typically ignored, there are in fact more shared aquifers than shared river basins. The areal extent of shared aquifers has not yet been compiled due to uncertainties about the spatial extent of many transboundary aquifers.

TABLE 1.1 The World's Transboundary Rivers and Aquifers

	Transboundary River Basins		Transboundary Aquifers	
	Number	Percent of Area in International Basins (%)	Number	Percent of Area in International Aquifers (%)*
Africa	59	62	40	—
Asia	57	40	70	—
Europe	69	55	89	—
North and Central America	40	37	41	—
South America	38	59	29	—
Total (global)	263	48	269	—

*Data on areas of transboundary aquifers is limited, and only available for select aquifers.

Source: International river basins from Wolf et al. 1999 and updated in 2002; international aquifers from UNESCO 2009.

Managing Transboundary Basins

Since transboundary watersheds traverse political and jurisdictional lines, heterogeneous and sometimes conflicting national laws and regulatory frameworks make management a major challenge, particularly when no single national government has authority over another. As such, transboundary water management often requires the creation of international guidelines or specific agreements between riparian states. Thus, transboundary water agreements typically take two forms: (1) general principles of international behavior and law and (2) specific bilateral or multilateral treaties negotiated for particular river basins. We describe each below.

General Principles of International Behavior and Law

At the turn of the nineteenth century, the Attorney General of the United States (Justice Judson Harmon) gave an opinion regarding the uses of the Rio Grande, a transboundary watershed shared by the United States and Mexico. In his opinion, Justice Harmon concluded that a state is free to dispose of the waters of an international river that are within its own territory in any manner it deems fit, without concern for the harm or adverse impact that such use may cause to other riparian states. This approach—now known as the Harmon Doctrine—was criticized and ultimately rejected by subsequent legal decisions. In its place, international tribunals drew up a series of general principles that prohibit riparian states from causing harm to other states and that call for cooperation and peaceful resolution of disputes (Salman 2007).

One of the first of these sets of principles was the Helsinki Rules on the Uses of the Waters of International Rivers (the Helsinki Rules), adopted by the International Law Association (ILA) in 1966. The Helsinki Rules were the first comprehensive, international guidelines to regulate the use of transboundary rivers and their connected groundwater aquifers. They established the principle of "reasonable and equitable utilization" of the waters of an international drainage basin among the riparian states as the basic principle of international water law (Salman 2007). For that purpose, the Helsinki Rules specified a number of factors for determining the reasonable and equitable share for each basin state, including (a) the geography and hydrology of the basin, including the contribution of water by each basin state; (b) past utilization of the waters of the basin; (c) the economic and social needs of each basin state; and (d) the availability of other resources (ILA 1966). Although these principles are widely recognized and have greatly influenced subsequent agreements, there is no mechanism in place to enforce them.

The Helsinki Rules were followed by the Convention on the Law of the Non-navigational Uses of International Watercourses (UN Convention), adopted by the UN General Assembly in May 1997 after two decades of negotiations.[1] The UN Convention is the strongest international legal instrument regarding transboundary water management to date. Several articles of the UN Convention are designed to reduce the risks of disputes over shared rivers: Article 7 obliges states to take all appropriate measures to prevent harm to other states from their use of water; Article 8 obliges watercourse states to cooperate on the basis of equality, integrity, mutual benefit, and good faith in order to optimally use and protect shared watercourses; and Article 33 offers provisions for the peaceful settlement of disputes by negotiation, mediation, arbitration, or appeal to the

1. The full text of the Convention can be found at the United Nations, http://untreaty.un.org/ilc/texts/instruments/english/conventions/8_3_1997.pdf.

International Court of Justice. More than a decade after its adoption by the vast majority of the General Assembly of the United Nations, however, the Convention has not obtained the necessary number of signatures to enable it to enter into force and effect. As of February 2011, only 16 countries had ratified or acceded to the Convention; 35 signatures are needed for the Convention to enter into force.

The most recent set of international rules for transboundary water management were established in 2004 and are known as the Berlin Rules. These rules draw heavily from both the Helsinki Rules and the UN Convention, although they also attempt to better integrate emerging principles, such as ecological integrity, sustainability, public participation, and minimization of environmental harm. These principles, according to Dellapenna (2007), are not reflected in the Helsinki Rules and are developed only in rudimentary form in the UN Convention. Thus, the Berlin Rules are an effort to bring all relevant established and emerging international law together in regard to transboundary water resources. Salman (2007) points to three basic features that distinguish the Berlin Rules from their predecessors:

1. Provisions in the Berlin Rules apply to both national and international waters;
2. The Berlin Rules incorporate emerging principles from international environmental and human rights law; and
3. The Berlin Rules have developed coequal goals of both equitable and reasonable utilization and the obligation to cause no harm.

Specific Transboundary Agreements

In addition to basic principles of international law, hundreds of bilateral and multilateral river treaties have been signed by parties to allocate water, regulate navigation and power, monitor and control water quality, and influence all other aspects of joint water management. Given the lack of enforceable international guidelines for transboundary water management, specific transboundary treaties are currently the strongest mechanism for encouraging transboundary cooperation. The International Court of Justice has shown its desire to uphold the power of these treaties by not allowing Hungary to nullify its 1977 treaty with Slovakia regarding management of the Danube River (the Budapest Treaty) based on increased understanding of the environmental harm associated with planned infrastructure (the Gabčíkovo-Nagymaros case).

The first transboundary water agreements were written in the early and mid-19th century between countries that share the Rhine River, which flows from its headwaters in Switzerland through Germany, Luxembourg, France, and the Netherlands and empties into the North Sea.[2] These treaties established rules for allowing navigation, dividing fish harvests, and withdrawing water along the Rhine. Today, there are approximately 300 transboundary agreements on record (Gleick 2000, UNEP/OSU 2002). Of the 145 agreements negotiated in the 20th century, an overwhelming 86 percent are bilateral, suggesting that many states that should be a party to the agreement are excluded (Jägerskog and Phillips 2006). The Nile Basin Treaty, for example, was negotiated between Egypt and the Sudan, despite that fact that eight other nations are located

2. Treaty of Limits Between France and the Netherlands, 1820; the Convention between the Delegates of the Riparian States of Lake Constance: Bade, Bavaria, Austria, Switzerland and Wurtemberg, Concerning the Regulation of the Flow of Water of Lake Constance near Constance, 1857; and Treaty for the Regulation of Water Withdrawal from the Meuse, Signed at the Hague, 1863.

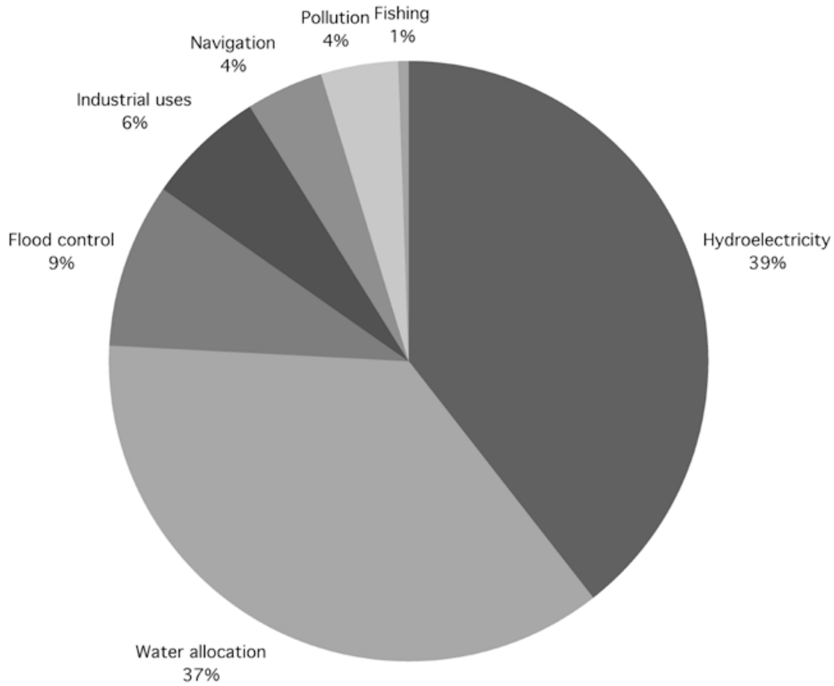

Figure 1.1 Primary Focus of Transboundary Water Agreements Adopted During the 20th Century.

Source: Jägerskog and Phillips 2006

upstream of these nations.[3] Only recently have efforts been made to bring the other nations together for a more comprehensive agreement.

Figure 1.1 provides a summary of the transboundary agreements negotiated during the 20th century. Most treaties (40 percent) focus on hydropower and, not surprisingly, are often among mountainous nations at the headwaters of the transboundary rivers. Nepal alone, with an estimated 2 percent of the world's hydropower potential, has four treaties with India (the Kosi River agreements, 1954, 1966, 1978, and the Gandak Power Project, 1959) to utilize the huge power potential in the region (Hamner and Wolf 1998). Surprisingly few treaties, only 37 percent, address water allocation and include volumetric allocations among riparian countries (Hamner and Wolf 1998). In cases where volumetric allocations are specified, they often are fixed, leaving little flexibility for changing flow conditions. As discussed below, this characteristic is especially problematic in the context of climate change.

A number of important elements of the hydrologic cycle are commonly left out of transboundary agreements. Groundwater is typically excluded; if it is mentioned at all, it is usually in reference to contamination rather than to use of groundwater resources. Many transboundary agreements that identify water allocations fail to include any standards for the quality of that water. This omission proved problematic in the 1950s and 1960s for farmers in Mexico, where increasingly saline Colorado River deliveries impaired crop production. Extensive negotiations and several amendments were

3. The ten nations sharing the Nile are Egypt, Sudan, Ethiopia, Eritrea, Uganda, Kenya, Tanzania, Burundi, Rwanda, and the Democratic Republic of Congo. While the Central African Republic also has a tiny fraction of land in the watershed (0.04 percent of the watershed), they have never claimed any legal representation or acted as a riparian in any way.

made to the U.S.–Mexico Colorado River treaty (Hundley 1966), and today, deliveries to Mexico are subject to salinity thresholds. Annual water deliveries to Mexico at Morelos Dam, for example, must have an average salinity of no more than 115 parts per million (ppm) (±30 ppm) greater than the salinity of the river at Imperial Dam.

Many transboundary agreements also lack monitoring, enforcement, and conflict resolution procedures. Only about half of the treaties have provisions for monitoring, and most monitoring efforts include only the most rudimentary elements. This is particularly problematic given that data collection and sharing often provides a base for negotiation. While disputes can be resolved by technical commissions, basin commissions, or government officials, 22 percent of treaties make no provisions for dispute resolution, and 32 percent are either incomplete or uncertain as to the creation of dispute-resolution mechanisms (Hamner and Wolf 1998).

While the conflict-resolution mechanisms in most treaties are fairly rudimentary, new monitoring technology introduces new enforcement possibilities. It is now possible to manage and monitor a watershed in real time, using a combination of remote sensing and radio-operated control systems. In fact, Hamner and Wolf (1998) suggest that the next major step in treaty development may well be mutually enforceable provisions, based in part on objective and highly detailed remote images, better chemical testing, and more accurate flow computations than previously available.

Transboundary Water Management Policies and Climate Change

Rising greenhouse-gas concentrations from human activities are causing large-scale changes to the Earth's climate system. These changes will have important implications for the hydrologic cycle. Indeed, all of the comprehensive climate reports from the Intergovernmental Panel on Climate Change (IPCC) and other national and international climate assessments conclude that freshwater systems are especially vulnerable to climate change. The Fourth Assessment Report notes that climate change will lead to "changes in all components of the freshwater system" (Kundzewicz et al. 2007) and include impacts on water availability, timing, quality, and demand.

Most transboundary water agreements, however, are based on the assumption that future water supply and quality will not change. Moreover, most treaties and international agreements lack adequate mechanisms for addressing changing social, economic, or climate conditions (for an early analysis of this problem, see Gleick 1988 and Goldenman 1990). In many cases, adapting to climate change will require changes in the institutions and policies that have been put in place under international treaties. As noted by McCaffrey (2003) in an analysis of a treaty dispute before the International Court of Justice between Hungary and Slovakia: "the law of treaties itself will not ordinarily permit unilateral modification or withdrawal" under changing circumstances, including climate change. Rather, "parties will be required to work within the framework of existing treaties to respond to changes."

A variety of mechanisms can be incorporated into existing treaties to allow for flexibility in the face of climate change. Fischhendler (2004) and McCaffrey (2003) identify four categories: (1) flexible allocation strategies, (2) drought provisions, (3) amendment and review procedures, and (4) joint management institutions. Although important, these mechanisms are highly focused on water scarcity and are less applicable to other potential climate change impacts on water resources, including increased frequency and intensity of floods and water-quality concerns. Below, we expand the scope of these mechanisms to include other potential water-related climate change impacts and provide examples where these mechanisms have been implemented.

Flexible Water Allocation Strategies and Water Quality Standards

Given the impact of climate change on water resources, transboundary agreements should address how riparian states will adapt to altered timing and availability of flows. Few treaties, however, address water allocation, perhaps due to its intensely political nature. Among those that do, about a quarter require equal allocations and the rest assign specific amounts to the various riparian states (Hamner and Wolf 1998). In most cases, these water allocations remain fixed (UNEP/OSU 2002), which does not provide the flexibility needed to adapt to changing conditions (McCaffrey 2003).

There are several legal and institutional arrangements for transboundary cooperation that can accommodate flow variability. For example, a treaty may specify that an upstream riparian state deliver a minimum flow to a downstream riparian state in order to maintain human health and key ecological functions. While this approach may be less restrictive than requiring fixed deliveries, downstream riparian nations may consider minimum flows to offer too little protection while upstream parties may be concerned about their ability to always deliver the minimum flow. Another way to enhance treaty flexibility is to allocate water based on a percentage of the flow. This allows flow regimes to respond to both wet and dry conditions, although it requires flexible infrastructure, effective operating rules, and regular communication.

Much of the literature on transboundary agreements and climate change has focused on how changes in water flows will affect various water allocation strategies. Climate change, however, may also exacerbate water-quality concerns in some locations. For example, sea-level rise may intensify saltwater intrusion in deltas; in some cases, downstream water-diversion facilities may become unviable unless freshwater inflows are increased. Greater discussion is needed on how water quality will be affected by climate change within the context of transboundary agreements. Furthermore, climate change assessments must include all of the potential impacts of climate change on water resources in order to inform transboundary management.

Response Strategy for Extreme Events

Many transboundary agreements include provisions for exceptional circumstances, such as droughts. In the agreement over the Rio Grande between the United States and Mexico, for example, Mexico is allowed to supply less than the minimum amount of water to the United States during an extraordinary drought for up to five years. During this period, Mexico incurs a water debt that they must then repay by increasing flows during the next five-year cycle. Provisions on the Colorado River are even more defined. In 2007, the United States implemented the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead*. This agreement, developed in the eighth year of the worst drought in over 100 years of record keeping, establishes specific guidelines for reduced water deliveries among basin states under drought and low-reservoir conditions. These shortage guidelines, which were developed in consultation with the Mexican government, are triggered at specific reservoir water levels in major reservoirs on the Colorado River (Lake Mead and Lake Powell), thereby providing water users with some indication of the frequency and magnitude of these events. While these guidelines were drawn up among the U.S. basin states and do not address deliveries to Mexico, they can be used as a model for transboundary agreements.

Much of the literature on transboundary agreements and climate change emphasizes the impacts of droughts on water allocation schemes (Fischhendler 2004, Kistin and Ashton 2008, McCaffrey 2003). Floods are often ignored in transboundary water management. Yet floods pose a real risk for downstream riparian nations and are expected to increase in frequency and intensity in some regions as a result of climate change. The failure to manage these risks can have catastrophic consequences. In a recent analysis, Bakker (2009) found that flood losses were higher in basins that lacked the institutional capacity for managing these events.[4] An overwhelming 43 international river basins where transboundary floods were frequent during the period 1985–2005 lacked the institutional capacity for managing these events.

Coordinated flood management can greatly reduce the risk of these events. Flood management was one consideration in the Columbia River Basin Treaty, which stipulates that Canada (the upstream party) will adjust its operation of hydroelectric dams to mitigate flooding in the United States. In the Agreement on the Cooperation for Sustainable Development of the Mekong River Basin, maximum river flow rates are set and upstream dam operations must be adjusted to meet these requirements. This kind of basin-wide coordination of flood management activities is critical, and flood management protocols should be integrated into all transboundary agreements.

Amendment and Review Process

Even when the understanding about the hydrological dynamics of a particular basin is fairly advanced, conditions may change. Population and economic growth can create new demands for water resources. New water-quality criteria may develop. Scientific knowledge may advance. Societal perceptions about the importance of ecosystems may shift. In addition, global climate change may cause fundamental changes in the hydrologic cycle and be more severe and occur more quickly than anticipated. An amendment and review process in transboundary agreements is needed to allow for changing hydrologic, social, or climatic conditions or in response to new scientific knowledge (Fischhendler 2004). Treaty amendments can be made through a variety of mechanisms, but only if such mechanisms are included in treaty designs. Within the Colorado River Basin, for example, amendments are made using “minutes” that then must be approved by all parties. A treaty could also be designed such that a separate body, such as a joint commission, could make treaty amendments (McCaffrey 2003).

Joint Institutions

Joint institutions can play an important role in managing transboundary water resources, particularly in light of changing conditions. According to a recent survey, only 106

4. Here, institutional capacity is defined as international water management bodies and freshwater treaties related to transboundary river flood events.

international river basins have water institutions. And although approximately two-thirds have three or more riparian states, fewer than 20 percent of the accompanying agreements are multilateral (UNEP/OSU 2002). The roles and authority of these institutions vary widely. The ideal institution would have a broad scope, include all riparian nations, and have management and enforcement authority. Yet the creation of such a supranational authority can be perceived as a threat to more politically powerful nations for fear of losing power or control over water (Fischhendler 2004).

A joint body can fulfill a variety of roles to facilitate adaptation to climate change. In particular, such a body could convene a technical committee to develop a common hydrologic model of the basin and common climate change scenarios. The International Commission on the Protection of the Rhine, for example, recently commissioned an assessment of the state of knowledge on climate change and its expected impacts on the water regime of the Rhine (ICPR 2009). Most of the hydrological models of future climate change in the Rhine River Basin show a risk of an increase in winter runoff and a reduction in summer runoff, indicating a need to adjust the water management regime to accommodate greater seasonal variability, especially the equitable allocation of lower summer flows. The Commission established a climate change expert group to develop hydrological scenarios, assess impacts of climate change on water quality and uses, and identify adaptation options. This approach has helped facilitate a shared understanding of the potential impacts of climate change and is paving the way for developing and implementing an adaptation strategy throughout the entire Rhine River Basin.

Case Studies

As described above, most transboundary agreements remain inflexible, and efforts to integrate climate change into transboundary management have been limited. We provide three case studies to demonstrate the range of potential impacts of climate change, including greater uncertainty in the Nile River Basin, wetter conditions in the Mekong River Basin, and drier conditions in the Colorado River Basin. In each of these regions, climate change has been integrated into transboundary water management, although to varying degrees.

The Nile River Basin

The Nile is the world's longest river, flowing nearly 6,700 kilometers (km) across northeastern Africa. The Nile drains an area of approximately 3.3 million square kilometers (km^2), about 10 percent of the African continent, across 11 countries—Egypt, Sudan, Ethiopia, Eritrea, Uganda, Kenya, Tanzania, Burundi, Rwanda, the Democratic Republic of Congo, and to a tiny degree the Central African Republic (Figure 1.2). The basin is home to an estimated 160 million people, who depend on its waters for navigation, irrigation, drinking water, hydroelectricity generation, and waste disposal. Natural flows in the Nile River average 110 cubic kilometers (km^3) per year but are subject to significant spatial and temporal variation (NBI 2009). Nearly all of the Nile flows originate in the headwaters, whereas half of the river's length flows through countries with no effective precipitation (i.e., Egypt and Sudan), where demands and dependence on the river are especially high (UNEP 2000).

Water scarcity is the primary water management challenge in the Nile River Basin.

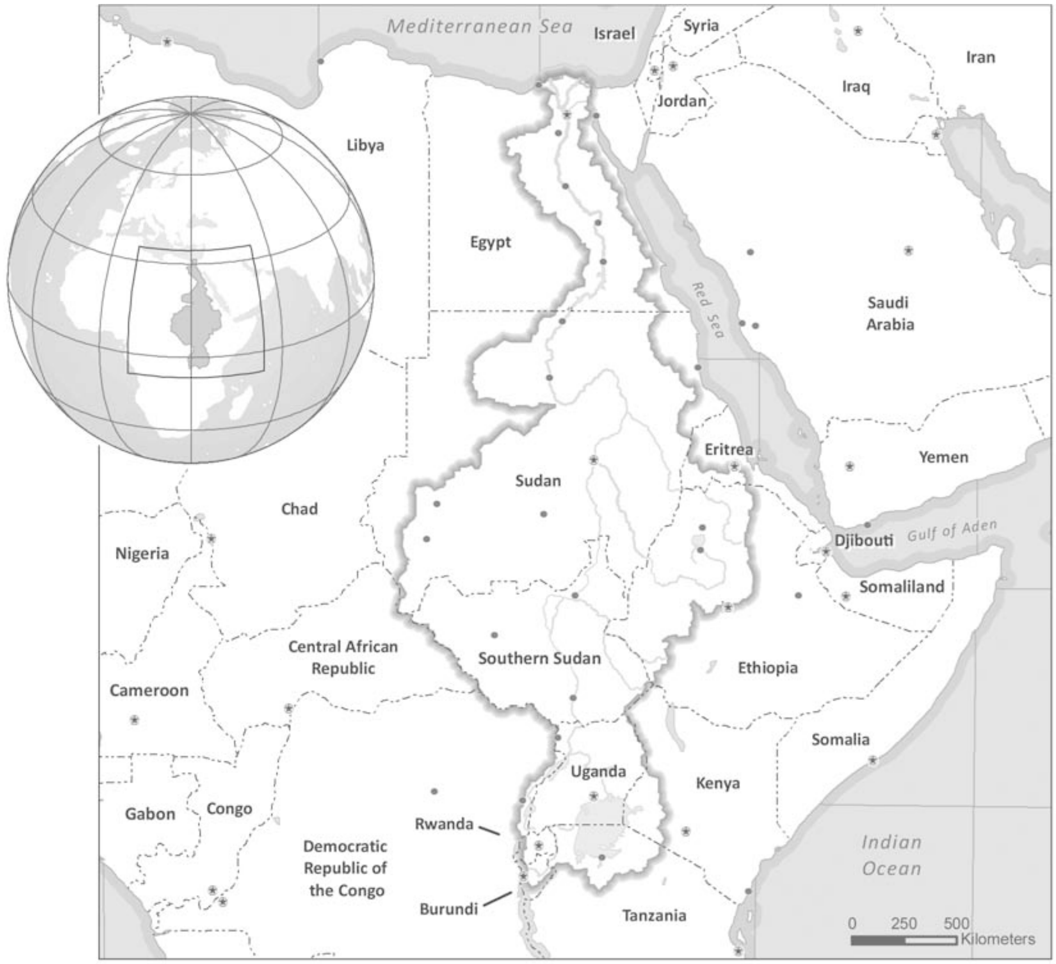

FIGURE 1.2 MAP OF THE NILE RIVER BASIN.
Source: M. Heberger, Pacific Institute, 2011

Currently, concerns about water scarcity have been limited to drought periods, such as the prolonged drought that gripped the region from 1978 to 1987. Rapid population growth in both upstream and downstream countries, especially Ethiopia and Egypt, is increasing demand for scarce resources. Irrigated agriculture is also on the rise, placing additional pressure on the region's limited water resources. Egypt is planning a major expansion of irrigated agriculture in the Western Desert and Sinai and has initiated work on what may be the world's largest pumping station (Conway 2005). In a recent analysis, Conway (2005) notes that "scarcity at the moment is not compelling as there is still some slack in the system but it is rapidly approaching and potentially a huge threat to the status quo." Environmental degradation and threats to water quality are also major regional challenges.

Legal Framework for Managing the Nile River

The Nile River has been the subject of numerous treaties, many of which originated in the colonial era. Today, the distribution of Nile water is governed by the Nile Waters Treaty, a bilateral agreement between Egypt and Sudan that was signed in November 1959. Under this agreement, Egypt and Sudan are apportioned 55.5 km^3 and 18.5 km^3 per year, respectively. An additional 10 km^3 was allocated to evaporation from the

Aswan Dam. The cost of projects that increased water flows in the Nile and the water produced by such projects would be split equally between Egypt and Sudan. The Nile Waters Treaty also established a Permanent Joint Technical Commission to resolve disputes and review claims made by other riparian countries. The commission was also tasked with devising a fair water allocation scheme for persistent low-flow periods that would then be presented to each government for approval.

There have been numerous activities and initiatives within the region designed to promote cooperation among the Nile Basin countries. The first of these was the Hydromet Survey Project, which was established in the 1960s and designed to collect and process hydrometeorological data in support of more effective management of the Nile (see UNEP 2000 for an overview of many of these initiatives). A more recent and ongoing effort, the Nile Basin Initiative (NBI), was established in 1999 by the water ministers of nine riparian countries—Egypt, Sudan, Ethiopia, Uganda, Kenya, Tanzania, Burundi, Rwanda, and the Democratic Republic of Congo.[5] The NBI "seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security." With support from its member countries and a series of bilateral and multilateral donors (e.g., the World Bank, African Development Bank, and Global Environmental Facility), the NBI has funded projects to build trust and cooperation among basin countries and contribute to technical information and scientific knowledge about the basin. Rather than focusing on reallocating flows, the Nile Basin Initiative has worked on the concept of sharing the many benefits of water, including energy generation, industrial use, and navigation (Jägerskog and Phillips 2006). Upon conclusion of the decade-long negotiations over the Agreement on the Nile River Basin Cooperative Framework, the Nile Basin Initiative is to be replaced by the Nile River Basin Commission.

Climate Change and the Nile River Basin

Studies on the impacts of climate change on water resources in the Nile Basin are numerous and span nearly three decades (see, for example, Kite and Waititu 1981, Hulme 1990, Gleick 1991, Conway and Hulme 1996, Yates and Strzepek 1998, Strzepek et al. 2001, Kim et al. 2008). The Nile is a rain-dominated system, and changes in precipitation and evaporation are likely the primary driver for changes in runoff. While most general circulation models agree that temperatures will rise in the region, the direction and magnitude of changes in precipitation and, by extension, runoff remain uncertain. Yates and Strzepek (1998), for example, found that runoff increased in two out of three scenarios. In a later study, however, the Nile became drier and runoff declined (Strzepek et al. 2001). In a recent study focused on the Upper Blue Nile, Kim et al. (2008) project that the region will become warmer and wetter by mid-century, low flow periods may decline, and "severe mid- to long-term droughts are likely to become less frequent throughout the entire basin."

Efforts to integrate climate change into long-term planning and management of the Nile River Basin have been limited, although recent efforts suggest this may be slowly changing. The 1959 Nile Waters Treaty dates, not surprisingly, make no explicit mention of climate change. Water allocations are fixed, which raises concerns about the ability

5. Eritrea and the Central African Republic, which lie within a very small portion of the Nile Basin but are not riparian countries, are not members of the Initiative.

to adapt to changing runoff patterns. The treaty does, however, have provisions that offer some degree of flexibility. In particular, the Permanent Joint Technical Commission can make recommendations for new water allocations in response to flow reductions, although this power has never been exercised by the commission (Conway 2005). In recent years, the NBI has supported research and analysis to better understand the vulnerability of the Nile Basin to climate change and to evaluate adaptation actions to reduce climate-related risks. They are now developing a Nile Basin decision-support system that will provide a framework for sharing information, understanding river system dynamics, and evaluating alternative development and management schemes. Although climate change was not explicitly mentioned in the project scoping information, the tool may prove useful in integrating climate change into management of the Nile Basin water resources.

Mekong River Basin

The Mekong is among the world's longest rivers, flowing 4,800 km across southeastern Asia. The Mekong drains an area spanning 795,000 km^2 across six countries—China, Myanmar, Vietnam, Thailand, Cambodia, and Loa PDR (Figure 1.3). Flows in the Mekong average around 470 km^3 per year but are subject to significant seasonal variation.

Legal Framework for Managing the Mekong River

Unlike in many other transboundary basins, an international committee and management framework were created in the Mekong Basin before water stress or other tensions became a problem. Studies by the United Nations Economic Commission for Asia and the Far East (UNECAFE) and the U.S. Bureau of Reclamation in the 1950s noted the potential for irrigation and hydroelectric development and the need for coordinated development of the Mekong River Basin (MRC 2009). The first treaty was signed by the four lower-basin countries—Cambodia, Laos, Thailand, and Vietnam—in 1957, establishing a joint committee for investigation, planning, and development projects in the basin. Cambodia left the committee in 1977 but rejoined in 1995 when the Agreement on the Cooperation for Sustainable Development of the Mekong River Basin (Mekong Basin Agreement) was signed. This agreement established the Mekong River Commission that exists today. The Mekong River Commission was charged with writing a Basin Development Plan to help balance economic development and environmental protection in the basin. The plan combines three elements: development scenarios, an Integrated Water Resources Management (IWRM)-based strategy, and structural and nonstructural investment. The IWRM strategy is meant to integrate development concerns and resource protection in order to create a sustainable management strategy (MRC 2009). Cambodia, Laos, Thailand and Vietnam are full members of the commission, whereas China and Myanmar are not parties to the agreement and have observer status.

The Mekong Basin Agreement does not allocate water but requires that the countries "utilize the waters of the Mekong River system in a reasonable and equitable manner" (MRC 1995). Uses of water that will significantly affect water flows or quality must be reviewed and approved by the commission. The commission has developed minimum monthly flows, along with a requirement to prevent daily average peaks greater than what naturally occurs during flood season (MRC 1995).

Figure 1.3 Map of the Mekong River Basin.
Source: M. Heberger, Pacific Institute, 2011

Climate Change and the Mekong River Basin

A number of studies have assessed the potential impacts of climate change on the Mekong Basin. The basin is expected to be affected by climate change through warmer, wetter weather, and by sea-level rise, both of which will change flooding patterns. All recent studies that modeled climate change in the basin (Kiem et al. 2008, TKK and SEA START RC 2009, Eastham et al. 2008, Hoanh et al. 2003) agree that temperatures will rise in the basin. One study found that the increase will be relatively homogeneous throughout the basins (Hoanh et al. 2003), while others found that it will be greatest in the cold, northern part of the basin (Kiem et al. 2008, Eastham et al. 2008). Precipitation is predicted to increase, although some studies suggest that increases will not be notable until the second half of the century (TKK and SEA START RC 2009, Hoanh et al. 2003). It is unclear whether increased annual precipitation would be caused by an increase in the length of the rainy season or only by increased intensity of rain events. As a result of increases in precipitation, some studies found that the number of river "low flow" days will decrease (Kiem et al. 2008) or that minimum flows will increase (Eastham et al. 2008). Various studies have found that there will be higher water levels during flooding (TKK and SEA START RC 2009), increased area of land flooded (TKK and SEA START RC

2009, Eastham et al. 2008), longer flood duration (TKK and SEA START RC 2009), and more frequent flooding in some areas (Eastham et al. 2008).

Treaties in the basin do not explicitly mention climate change, so there is no legal framework for collectively addressing this issue. The Mekong River Commission, however, has developed a climate change adaptation initiative. At a forum held in 2009, all six basin countries met and shared research and data, discussed national climate change adaptation strategies and challenges, and identified research gaps. Challenges identified included the need to integrate climate change considerations into development planning and the need for adequate funding and institutional capacity to implement adaptation strategies. The forum expressed the need for continued meetings of basin countries to discuss climate change and a basin-wide mitigation and adaptation plan (MDCCF 2009). Additionally, the Mekong River Commission has agreed on certain mainstream flow requirements, which may be important in the future as continued hydroelectric development and climate change alter river flows.

The Colorado River Basin

The Colorado River Basin covers 632,000 km^2, roughly 95 percent of which is in the southwestern U.S. and the remainder in northwestern Mexico (Figure 1.4). The river itself runs more than 2,300 km from its headwaters in the Rocky Mountains to its mouth at the Gulf of California. The river's estimated natural, undepleted average annual flow near the border for the period 1950–2006 was 19.4 km^3, but it is subject to significant spatial and temporal variation. An estimated 70 to 80% of the river's waters are diverted by farmers to irrigate some 12,000 km^2. Much of the remaining water satisfies the domestic and municipal needs of at least 27 million people in the United States and Mexico. Tight institutional and structural controls severely constrain the river's natural variability and significantly reduce the volume of water actually flowing to the border. In recent years, the river has rarely had enough water to reach the sea.

Legal Framework for Managing the Colorado River

A dense yet dynamic set of regulations, interstate compacts, agreements, contracts, judicial decisions, and an international treaty with 317 "minutes" (essentially, amendments and clarifications of the treaty), known collectively as the "Law of the River," govern the allocation and use of the Colorado River. Within the U.S., the Law of the River has allocated around 18 km^3/yr (15 million acre-feet/year) of Colorado River water to users, divided equally between the upper basin (comprised of the upper division states of Colorado, New Mexico, Utah, and Wyoming) and the lower basin (composed of the lower division states of Arizona, California, and Nevada). By treaty, the U.S. also delivers a minimum of 1.85 km^3 of water to Mexico each year, within a prescribed salinity range.

The 1944 Treaty with Mexico governs deliveries to Mexico. The treaty stipulates that deliveries to Mexico may be reduced "in the same proportion as consumptive uses in the United States are reduced during an 'extraordinary drought.'" The treaty, however, offers no definition of "extraordinary drought," and no agency is charged with determining or declaring an "extraordinary drought." With the prospect of a unilateral determination of "extraordinary drought" by the upstream riparian, however, representatives from Mexico and the U.S. have begun discussions about potential reductions in deliveries to Mexico.

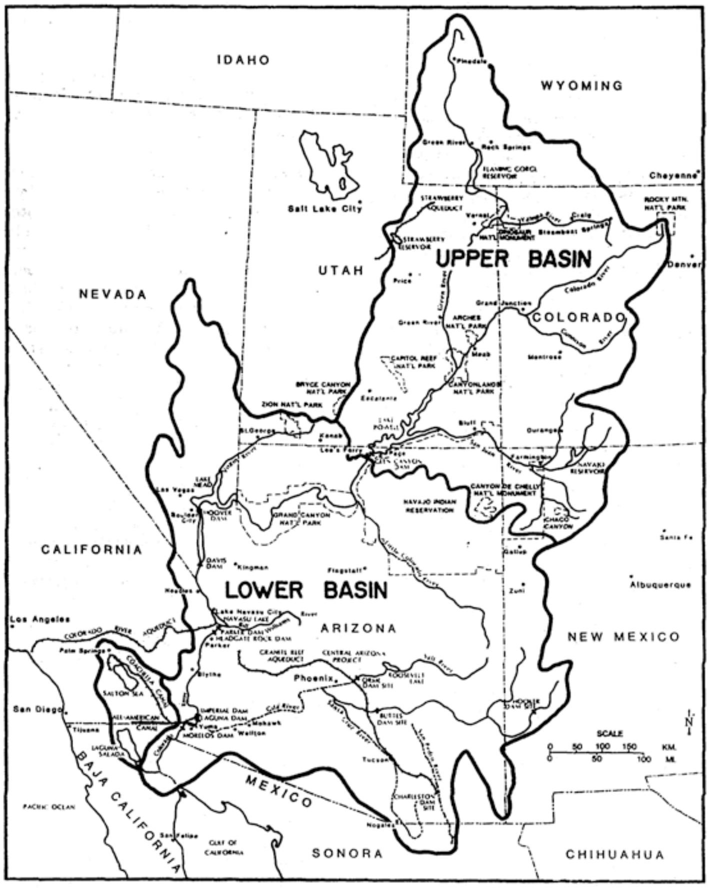

Figure 1.4 Map of the Colorado River Basin.
Source: U.S. Bureau of Reclamation

These discussions have purposefully avoided the definition of "extraordinary drought," choosing instead to explore conditions under which Mexico would voluntarily accept reductions in the volume of water allotted to it, the conditions that would trigger such a voluntary reduction, and initial modeling efforts to project potential reductions in deliveries under various scenarios and operating guidelines. Parallel discussions among a variety of stakeholders have been exploring opportunities to develop a mechanism by which U.S. and Mexican water users or other entities could invest in efficiency and augmentation programs in Mexico, such as lining canals or building desalination plants, in return for permanent or temporary use of a portion of the water conserved or generated. Additionally, the U.S. and Mexico recently agreed to let Mexico store some of its share of Colorado River water in Lake Mead in order to allow Mexico to repair irrigation canals damaged in a 7.2-magnitude earthquake that hit the region in early 2010 and potentially to create environmental pulse flows. Although this is a temporary measure set to expire in 2013, there may be hope for instituting a similar arrangement for storing conserved water in Lake Mead as a buffer against future delivery reductions and as a means to create environmental pulse flows.

Climate Change and the Colorado River Basin

A number of studies have assessed the potential impacts of climate change on the Colorado River. These studies generally find that the Colorado River Basin will become warmer and drier and that Colorado River runoff will decline. Estimates of average temperature increases in the basin by the year 2050 range from 2°C to 4°C (Nash and Gleick 1993, Christensen and Lettenmaier 2007, Barnett and Pierce 2009). Eighteen of nineteen climate models show a drying trend in the lower and Mexican portions of the Colorado River Basin, with the hydrology becoming consistently drier throughout the century (Seager et al. 2007). However, 80 to 85 percent of Colorado River runoff originates from precipitation at elevations above 2,500 meters, where projections of changes in the timing and magnitude of precipitation are less certain. Nonetheless, a recent study projects that greater water losses to evaporation and infiltration to drier soils will likely reduce Colorado River runoff by 6 to 20 percent by 2050 (Ray et al. 2008). Most of the climate change literature for the Colorado River Basin does not address impacts on water quality, although Nash and Gleick (1991, 1993) evaluated how climate-induced changes in flow would alter salinity.

Extensive modeling by the U.S. Bureau of Reclamation projects a greater than 30 percent probability of reduced water deliveries to lower basin users in 2026, even without climate change. Studies of conditions in the basin under climate change project that shortages will be chronic by mid-century, though the frequency and magnitude of such shortages depend on assumptions about future runoff and upper basin use (Barnett and Pierce 2009, Rajagopalan et al. 2009). These reductions in runoff will come just as the combination of rising temperatures and decreasing precipitation increases irrigation demands, already the largest user of Colorado River water.

Neither the 1944 Treaty with Mexico nor any of the subsequent “minutes” of the International Boundary and Water Commission contain any reference to climate change. Yet the treaty has demonstrated resilience in the face of changing conditions, evidenced by the many amendments adopted to date. The precedent of modifying the treaty to address new environmental concerns, such as salinity, suggests that recognition and integration of climate change impacts is also possible (Tarlock 2000).

Although not directly tied to concerns about climate change, the recently negotiated Interim Guidelines (USBR 2007) and subsequent discussions with Mexico demonstrate the willingness among users to adjust operation and management of the system in the face of changing conditions, especially extreme events. In December 2007, water users in the United States adopted the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead* (“Interim Guidelines”) that define and allocate water shortage among lower basin users, providing certainty and predictability about future deliveries. The Interim Guidelines also create a novel multiyear water augmentation and banking program that allows lower basin water users to invest in water conservation efforts and store the water saved by such efforts for delivery in future years. A related program creates similar mechanisms to generate and store water to be delivered during declared shortages, buffering the users against major reductions. Although the Interim Guidelines create a loophole to allow Mexican users to participate in such programs at some future time, they explicitly apply only to U.S. users and do not affect deliveries to Mexico. Additionally, the Interim Guidelines include an appendix that reviews the science and methods for incorporating climate change information into the U.S. Bureau of Reclamation’s Colorado River Basin Planning Studies, which lays the foundation for future integration.

Recent remarks by a senior U.S. official (Castle 2009) also indicate that adapting to climate change impacts in the basin is a high priority. The ongoing bilateral discussions among federal officials and other parties build on the long-term efforts of municipal water agencies in the U.S. to develop creative mechanisms to increase the flexibility of the Law of the River, and benefit from the rich historic streamflow record and extensive modeling experience and capacity. These discussions, about criteria for accepting voluntary reductions as well as extension of the market-based conservation and augmentation mechanisms within the Interim Guidelines, offer hope that, at least in the near term, the impacts of the continuing drought on the basin and potentially those of climate change may be managed and mitigated through mutual agreement.

Summary of Case Studies

These case studies highlight the diversity of principles, policies, and institutions that guide the management of transboundary waters. Each example of a transboundary agreement was developed under diverse circumstances, addresses different concerns, and has a unique set of constraints. These case studies also demonstrate a range of potential climate change impacts; some areas will become wetter, others will become drier, and many will exhibit greater variability.

Given these differences, each agreement must be evaluated independently. Natural Resources Canada, for example, evaluated the potential impacts of climate change and the implications for existing treaties and agreements in each of its shared river basins (Bruce et al. 2003). For each basin, they developed a short list of immediate actions for improving these agreements in the face of climate change. In the Columbia River Basin, for example, Natural Resources Canada recommends shortening the period between operating rule revisions for flood management (the current treaty revises these rules every five years) as a way to regularly review changing circumstances. In the Saint Mary and Milk River Basins, they recommend recalculating "natural flows" to take into account increased evaporation from surface reservoirs. This kind of regular reanalysis should be expanded and completed for all shared water basins.

Conclusions and Recommendations

Global climate change will pose a wide range of challenges to freshwater resources, altering water quantity, water quality, and system operations, and imposing new governance complications. For countries whose watersheds and river basins lie wholly within their own political boundaries, adapting to increasingly severe climate changes will be difficult enough. When those water resources cross borders, affecting multiple political entities and actors, sustainable management of shared water resources in a changing climate will be especially difficult.

Shared waters can be a source of conflict, but they can also be a source of cooperation and negotiation. Future pressures, such as population and economic growth and climate change, could increase tensions, even in areas that in the past have been characterized by cooperation. Yet shared challenges may also be a platform for developing new institutional arrangements to plan for the future. Below, we provide recommendations for improving the management of transboundary waters in the face of climate change. Several of these recommendations make sense to address a range of change conditions, including population and economic growth. Climate change, however, poses new risk; the last two recommendations specifically address climate change.

Establish Agreements in Transboundary Basins

Formal treaties or agreements for the management of transboundary water are not universal. Treaties covering transboundary aquifers, in particular, are rare (UNECE 2009). Climate change increases the need for such agreements to reduce the risk of potential future conflicts. Efforts to reach agreement on new treaties should be initiated before new conflicts or tensions have emerged that would complicate already difficult negotiations.

Bring the UN Convention into Force

The Convention on the Law of the Non-navigational Uses of International Watercourses, adopted by the UN General Assembly in May 1997, has not yet come into force. Dellapenna (2007) observes that "none of the most disputed internationally shared fresh waters are covered by agreements involving all interested States, indicating the need, despite the growing prevalence of international agreements regarding internationally shared waters." As much as we hope that treaties will be developed in all transboundary watersheds to foster cooperation and collaboration among all riparian states, certain political and financial constraints make this difficult in many areas of the world. Therefore, adopting an effective international legal framework is a critical step for addressing future challenges, particularly climate change.

Expand the Scope of Existing Agreements

Climate change will affect all elements of the hydrologic cycle in complex and sometimes nonlinear ways. A number of these elements, especially water quality and flood management, are commonly excluded from transboundary agreements. Existing agreements should be expanded to include all elements of the hydrologic cycle. Integrated Water Resource Management provides one such framework. IWRM recognizes the interdependency of all water uses and seeks to balance social, economic, and environmental objectives in the management of water resources.

Evaluate Existing Treaties and Agreements to Assess Flexibility in Light of Changing Conditions

No two water treaties are the same. Each is developed under diverse circumstances, addresses different concerns, and has a unique set of constraints. Additionally, climate change will affect each basin differently. As a result, each treaty must be evaluated to determine what flexibility mechanisms currently exist and where significant vulnerabilities remain. This process should be started before a problem arises so as to improve the atmosphere for cooperation and negotiation.

Amend Existing Treaties to Improve Flexibility

Most treaties and international agreements fail to have adequate mechanisms for addressing changing social, economic, or climate conditions. The following mechanisms should be incorporated into existing treaties to allow for flexibility in the face of change: (1) flexible allocation strategies and water quality criteria, (2) provisions for extreme events, (3) amendment and review procedures, and (4) joint management institutions.

Establish Joint Monitoring Programs

Joint monitoring programs can improve cooperation among nations and data collection capacities. This exchange of information provides a number of benefits, including expanding and deepening our understanding of climate change impacts and vulnerabilities and improving hydrological and socioeconomic models. Such programs should include water flow and a range of water-quality parameters. Additionally, early warning systems should be developed in order to reduce the impacts of extreme events.

Conduct Climate Impact, Vulnerability, and Adaptation Assessments

Riparian countries should work on common scenarios and models to develop a joint understanding of possible impacts. Transboundary cooperation can broaden our knowledge base; enlarge the range of measures available for prevention, preparedness, and recovery; and help identify better and more cost-effective solutions.

References

Bakker, M. 2009. Transboundary river floods and institutional capacity. *Journal of the American Water Resources Association* 45(3): 553–566.

Barnett, T.P., and D.W. Pierce. 2009. Sustainable water deliveries from the Colorado River in a changing climate. *Proceedings of the National Academy of Sciences.* doi: 10.1073/pnas.0812762106

Bruce, J.P., Martin, H., Colucci, P., McBean, G., McDougall, J., Shrubsole, D., Whalley, J., Halliday, R., Alden, M., Mortsch, L., and Mills, B. 2003. Climate Change Impacts on Boundary and Transboundary Water Management. A Climate Change Action Fund Project—Natural Resources Canada. Project A458/402.

Castle, A. 2009. Remarks at the Colorado River Water Users Association. Las Vegas, Nevada, December 10. http://www.doi.gov/news/speeches/2009_12_10_speech_castle.cfm

Christensen, N.S., and Lettenmaier, D.P. 2007. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River Basin. *Hydrology and Earth System Sciences* 11: 1417–1434.

Conway, D. 2005. From headwater tributaries to international river: Observing and adapting to climate variability and change in the Nile Basin. *Global Environmental Change* 15: 99–114.

Conway, D., and Hulme, M. 1996. The impacts of climate variability and future climate change in the Nile Basin on water resources in Egypt. *International Journal of Water Resources Development* 12(3): 277–296.

Cooley, H., Christian-Smith, J., Gleick, P.H., Allen, L., and Cohen, M.J. 2009. *Understanding and Reducing the Risks of Climate Change for Transboundary Waters.* Oakland, California: Pacific Institute in cooperation with the United Nations Environment Programme.

Dellapenna, J. 2007. The Berlin Rules on water resources: The new paradigm for international water law. In *Proceedings of the ASCE Conference: Examining the Confluence of Environmental and Water Concerns Proceedings of the World Environmental and Water Resources Congress, 2006*. http://dx.doi.org/10.1061/40856(200)250 (accessed December 27, 2009).

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G., Ali, R., and Kirby, M. 2008. Mekong River Basin Water Resources Assessment: Impacts of Climate Change. CSIRO: Water for a Healthy Country National Research Flagship.

Fischhendler, I. 2004. Legal and institutional adaptation to climate uncertainty: A study of international rivers. *Water Policy* 6(4): 281–302.

Gleick, P.H. 1988. The effects of future climatic changes on international water resources: The Colorado River, the United States, and Mexico. *Policy Science* 21: 23–39.

Gleick, P.H. 1991. The vulnerability of runoff in the Nile basin to climatic changes. *The Environmental Professional* 13: 66–73.

Gleick, P.H. 1993. Water and conflict. *International Security* 18(1): 79–112.

Gleick, P.H. 1994. Water, war, and peace in the Middle East. *Environment* 36(3): 6–15, 35–42. Washington, D.C.: Heldref Publishers.

Gleick, P.H. 1998. Conflict and cooperation over fresh water. In: *The World's Water 1998–1999*. Washington, D.C.: Island Press, pp. 105–136.

Gleick, P.H. 2000. How much water is there and whose is it? In: *The World's Water 2000–2001: The Biennial Report on Freshwater Resources*. Washington, D.C.: Island Press.

Goldenman, G. 1990. Adapting to climate change: A study of international rivers and their legal arrangements. *Ecology Law Quarterly* 17(4): 741–802.

Hamner, J., and A. Wolf. 1998. Patterns in international water resource treaties: The Transboundary Freshwater Dispute Database. *Colorado Journal of International Environmental Law and Policy*. 1997 Yearbook.

Hatami, H., and Gleick, P. 1994. Chronology of conflict over water in the legends, myths, and history of the ancient Middle East. In: Water, war, and peace in the Middle East. *Environment* 36(3): 6–15. Washington, D.C.: Heldref Publishers.

Hoanh, C.T., Guttman, H., Droogers, P., and Aerts, J. 2003. Water, Climate, Food, and Environment in the Mekong Basin in Southeast Asia. Contribution to the project ADAPT Adaptation strategies to changing environments: Final Report.

Hulme, M. 1990. Global climate change and the Nile Basin. In: *The Nile: Resource Evaluation, Resource Management, Hydropolitics and Legal Issues*. P.P. Howell and J.A. Allen, editors. London, United Kingdom: School of Oriental and African Studies (SOAS).

Hundley, N. 1966. *Dividing the Waters: A Century of Controversy between the United States and Mexico.* Los Angeles: University of California Press.

International Commission for the Protection of the Rhine (ICPR). 2009. Analysis of the State of Knowledge on Climate Changes So Far and on the Impact of Climate Change on the Water Regime in the Rhine Watershed: Literature Evaluation. Report Number 174. http://www.iksr.org/uploads/media/Bericht_174_e.pdf (accessed December 23, 2009).

International Law Association (ILA). 1966. Helsinki Rules on the Uses of the Waters of International Rivers. http://webworld.unesco.org/water/wwap/pccp/cd/pdf/educational_tools/course_modules/reference_documents/internationalregionconventions/helsinkirules.pdf (accessed December 29, 2009).

Jägerskog, A., and Phillips, D. 2006. Human Development Report 2006: Managing Trans-boundary Waters for Human Development. Human Development Report Office Occasional Paper. http://www.unwater.org/downloads/jagerskog_anders.pdf (accessed December 17, 2009).

Kiem, A.S., Ishidaira, H., Hapuarachchi, H.P., Zhou, M.C., Hirabayashi, Y., and Takeuchi, K. 2008. Future hydroclimatology of the Mekong River basin simulated using the high-resolution Japan Meteorological Agency (JMA) AGCM. *Hydrological Processes* 22: 1382–1394.

Kim, U., Kaluarachchi, J.J., and Smakhtin, V.U. 2008. Generation of monthly precipitation under climate change for the Upper Blue Nile River Basin, Ethiopia. *Journal of the American Water Resources Association* 44(5): 1231–1247.

Kistin, E.J., and Ashton, P.J. 2008. Adapting to change in transboundary rivers: An analysis of treaty flexibility on the Orange-Senqu River Basin. *Water Resources Development* 24(3): 385–400.

Kite, G.W., and Waititu, J.K. 1981. Effects of changing precipitation and evaporation on Nzoia river flows and Lake Victoria levels. A Contribution to the World Climate Program, Report, World Meteorological Organization, Geneva.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z., and Shiklomanov, I.A. 2007. Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, editors. Cambridge, United Kingdom: Cambridge University Press, pp. 173–210.

McCaffrey, S.C. 2003. The need for flexibility in freshwater treaty regimes. *Natural Resources Forum* 27(2): 156–162.

Mekong Delta Climate Change Forum (MDCCF). 2009. Summary Statement from the Chair. http://www.icem.com.au/02_contents/01_homepage/documents/mdcc_chairs_summary_statement_13_nov_09.pdf (accessed December 18, 2009).

Mekong River Commission (MRC). 1995. Agreement of the Cooperation for the Sustainable Development of the Mekong River Basin. April 5, 1995. http://www.mrcmekong.org/agreement_95/agreement_95.htm (accessed December 17, 2009).

Mekong River Commission (MRC). 2009. Website. http://www.mrcmekong.org/

Nash, L.L., and Gleick, P.H. 1991. The sensitivity of streamflow in the Colorado Basin to climatic changes. *Journal of Hydrology* 125: 221–241.

Nash, L., and Gleick, P. 1993. The Colorado River Basin and Climatic Change: The Sensitivity of Streamflow and Water Supply to Variations in Temperature and Precipitation. EPA230-R-93-009. Washington, D.C.: U.S. Environmental Protection Agency.

Nile Basin Initiative (NBI). 2009. Website. http://www.nilebasin.org/index.php?option=com_content&task=view&id=106&Itemid=120 (accessed December 30, 2009).

Rajagopalan, B., Nowak, K., Prairie, J., Hoerling, M., Harding, B., Barsugli, J., Ray, A., and Udall, B. 2009. Water supply risk on the Colorado River: Can management mitigate? *Water Resources Research* 45. W08201. doi:10.1029/2008WR007652

Ray, A.J., Barsugli, J.J., Averyt, K.B., Wolter, K., Hoerling, M., Doesken, N., Udall, B., and Webb, R.S. 2008. *Climate Change in Colorado: A Synthesis to Support Water Resources Management and Adaptation*. Boulder, Colorado: CU NOAA Western Water Assessment.

Salman, S. 2007. The Helsinki Rules, the UN Watercourses Convention and the Berlin Rules: Perspectives on international water law. *Water Resources Development* 23(4): 625–640.

Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.P., Harnik, N., Leetmaa, A., Lau, N.C., Li, C., Velez, J., and Naik, N. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science* 316: 1181–1184. 10.1126/science.1139601

Strzepek, K., Yates, D.N., Yohe, G., Tol, R.J.S., and Mader, N. 2001. Constructing "not implausible" climate and economic scenarios for Egypt. *Integrated Assessment* 2: 139–157.

Tarlock, A.D. 2000. How well can international water allocation regimes adapt to global climate change? *Journal of Land Use and Environmental Law* 15: 423–449. http://www.law.fsu.edu/journals/landuse/Vol153/tarlock.pdf (accessed December 30, 2009).

TKK & SEA START RC. 2009. *Water and Climate Change in the Lower Mekong Basin: Diagnosis and Recommendations for Adaptation*. Water and Development Research Group, Helsinki University of Technology (TKK), and Southeast Asia START Regional Center (SEA START RC), Chulalongkorn University. Espoo, Finland: Water and Development Publications, Helsinki University of Technology. http://users.tkk.fi/u/mkummu/water&cc (accessed December 18, 2009).

United Nations (UN). 1958. *Integrated River Basin Development.* UN Publications no. 58.II.B.3. New York: United Nations Publications.

United Nations (UN). 1978. *Registry of International Rivers.* Prepared by the Centre for Natural Resources, Energy and Transport of the Department of Economic and Social Affairs. Oxford, United Kingdom: Pergamon Press.

United Nations Economic Commission for Europe (UNECE). 2009. Guidance on Water and Adaptation to Climate Change. Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 2009. *Atlas of Transboundary Aquifers: Global Maps, Regional Cooperation, and Local Inventories.* Paris, France: International Hydrological Programme.

United Nations Environment Programme (UNEP). 2000. Water Sharing in the Nile River Valley. Project GNV011.

United Nations Environment Programme and Oregon State University (UNEP/OSU). 2002. *Atlas of International Freshwater Agreements*. Nairobi, Kenya: UNEP Press.

U.S. Bureau of Reclamation (USBR). 2007. Final Environmental Impact Statement, Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. www.usbr.gov/lc/region/programs/strategies/FEIS/index.html

Wolf, A.T., Natharius, J., Danielson, J., Ward, B., and Pender, J. 1999. International river basins of the world. *International Journal of Water Resources Development* 15(4): 387–427.

Yates, D.N., and Strzepek, K.M. 1998. An assessment of integrated climate change impacts on the agricultural economy of Egypt. *Climatic Change* 38: 261–287.

C H A P T E R 2

Corporate Water Management

Peter Schulte, Jason Morrison, and Peter H. Gleick

Water is an essential input for industries and economies around the world. It is used to cool industrial processes, to dilute contaminants, as a solvent, and as a key ingredient in many products, among other uses. Industrial water use and wastewater discharge can adversely affect nearby communities and ecosystems. For example, improper wastewater discharge can severely pollute recreational water bodies, contaminate drinking water supplies, and make water unusable for other needs. Excessive groundwater pumping increases pumping costs for local growers. Large water withdrawals can also take water away from other uses and exacerbate water-quality concerns by further concentrating contaminants.

Despite these concerns, water has only recently risen to the forefront as a strategic concern for many companies around the world. Emerging corporate practice and research suggest that the environmental, political, and social realities of the 21st century mean that environmentally and socially responsible corporate water management is not only a moral responsibility for companies but also increasingly an integral part of ensuring business viability and reducing business risk. The strategic decision to proactively manage water-related risks is driven by five primary motivations:

- Ensuring the company's local legal or social license to operate in a specific location;
- Preventing or reacting to operational crises resulting from inadequate supply or quality of water or water-dependent inputs in a specific location;
- Assuring current and potential investors and markets that business operations will continue to be profitable into the future by ensuring water availability for operations and supply chains;
- Upholding corporate values and ethics based on sustainable and equitable principles by contributing to the well-being of watersheds, ecosystems, and communities; and
- Gaining competitive advantage over competitors due to stakeholder and consumer perceptions that the company uses natural resources responsibly with minimal impacts on communities or ecosystems.

This chapter will explore the risks that water poses for companies and how more responsible and sustainable management practices can help reduce those risks.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_2,

Global Trends that Affect Businesses

Increased interest in improved corporate water management has been driven by a number of emerging trends in the past two decades. Growing water demand and limited supplies have led to water scarcity in many regions. Overallocation of surface water has led to insufficient environmental flows and therefore damage to important habitats and ecosystems. Climate change is already altering the hydrologic cycle, leading to changes in the supply of and demand for water resources.

Agricultural runoff, industrial effluent, and residential wastewater have led to higher concentrations of many chemical contaminants, higher temperatures, increased turbidity, and altered pH in many rivers, lakes, and aquifers. This has led to environmental damage, human health concerns, and increased costs for water treatment. Even in areas relatively unaffected by water demand exceeding supply, many basic water needs go unmet. Currently, an estimated 900 million people worldwide (over 10 percent of the world's population) do not have access to an improved water source, while over 35 percent of the world's population does not have access to improved sanitation (Figure 2.1) (CDCP 2009).

The past decade has seen a substantial rise in the extent to which consumers and investors consider the sustainability or social responsibility of companies and products. For instance, in the United Kingdom, expenditure on ethical goods and services has tripled in the last decade (The Co-Operative Bank 2009). A different study showed that 81 percent of Koreans, 70 percent of Singaporeans, and nearly half of British consumers are willing to pay a premium for environmentally friendly products (Czarnowski 2009). Consumer and investor demand for "green" products has led to competitive advantage

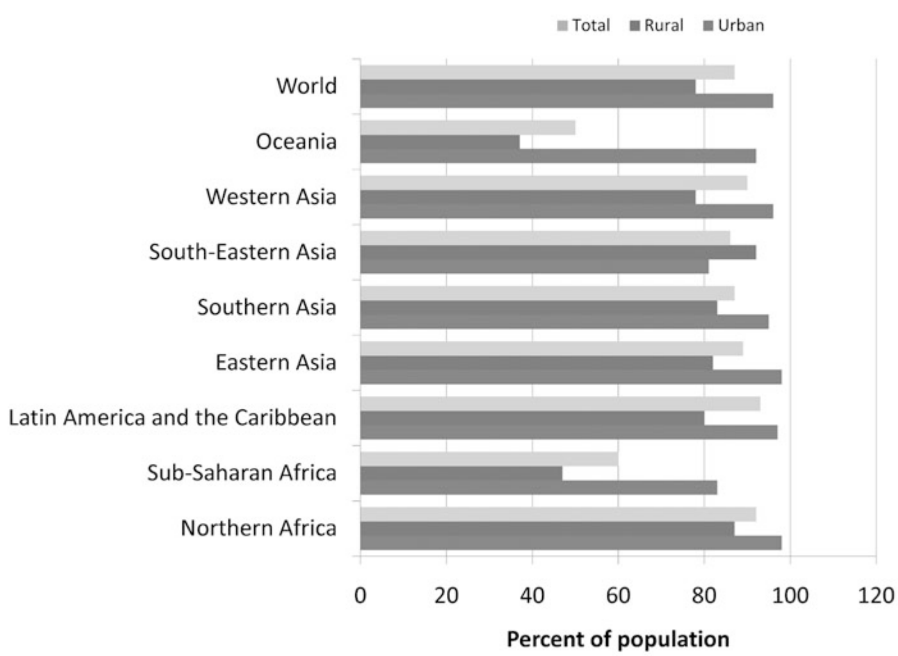

Figure 2.1 Access to Safe Drinking Water by Region, 2008.

Source: United Nations 2010. The Millennium Development Goals Report 2010. http://www.un.org/en/mdg/summit2010/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf for companies perceived as "green" and to significant reputational damage for companies perceived as bad actors. This demand has led to the concept of corporate social responsibility that has seen companies investing in improved sustainable practice and reporting on a variety of issues, including water use and wastewater discharge.

Policy makers are also increasingly considering new water policies that will affect the private sector, such as imposing stringent limits on wastewater discharge or reducing allocations due to local water scarcity. For instance, the 1972 U.S. Clean Water Act and later amendments—which restricted industrial effluent—was the first major and arguably most important regulatory driver of improved industrial water management. More recently, the 2000 European Union Water Framework Directive commits member states to a wide range of improved water management practices.[1]

Water is also a key input for many forms of energy generation, such as hydropower, nuclear, coal, and biofuels (Table 2.1). Because of this close relationship between water and energy, water stress due to climate patterns or overallocation can often lead to reduced energy production and/or increased energy costs for businesses and municipalities.

Water-Related Business Risks

All of these trends are driving companies to more closely consider and address uncertainty about water availability and quality, as well as the adverse impacts their water use and wastewater discharge might have on communities and ecosystems. Increasingly, companies recognize that there is a strategic interest in proactively assessing water-related risks and developing long-term water management plans to mitigate these risks. These plans generally take into account water scarcity, water quality, climate change, stakeholder expectations, and existing and potential regulations.

Inefficient water use, water scarcity, pollution, competition for water, climate change, and other water-related concerns can affect companies in a number of ways: they can reduce the ability of facilities to maintain production levels, alter the way the company is perceived by its stakeholders, and influence the actions governments take to regulate

1. For more on the EU Water Framework Directive, see: http://ec.europa.eu/environment/water/water-framework/index_en.html.

Table 2.1. Water Consumption by Energy Type in the United States

	Total water consumed per megawatt hour (m^3/MWh)	Water consumption required for U.S. daily energy production (millions of m^3)
Solar	0.0001	0.011
Wind	0.0001	0.011
Gas	1	11
Coal	2	22
Nuclear	2.5	27.5
Oil	4	44
Hydropower	68	748
Biofuel (first generation)	178	1958

businesses. Understanding these consequences is essential in identifying effective response strategies. Below is a typology of water-related business risk, as well as the implications of the different types of risk for businesses.

Physical/Operational Risk

Physical risks stem from having too little water to maintain production (scarcity), too much water (flooding), or water that is unfit for use (pollution). Even where water is physically abundant, companies can have limited access to water due to poor public water management and insufficient or inconsistent water services. Declines or disruptions in water supply can undermine industrial and manufacturing operations where water is needed for production, irrigation, material processing, cooling, washing, or cleaning. Contaminated water supply may require additional investment and operational costs for pretreatment. Availability and affordability of clean water may also affect the interest or ability of customers to purchase or use certain water-intensive products and services.

For instance, in 2001, energy production in São Paulo, Brazil, was highly constrained as a result of both severe drought and government energy tariff policies. In order to prevent blackouts, the government imposed quotas aimed at reducing energy consumption by 10 to 35 percent. Many industries based in Brazil's southeast were plagued by reductions in operational capacity, production delays, or increased production costs (Ceres 2009).

Reputational/Stakeholder Risk

Reputational risks stem from changes in how stakeholders view companies due to their real or perceived negative impacts on the quantity and quality of water resources, the health and well-being of workers, aquatic ecosystems, communities, and future business viability. Reputational concerns can lead to decreased brand value or consumer loyalty, reduced investor confidence, or adverse regulatory responses. When particularly severe, such risks ultimately threaten a company's legal and social license to operate.

In water-scarce regions, tensions can arise between businesses and local communities when corporate water use affects or is perceived to affect another stakeholder's water use. Similarly, tensions arise when industrial wastewater effluent degrades ecosystems or causes human health problems. Local conflicts can damage brand image. In Kerala, India, for example, both PepsiCo's and Coca-Cola's bottlers lost their licenses to use groundwater after drought spurred community action and increased competition for local aquifers (Ceres 2009). The reputation of both companies in India has suffered as a result, with a substantial loss of both revenue and goodwill.

As public interest in the impacts of water withdrawal and wastewater discharge on ecosystems and local communities grows, companies' water practices are subjected to greater scrutiny. Major media outlets now routinely cover water-related protests and controversies. For instance, the recent discovery that Starbucks's 10,000 coffee shops worldwide have been "wasting" 23.4 million liters of water daily as a result of the company's "open tap" or "dipper well" policy has generated negative media attention and public criticism (Ceres 2009). The Alliance for Water Stewardship is currently drafting

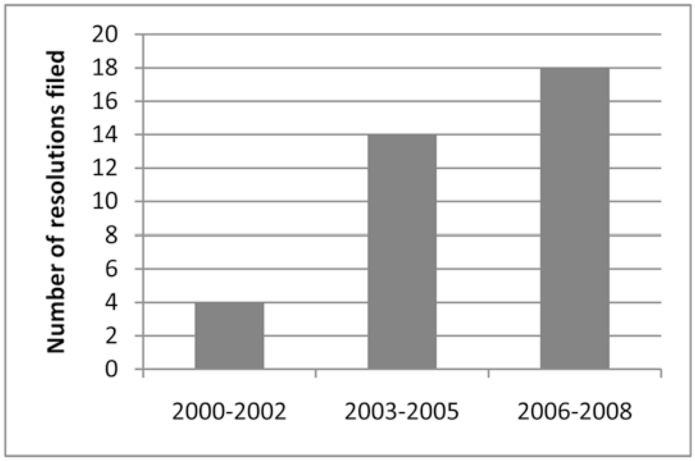

Figure 2.2 Shareholder resolutions Addressing Water Issues.
Source: ICCR 2010

a certification standard that will enable greater scrutiny of companies and products in respect to their water use and water-related impacts.[2]

Furthermore, investors are increasingly making decisions based on the degree to which companies sufficiently consider and plan for water-related risks. Citi, JPMorgan, Merrill Lynch, and Morgan Stanley all issued water-focused research reports in 2008. The reports highlighted both emerging investment opportunities and massive data gaps investors and analysts face in assessing corporate water risks. Shareholder resolutions on water—mostly focused on the food, beverage, oil, and chemical industries—more than quadrupled over the past 10 years (Figure 2.2). Recognizing the plethora of risks associated with water, investors are now filing resolutions asking companies for more disclosure on water practices and performance.

Regulatory/Political Risk

Regulatory risks can occur in response to changing, ineffective, poorly implemented, or inconsistent water-related policies. Stricter regulatory requirements often result from water scarcity and/or ensuing conflict among various needs (e.g., urban, agricultural, industrial, ecological) or because of public perception of a company's water uses and discharges as wasteful, disproportionately harmful, or inequitable. These changes can create a less inviting or less stable business environment and can affect a company's access to water supplies and services, increase the costs of operation, or otherwise make corporate water use and management more challenging.

Water scarcity, coupled with increased concern among local communities about water withdrawals, puts pressure on local authorities and policy makers to consider water reallocations, regulations, and development of water markets that cap usage and suspend permits to draw water. For instance, Chinese authorities have already shown a willingness to restrict water-intensive industries and will likely continue to do so in the future as water resources face unsustainable demands. A 2007 Draft Plan for National

2. The Pacific Institute is a founding member of the Alliance for Water Stewardship. For more on the Alliance, see: http://www.allianceforwaterstewardship.org/.

Economic and Social Development asked beverage, plastics, and pharmaceutical manufacturers to meet water conservation restrictions in order to gain approval. Moreover, Beijing officials forced "water hungry" and polluting industries to close in Southern China to ensure sufficient water supplies for the capital (CLSA 2006, Ceres 2009).

Water scarcity is also driving water service providers to consider pricing policies that promote greater efficiency. Concerns over water pollution and its impacts on ecosystems and local water resources may lead to new and costly requirements on companies' wastewater discharges. Such standards can lead to costly litigation, civil penalties, or criminal fines. Products and services that require large amounts of water to produce or use may also be regulated by law. For instance, the U.S. Federal Energy Policy Act of 1992 restricts maximum water flows for faucet fixtures manufactured in the United States (Efficiency Partnership 2011). In 2005, Australia enacted the Water Efficiency Labelling and Standards Act, which required certain products (e.g., showers, tap equipment, flow controllers) to be registered and labeled according to their water-use efficiency (Commonwealth of Australia 2010).

Key Factors that Determine Extent and Type of Risk

The extent to which a company is exposed to water-related business risk depends on a number of different factors, some pertaining to internal company performance, others pertaining to external environmental, social, and political conditions unrelated to the company. These factors and how they can create risk for businesses are discussed below.

Internal Factors

Many factors create risk over which companies have direct control. This includes the water performance of a company's suppliers and the end use of its products, though companies often have limited control in these areas. These factors include the following.

Maturity of Practice

The more water a facility uses, the more likely it is to face excessive costs, regulatory pressure, or stakeholder discontent. Water-intensive (e.g., laundry machines) or heavily polluting products (e.g., laundry detergent) can lead to competitive disadvantage or be phased out by standards. Similarly, the extent to which wastewater discharge creates impact depends on the volume and quality of wastewater discharged from a facility. Because of this, risk exposure is partly dependent on a facility's investment in technologies that improve the efficiency of water use and the treatment of wastewater effluent, as well as on product design.

Nature of Use and Discharge

Risk also depends on the way in which facilities use and affect water resources. For instance, many industries, such as steelmaking or oil refining, need large volumes of low-quality input water primarily for cooling purposes, while others, particularly in high-tech industries, need smaller amounts of ultra-pure water. Differences in the nature of water use influence whether facilities are more reliant on sufficient water quantity or quality, and therefore the types of risk to which they are exposed.

Furthermore, while many industries withdraw water and return it to the same watershed with minimal changes to the physical, biological, and chemical quality of the water, others degrade its quality before returning it to the same watershed or consume water (i.e., remove it from a watershed completely) and therefore potentially contribute to supply concerns. In cases when facilities return wastewater to local watersheds, companies can face risk related to impacts on water quality. The quality of wastewater varies greatly depending on commercial activity. Industrial facilities that use water primarily for cooling will often lead to increased stream temperatures, while others may contain heavy loads of heavy metals or chemical contaminants. Agricultural runoff often leads to higher concentrations of nitrogen, phosphorous, fertilizers, and pesticides.

External Factors

The extent to which companies negatively affect ecosystems or communities or are otherwise exposed to risk depends highly on interrelated external conditions over which companies may have little or no control. These conditions include the following.

Hydrologic Context

A region's physical water availability often has great bearing on the functioning of ecosystems and access to water services for industry and local communities. Less water means less instream flow to support habitat and less water supply to meet human demand. As water scarcity worsens, the likelihood that companies will have insufficient water supplies to maintain their operations or that their water use will result in negative impacts and therefore lead to reputational damage or regulatory pressure (e.g., allocation changes or higher water pricing) also increases.

A region's water quality is also a key factor in determining risk. As discussed above, a facility's own effluent and its affect on ambient water quality create risk. However, water pollution caused by others within a watershed can impose costs on a business. For many industries, degraded ambient water quality increases the level of treatment (and therefore cost) required to purify water to appropriate levels for industrial production. Furthermore, the more a water body is already polluted, the greater the chance that industries in that watershed will face regulatory restrictions due to environmental damage or human health problems.

Environmental Context

Many other environmental conditions can inform hydrologic conditions or otherwise create water-related risk. Different land uses and land covers can lead to drastically different water conditions. For instance, a forested area may prevent runoff to rivers, streams, and aquifers, while a newly logged area may have greatly increased flow contaminated by erosion. Similarly, soil quality has a great impact on runoff patterns. Areas with heavy agricultural production will likely have a greater demand for local water and lead to higher concentrations of contaminants in waterways. Industries in areas with many endangered aquatic species or dysfunctional freshwater ecosystems are also more likely to face community action or regulatory pressure.

Social Context

As discussed earlier, community access to water services often depends on a number of socioeconomic and political conditions, in addition to an area's physical water availability. Limited community access to water increases the likelihood that industrial presence in an area will in reality or perception contribute to this lack of access. Limited access to water services may be caused by a lack of political will or capacity unrelated to industrial activity. Regardless, an industrial facility with plentiful access to water supplies in an area where communities do not have sufficient water services can lead to reputational damage for the company.

Political and Institutional Context

An industrial facility's exposure to risk depends on the ability of public water policy and management to deliver water services, manage their own water-related risks (e.g., water scarcity, climate change, etc.) over the long term, create effective allocation regimes, and develop and enforce water-quality regulations. In many cases, failures in water policy and management lead to insufficient (both in terms of quantity and quality) or inconsistent water deliveries to industry. In others, poor management leads to insufficient instream flows, degraded water quality, and limited community access to water, all of which can exacerbate the negative impacts of industrial water practices. Political and institutional problems are most common in the global South, where governments typically have less money to manage water resources and where corruption is more widespread (though institutional water problems are evident throughout the world).

Risk and Impact Assessment

Companies' ability to measure and understand their water risks is key to effectively mitigating specific water problems and becoming responsible water stewards. Risk and impact assessments are largely based on a process often referred to as water footprinting or corporate water accounting, in which companies use quantitative measures of water use and wastewater discharge as a starting point to assess impacts and risks, track the effects of management changes over time, and report this information to stakeholders. Water accounting also allows consumers, civil society groups, and the investment community to compare different companies' water risks and impacts in order to inform their actions and decision making. In sum, the ability to effectively account for corporate water use and impacts is essential in helping companies drive improvement and become aligned with external stakeholders' expectations, as well as their efforts to advance sustainable water management.

Collecting and disseminating meaningful water-related information, however, is a complicated and difficult undertaking. Corporate water accounting methods and tools have been under development for the past decade, yet there is near universal agreement that current methods—though a good start—are inadequate and need to be refined.

The Process of Assessing Risks and Impacts

Corporate water accounting today can be seen as serving four general, interrelated steps.

Measurement of Water Performance

In the first stage, companies quantitatively measure the water performance of their various facilities and products. This process often includes an assessment of water use, water-use efficiency (e.g., water use per unit of production or number of employees), recycled water use, and volume and quality of wastewater discharge throughout their value chain, including their own direct operations, suppliers, and product use. The extent and distribution of corporate water footprints vary greatly from company to company and depending on industry sector (Table 2.2). These assessments can be used to evaluate where in the value chain water risks are most likely to occur and which facilities have the greatest potential to improve efficiency and therefore which areas should be prioritized for action.

Assessing Water-Related Social and Environmental Impacts

The actual social and environmental impacts associated with corporate water use and wastewater discharge can differ drastically depending on the local water resource context (i.e., physical availability of water, instream flows, and community access to water). A company using a given volume of water in a large, water-abundant system will typically have less impact than a company using the same amount of water in an arid region, or one where water is not equitably allocated to meet basic human and environmental needs.

Impact assessments take facility water performance and overlay it with data on local watershed conditions, such as physical water availability, the proportion of available water currently being used by humans, community access to water services, environmental flows, and water quality. This allows them to assess, for instance, where major water uses coincide with water scarcity. Impact assessments ultimately aim to understand and quantify the ways in which business activities may affect such issues as community access to water, human health, or the instream flows required for healthy ecosystems. A successful impact assessment provides companies with data and information to prioritize management practices and tailor mitigation/stewardship strategies to address the impacts deemed most important. It can answer specific questions, such as:

- Which of my facilities or products pose the greatest social and environmental impacts?
- Which components of my value chain or product life cycle result in the greatest impacts?
- How do my operations in a specific watershed affect ecosystem functions and/or instream flows?

Table 2.2. Relative Water Footprint of Various Industry Sectors

	Raw material production	**Suppliers**	**Direct operations**	**Product use/ end of life**
Apparel	● ○ ◍	◍		
High-Tech/Electronics	◍	◍		◍
Beverage	● ○	●	●	
Food	● ○ ◍		● ◍	
Biotech/Pharmaceuticals			◍	
Forest Products	○		●	
Metals/Mining	● ◍		● ◍	
Electric Power/Energy	● ◍		● ◍	

The circles indicate the value chain segments that have relatively high blue water (black circle), green water (white circle), and gray water (gray circle) footprint intensities.

Source: Ceres 2009.

- How do my operations in a specific watershed affect the ability of communities to access or afford adequate water services?
- How do my operations in a specific watershed affect human health?

Determining Business Risks Associated with Water Performance and Impacts

Quantitative measures of a facility's water performance and impacts can be coupled with assessments of local watershed conditions to determine risk. Unlike these previous two measures, risk assessments are typically qualitative for the most part. They aim to determine which facilities or value chain segments have the greatest impacts or costs, where water supply may be unreliable or unsecure, and where water quality may be prohibitive.

Communicating Water Risk/Performance with Stakeholder

For more on this topic, see the discussion on corporate water disclosure on page 40.

Corporate Water Accounting Tools

There are currently four main tools and methods through which companies can account for their water performance and impacts and can assess risks. Below we give a brief synopsis of these tools and methods. Their strengths and weaknesses are further illustrated in Table 2.3.

Water Footprinting (as Managed by the Water Footprint Network)

Water footprinting—a methodology introduced in 2002 and developed primarily by researchers at the University of Twente (Netherlands)—measures the total annual volume of freshwater used to produce the goods and services consumed by any well-defined group of consumers, including a family, village, city, province, state, nation, and more recently, a business or its products (Hoekstra 2008). Water footprints are intended to allow these entities to better understand their relationship with watersheds, make informed management decisions, and spread awareness of water challenges worldwide.

A water footprint captures the volume, location, and timing of water uses and discharges. Water footprints are divided into three separate components. The blue water footprint measures the volume of water consumption taken from surface waters and aquifers. The green water footprint measures the volume of water consumption taken from soils (e.g., by nonirrigated crops) or used directly as rainfall. The gray water footprint measures the volume of water needed to dilute pollutants discharged to water bodies to the extent that they do not exceed minimum regulatory standards.

Life Cycle Assessment

Historically geared toward and used by the private sector, Life Cycle Assessment (LCA) is a systems analysis tool that was designed specifically to measure the environmental sustainability of products and services through all components of the value chain. LCA quantifies and compares the multiple types of resource uses, emissions, and impacts caused by one type of use or emission, as well as the various resource uses or emissions that contribute to one type of impact. Properly done, an LCA allows companies and other interested parties (including consumers) to make comparisons among products and services. Traditionally, water use has not been accounted for within this method.

Table 2.3 Summary of Water Accounting Methodologies and Tools

	Water Footprint (WF)	Life Cycle Assessment	WBCSD Global Water Tool	GEMI Water Sustainability Tools
General strengths	Good tool for "big picture" strategic planning purposes. Easily understood by nontechnical audiences. Best for water-use assessments, as opposed to water quality.	Uniquely well-suited for cross-media environmental assessments. Mature science-based methods for assessing water-quality impacts.	Good first-tier risk screen, Inexpensive, fast, and does not require company expertise. Simple inventory for companies to compile their water data.	Useful for companies just beginning to think about water stewardship. Inexpensive, fast, and does not require expertise.
General weaknesses	Generic, aggregated blue-green-gray WF figures are misleading. Gray WF deemed ineffective by many companies.	No universally accepted method of assessing water-use impacts. Results can be difficult to communicate to non-technical audiences.	Does not address water-quality/discharge-related risks. Does not address impacts. Assessments provide only rough estimates of risk.	Rudimentary assessment of relative risks. No quantified results.
Assess water-related business risks	Identifies hotspots linking corporate consumptive water-use and source water data. Green/blue WF distinction helps shed light on nature of risk.	Uses science-based impact assessment as the starting point for understanding business risk. Operational hotspots used for product design improvement and technical improvements.	Emphasizes place-based water metrics that contextualize company water use and that serve as the basis for understanding risk. Identifies hotspots by mapping facilities against external water and sanitation data.	The Planner assesses external factors that affect specific facilities. The Tool helps companies identify business-wide water-related risks.
Understanding and responding to water-use and water-quality impacts	WF calculation does not attempt to quantify water-related impacts. Green/blue WF distinction illustrates general extent and type of impact. Gray WF is underdeveloped/underutilized—focuses on primary pollutant and calculates theoretical volume of dilution water needed to reach regulatory standards.	Situates water impacts within a broader understanding of sustainability impacts. Characterizes water-use data based on relative water stress to quantify impacts. Measures individual contaminant loads. Does not typically quantify impact to specific local receiving bodies.	Does not characterize corporate water use or otherwise attempt to assess impacts. Does not assess water-quality issues.	Provides a compilation of information that can help better understand and identify impacts but does not quantify them. Provides questions that help companies understand their effects on quality of water bodies.
Conveying water information to stakeholders	Can be an effective tool for building public awareness. Conducive to business engagement with water resource managers.	In many instances, particularly in North America, is used for internal purposes only. Awareness levels in both business and the public vary greatly. Used to inform ecolabel programs.	Results of "hotspotting" are more frequently being included in CSR reports. Automatically calculates water-related GRI indicators to be used for CSR reports.	Is not intended for use as a communication tool, nor is it commonly used as one.

Source: CEO Water Mandate and United Nations Environment Programme 2010.

However, given companies' growing concerns over water scarcity, the development of better ways of accounting for water use within LCA has become a priority.

WBCSD Global Water Tool

Unlike water footprinting and LCA, which are comprehensive methodologies for assessing water use and discharge, the World Business Council for Sustainable Development (WBCSD) Global Water Tool provides an assessment of the conditions in the watersheds in which industrial facilities are located (WBCSD 2011). The Tool is a free online module that aims to couple corporate water use, discharge, and facility information input with watershed and country-level data. It allows companies to identify risk hotspots by illustrating which of their facilities are located in water-stressed regions or regions where communities have limited access to water services or sanitation. The WBCSD estimates that more than 300 companies worldwide have used the Tool since its launch in 2007 (WBCSD 2011).

GEMI Water Sustainability Tools

The Global Environmental Management Initiative (GEMI) has developed two tools to advance corporate understanding of water issues. Released in 2002, the GEMI Water Sustainability Tool is an online tool that helps organizations create a water strategy (GEMI 2002). It assesses a company's relationship to water, identifies associated risks and describes the business case for action, and helps address companies' specific needs and circumstances. The GEMI Water Sustainability Planner—an online tool released in 2007—focuses on the needs of a facility-level user rather than the company as a whole (GEMI 2007). It helps facility personnel to better understand the facility's dependence on water and the status of the local watershed (including local social and environmental considerations) and to identify its specific challenges and opportunities. A more detailed analysis of these methodologies and tools is found in the CEO Water Mandate/UNEP *Corporate Water Accounting* report (CEO Water Mandate and United Nations Environment Programme 2010).

Strategies for Improved Corporate Water Management

Improving operational efficiencies and product design is typically the first step companies take to mitigate water-related business risk and reduce costs. However, as discussed previously, operational and product improvements can address only a fraction of the water risks that companies face. Existing and emerging tools and strategies can be used to address a wide array of risks while promoting sustainable and equitable outcomes in the watersheds in which they operate. Here are several key strategies and tools for responsible water management.

Operational and Employee Engagement

Developing a company-wide policy or strategy for water management is essential to long-term mitigation of water-related business risks. Such policies and strategies can include company-wide protocol and benchmarks for water management practices, strategies for product development, company-wide and facility-specific water use and wastewater discharge goals, and rights-based approaches.

Developing protocol for facility managers can help (1) introduce technology and management practices that can improve efficiency, (2) standardize measurement metrics to allow for company-wide assessment and comparisons, and (3) provide benchmarks for appropriate water uses for each production stage and facility. Protocol can be specified and modified to reflect local conditions such as water stress, water quality, community access to water, and political/institutional capacity. Similarly, company-wide employee education programs can help foster buy-in and coordination among different levels of management.

Setting goals for water-use efficiency and wastewater discharge allows companies to demonstrate improved management when they are successful and helps stakeholders hold them accountable when they are not. Goals should be set—whenever possible—at the facility level in order to account for local water supply and quality. Reporting of progress toward these goals should be done on a regional basis or by degree of water stress. For instance, companies can report water savings in areas of water-stressed regions as compared to water savings in water-rich areas as a way to better illustrate risk and impact mitigation.

More broadly, upper-level management can create strategies that decrease dependency on water resources or that encourage growth in areas of minimal water risks. For instance, agribusiness could look to focus on producing crops that provide more economic value per unit of water. Industries that are inherently water intensive, such as microchip manufacturers, can promote future growth in regions with abundant water resources and unpolluted natural water bodies.

Supply Chain Engagement

Businesses' traditional water practices often fail to address water risks embedded in the supply chain. Water supply risks are often hidden in companies' raw material inputs or

BOX 2.1 Unilever Improves Operational Efficiencies

Unilever has been comprehensively analyzing its direct and indirect water impacts, taking into account water used by suppliers in growing raw materials, as well as water used by consumers using Unilever products. Since introducing systematic measurement of its water use in 1995, the company has reduced its direct water consumption per ton of production by roughly 62 percent. In 2007, Unilever reduced total water consumption in its operations worldwide by 4.9 million cubic meters and the volume of water per ton of production by 7.5 percent, exceeding its target of 4.7 percent.

On the consumer end, the company estimates that a reformulated version of laundry detergent requiring less rinsing will have considerable water-use impacts in water-stressed areas of India where washing clothes accounts for a large portion of domestic water consumption. Based on assumptions about laundry habits, Unilever estimates potential savings in the region of 14 billion liters of water per year (Unilever 2007).

BOX 2.2 PepsiCo Publicly Acknowledges the Human Right to Water

In 2009, PepsiCo became one of the first multinational companies to publicly commit to respecting the human right to water throughout its global operation. This commitment—driven partially by a shareholder resolution and collaboration with Northstar Asset Management—requires the company to proactively act to ensure that its facilities do not adversely affect any communities' access to sufficient and clean water supplies, as well as to provide those communities with a meaningful role in the development of processes that extract water from shared supplies. These goals can be achieved by decreasing water use, particularly in locations exposed to water scarcity or where communities have limited access to water services; improving wastewater treatment; conducting ongoing impact assessments; and regularly communicating with potentially affected communities (UUSC 2009).

intermediate suppliers. For instance, SAB Miller recently conducted a water footprint analysis of its beer production in South Africa, which concluded that over 98 percent of SABMiller's water use comes from agricultural production over which it does not have complete control (SABMiller/WWF 2009). For this reason, companies are increasingly seeking ways to leverage improved water management from their suppliers.

Supply chains inevitably change depending on the nature of the relationship with the supplier. If a large company is the primary purchaser from a smaller supplier outfit, it will have great leverage to influence supplier performance. If a relatively small company is buying from a massive supplier (and therefore comprises a small portion of the supplier's income) or from commodity markets, it will have much less ability to drive change. In cases where companies have little leverage over their suppliers, the most effective strategy is often to change suppliers or coordinate with other buyers to increase their leverage.

In cases where companies have an opportunity to influence supplier practice, they can implement various strategies to encourage good performance. In some situations, suppliers may simply not understand their impacts or how to improve their practices. A good starting point is to disseminate water performance tool kits that outline good practice and helpful technologies. When technological improvements are not feasible for suppliers, companies can agree to pay for a certain portion of costs or provide low-interest loans.

More and more companies are beginning to assess the environmental performance of their suppliers, including water use, wastewater discharge, greenhouse gas emissions, air pollution, energy use, and more. These criteria can in many cases be quite similar to those companies use to assess their own facilities, ideally including impact and risk assessment. Supplier water performance assessment can be used for prospective suppliers or continuing existing supplier contracts. In order to make supplier data collection more feasible, it may be necessary to ask suppliers to self-report (based on

BOX 2.3 Cadbury Distributes Energy and Water Savings Toolkits Throughout Business Operations and Suppliers

As part of its broader sustainability efforts known as Purple Goes Green, Cadbury has developed energy and water savings toolkits that it distributes throughout its business operations and suppliers. These toolkits, which are made available on the Cadbury intranet and on CD, cover a variety of sustainability issues, giving practical advice on ways to improve management practices. The water issues covered in the tool have been informed by engagement with stakeholders, particularly the World Wildlife Fund. By Cadbury's own characterization, its water program is still in its nascent stages; however, this strategy of developing standardized tool kits is an innovative and cost-effective way for corporations to help promote more sustainable water management practices across vast supply chains (Cadbury 2008).

metrics established by the company) followed by audits when suppliers are suspected of inaccurate reporting.

Measurement of supplier water performance is central to understanding and addressing associated risks. However, this task has proved daunting for many companies that purchase supplies from thousands of different suppliers worldwide or who buy supplies from commodity markets and do not have access to producers.

Community Engagement

Companies should also engage with communities potentially affected by their operations in order to better understand impacts and risks, incorporate stakeholder perspectives into water management plans, and support community efforts to enhance the quality and accessibility of water services. Though facilitating community access to water services is often regarded as purely philanthropic, in reality it is also an effective strategy to reduce the possibility of impacts (especially those related to competing for water resources) and to improve brand reputation. These strategies are often particularly effective in the global South, where local governments often have less capacity to provide consistent access to water services.

Examples of possible community engagement efforts to understand risk and impacts or to incorporate stakeholder perspectives into water management plans include (1) including community members on stakeholder advisory panels in impact assessments, (2) developing corporate social responsibility reports, and (3) building new facilities. Companies can also participate in, and help to support, local and regional water councils.

Direct support for access to water services in local communities can include digging boreholes, establishing inexpensive sanitation systems, cleaning waterways, and introducing technologies that promote water-use efficiency. This engagement is often achieved through simple monetary donations to communities or nongovernmental

BOX 2.4 Diageo's Water of Life Program

Diageo's Water of Life corporate citizenship program has established the One Million Challenge—a company goal to deliver a source of clean water to one million people in Africa every year until 2015. These efforts include community-based projects that improve access to drinking water, enhance environmental conversation, and deliver capacity-building training to communities. Since the program's start in 2007, they have delivered water to an estimated 3.2 million people.

The program is designed as a bottom-up initiative. Diageo's local businesses select projects based on local needs and priorities and utilize local resources. Each local business is expected to contribute 0.5 percent of its net operation profit to philanthropic water projects (and another 0.5 percent to non-water-specific CSR activities). The Diageo Foundation provides further funding for large-scale projects (Diageo 2008, 2009).

organization (NGO) partners, but can also include technical assistance in the form of data, expertise, or technology.

Community engagement can bring with it many risks, particularly in regard to "responsibility boundaries." Companies may be seen as forcing their actions on communities unless engagement is done in response to community requests or is decided on through legitimate multi-stakeholder decision-making processes. In addition, working effectively with communities to improve water supply and sanitation or other infrastructure requires specialist approaches and knowledge to embed sustainability, ownership, and equity.

Policy Engagement

As discussed previously, many water-related business risks stem from ineffective or nonexistent public water policy and management. These risks are much more difficult to address than those associated with internal business practice. However, emerging corporate practice reveals that it can be done through responsible business engagement with water policy,

Corporate engagement with public policy has traditionally been understood as direct policy advocacy and lobbying. However, engagement can be understood more broadly as initiatives that involve interaction with government entities, local communities, and/or civil society organizations with the goal of advancing two objectives: the responsible internal company management of water resources within direct operations and supply chains in line with policy imperatives (i.e., legal compliance), and the sustainable and equitable management of the catchment in which companies operate.

Policy engagement is built around the premise that the external catchment conditions that create risk for companies also create risk for other actors in that catchment.

BOX 2.5 Sasol Facilities Improved Water Pressure Management in Township

Sasol—a chemicals company based in South Africa—worked with a local township to save water through helping finance improved pressure management of its local water supply. This effort was spurred on as Sasol attempted to improve the water-use efficiency of one of its cooling towers. It found that it would cost $50 million to save 18 megaliters of water per day, or $2 per cubic meter. Acknowledging the high cost of this improvement, it sought alternative water-saving approaches and found that working with the nearby township on pressure management could save 28 megaliters per day at a total cost of only $0.5 million, or $0.02 per cubic meter. In sum, Sasol was able to spend less money to save more water, while simultaneously reducing costs for the local utilities district (Sasol 2010).

Indeed, communities, the environment, customers and suppliers, and government are all exposed to risk caused by such common problems as water scarcity, pollution, aging infrastructure, floods, droughts, and climate change. Collaborative efforts among different sectors can help ensure that water resources are managed sustainably and equitably. That said, companies engaging with public water policy must pay special attention to stakeholder concerns of policy capture due to a long history of the private sector abusing the political process.[3]

Companies engaging with governments and other stakeholders to advance sustainable water policies and management take a variety of approaches, including:

- Encouraging efficient water use across a catchment,
- Contributing to the development of effective and equitable policy and regulations,
- Supporting research, advocacy, and monitoring ,
- Aiding environmentally and socially responsible infrastructure development,
- Advancing public awareness of water resource issues,
- And, working with communities to remedy or prevent water resource problems.

The objectives and strategies of engagement activities vary depending on the political, environmental, and social contexts in which businesses operate as well as what

3. Policy capture exists where organizations unduly dominate a policy-making process to an extent that excludes or subdues other stakeholder views, resulting in policy that favors narrow vested interests to the detriment of the public good (Morrison et al. 2010).

resources and leverage points are available to the company. In November 2010, the CEO Water Mandate released comprehensive guidance on policy engagement entitled *Guide to Responsible Business Engagement with Water Policy* (Morrison et al. 2010).

Partnerships

Risks can also be both identified and mitigated through the creation of partnerships. Companies seek out partnerships with other organizational actors (e.g., NGOs, intergovernmental agencies, universities, trade associations, or directly with other businesses) in order to gain other perspectives, enhance credibility, increase leverage, and pool resources to address shared water risks.

Partnerships can also be an effective approach for preventing real and perceived policy capture. For example, partnerships with reputable NGOs can build credibility and provide access to stakeholder perspectives and, often, intimate knowledge of local water realities and catchment conditions. Partnerships with other companies can help build a broader foundation of resources for engagement and can also help increase the visibility of that action (and in doing so promote good practice). That said, partnerships comprised solely of private-sector entities or that are created to inhibit rather than encourage transparency and sustainability are likely to be met with more skepticism than those with a variety of public and NGO actors.

The end goal of partnerships can be quite similar to community and policy engagement efforts, namely sustainable public water policy and management and improved community access to water services. They can also be used to pool resources in the development of research on good management practices and better technology. Companies can receive and provide a number of different types of assistance through partnership: funding, influence/visibility, data, stakeholder perspectives, technologies, management strategies, and so forth. In contrast, as corporations do not always have the expertise to carry out development and other charitable projects, monetary donations to intergovernmental groups that are experienced and focused on such projects can serve to convert corporate resources into on-the-ground results.

In order for partnerships to ensure inclusivity and prevent policy capture, all parties—particularly traditionally marginalized stakeholders—must have a reasonable opportunity to influence the engagement strategy and outcomes.

Disclosure

Companies are increasingly choosing to publicly report their water uses and impacts in order to strengthen communication with stakeholders and enhance accountability to the public. Such transparency efforts foster trust, confidence, and goodwill among consumers and investors alike, thereby providing competitive advantage. Furthermore, companies have found such a process helps to identify significant business risks and opportunities. This trend has continued to such an extent that corporate reporting is now becoming a baseline expectation of global companies.

The most common metrics companies use include total water use, total wastewater discharge, water-use efficiency, or total amount of recycled water for their direct operations. However, the meaningfulness and legitimacy of such generic and aggregated data are widely disputed (JPMorgan 2008, Morrison and Schulte 2008). Emerging practice demonstrates reporting of more nuanced and comprehensive metrics. These

BOX 2.6 Groupe DANONE Aids UNICEF Projects

Groupe DANONE's Volvic Brand has been working with UNICEF on a project that aims to improve access to clean drinking water, particularly in the global South, by helping build and maintain wells. The program has a goal of providing 40 liters of drinking water per person per day—an approximate minimum value for basic human needs. The One Liter for Ten Liters program has already been deployed in Germany, France, Japan, Mexico, the United States, Indonesia, Niger, Ethiopia, Mali, and Ghana. Groupe DANONE's role in this project is largely fund-raising—it donates and collects money that it distributes to various UNICEF projects (Danone 2007).

metrics include water use, recycled water use, and wastewater discharge at the facility or regional level (rather than company totals), assessments of local watersheds (e.g., the number of facilities in water-stressed regions), impact assessments, supplier water performance, product water use, and financial and technical information for community or policy engagement efforts. Such metrics should be supported by qualitative information regarding company-wide water risks, facility- or region-specific risk, objectives and strategies for engagement efforts, and descriptions of corporate water policies and strategies. Companies are also providing more information on the process through which they determine which information is material for reporting purposes.

A number of existing and emerging initiatives attempt to standardize metrics and criteria for corporate water reporting. The most widely used and accepted metrics for sustainability reporting are known as the Global Reporting Initiative G3 Guidelines. The G3 Guidelines contain indicators for the economic, environmental, and social performance of companies. While certainly useful, the water-related GRI indicators are limited in the nature and scope of information they provide. The Carbon Disclosure Project (CDP) is currently developing a framework for collecting companies' water-related information and policies. This framework has significantly advanced the amount of reported information expected of companies, including (1) an in-depth examination of water risks and (2) an assessment of the local watershed context in which companies operate.[4] This information is expected from companies as well as their suppliers.

Conclusions: A Framework for Action

Mitigating water-related business risks requires action, both by investors and by companies themselves. Companies have a clear economic incentive to closely assess their relationship to their water inputs and outputs and to proactively address and manage them. To do so, companies should take the following steps:

4. For more on the CDP Water Information Request, see: https://cdproject.net/CDP%20Questionaire%20 Documents/CDP%20Water%20Disclosure%202010%20Information%20Request.pdf.

- Measure the company's water performance and assess local watershed conditions.
- Assess impacts and risk.
- Develop water policy and management strategy.
- Implement policies and strategies at all scales.
- Disclose water performance and associated impacts and risks, policies and strategies, and philanthropic activities.

The first three stages comprise the risk and impact assessment phase, in which companies measure their water use and wastewater discharge, assess the impacts they might have on ecosystems and communities, and ultimately determine the types of water-related risks they face and to what extent. In the final two stages, companies use their assessment of risk and impacts, as well as engagement with key stakeholders, to develop and implement water management plans that reduce those risks and impacts, and then to disclose their findings and actions to the general public.

This framework is intended as a cyclical process that achieves ongoing assessment and continuous improvement. Each stage is supported through ongoing stakeholder engagement to help determine meaningful metrics for assessment, identify impacts, and help in developing strategies and long-term management plans.

References

Cadbury. 2008. Corporate Responsibility & Sustainability Fact Sheets 2007/08. http://unglobalcompact.org/system/attachments/3051/original/COP.pdf?1262614369 (accessed October 14, 2010).

Center for Disease Control and Prevention (CDCP). 2009. Assessing Access to Water and Sanitation. http://www.cdc.gov/healthywater/global/assessing.html (accessed October 14, 2010).

CEO Water Mandate and United Nations Environment Programme. 2010. Corporate Water Accounting: An Analysis of Methods and Tools for Measuring Water Use and Its Impacts. Authored by Pacific Institute. http://www.pacinst.org/reports/corporate_water_accounting_analysis/corporate_water_accounting_analysis.pdf (accessed October 14, 2010).

Ceres 2009. Water Scarcity and Climate Change: Growing Risks for Businesses and Investors. Authored by Pacific Institute. http://www.pacinst.org/reports/business_water_climate/full_report.pdf (accessed October 14, 2010).

CLSA. 2006. *Remaining Drops: Freshwater resources, A Global Issue*. Hong Kong: CLSA Bluebooks.

Commonwealth of Australia. 2010. About the Water Efficiency Labelling and Standards (WELS) Scheme. http://www.waterrating.gov.au/about/index.html (accessed February 14, 2011).

The Co-Operative Bank. 2009. Ten Years of Ethical Consumerism: 1999–2008. http://www.goodwithmoney.co.uk/assets/Ethical-Consumerism-Report-2009.pdf (accessed October 14, 2010).

Czarnowski, A. 2009. Ethical purchasing: Ethics still strong in a cold climate. *Brand Strategy,* pp. 52–53. http://www.allbusiness.com/trends-events/investigations/11914169-1.html (accessed October 14, 2010).

Danone. 2007. Danone Sustainability Report 2007. http://www.danone.com/images/pdf/dan_ratechdevdurable07_en.pdf (accessed October 15, 2010).

Diageo. 2008. Water for Life: Reaching One Million People with Clean Drinking Water. http://www.businessactionforafrica.org/documents/DiageoWaterCaseStudy.pdf (accessed October 15, 2010).

Diageo. 2009. *Communications on Progress 2009*. United Nations Global Compact. http://www.unglobalcompact.org/docs/issues_doc/Environment/ceo_water_mandate/water_mandate_cops/Diageo.pdf (accessed October 15, 2010).

Efficiency Partnership. 2011. Showerheads. Flex Your Power. http://www.fypower.org/res/tools/products_results.html?id=100160 (accessed February 14, 2011).

Global Environmental Management Initiative (GEMI). 2002. Connecting the Drops: Toward Creative Water Strategies. http://www.gemi.org/water/

Global Environmental Management Initiative (GEMI). 2007. Collecting the Drops: A Water Sustainability Planner. http://www.gemi.org/waterplanner/

Hoekstra, A.Y. 2008. *Water Neutral: Reducing and Offsetting the Impacts of Water Footprints.* UNESCO-IHE Institute for Water Education. Value of Water Research Report Series No. 28. http://www.waterfootprint.org/Reports/Report28-WaterNeutral.pdf (accessed February 16, 2011).

Interfaith Center on Corporate Responsibility. 2010. EthVest Ethical Investing Database. http://www.iccr.org/ethvest.php (accessed October 14, 2010).

JPMorgan. 2008. Watching Water: A Guide to Evaluating Corporate Risks in a Thirsty World. Global Equity Research. http://pdf.wri.org/jpmorgan_watching_water.pdf (accessed October 15, 2010).

Morrison, J., and Schulte, P. 2008. Water Disclosure 2.0: Assessment of Current and Emerging Practice in Corporate Water Reporting. Pacific Institute. http://www.unglobalcompact.org/docs/news_events/9.1_news_archives/2009_03_11/Water_Disclosure.pdf (accessed October 15, 2010).

Morrison, J., Schulte, P., Christian-Smith, J., Orr, S., Hepworth, N., and Pegram, G. 2010. Guide to Responsible Business Engagement with Water Policy. CEO Water Mandate. http://www.unglobalcompact.org/docs/issues_doc/Environment/ceo_water_mandate/Guide_Responsible_Business_Engagement_Water_Policy.pdf (accessed February 16, 2011).

SABMiller/World Wildlife Fund (WWF). 2009. Water Footprinting: Identifying & Addressing Water Risks in the Value Chain. http://www.sabmiller.com/files/reports/water_footprinting_report.pdf (accessed October 14, 2010).

Sasol. 2010. *Managing the Challenge of Water Scarcity.* Sasol Sustainability Report 2009. http://www.sasolsdr.investoreports.com/sasol_sdr_2009/material-challenges/managing-the-challenge-of-water-scarcity/ (accessed October 15, 2010).

Unilever. 2007. Unilever Sustainable Development Report 2007. http://www.unilever.com/images/es_environmental_tcm13-130777.pdf (accessed October 14, 2010).

Unitarian Universalist Service Committee (UUSC). (2009). Shareholder Advocacy Advance: PepsiCo Adopts Human Right to Water Policy. http://www.uusc.org/content/pepsico_new_water_policy (accessed May 23, 2011).

World Business Council for Sustainable Development (WBCSD). 2011. The Global Water Tool. http://www.wbcsd.org/Plugins/DocSearch/details.asp?DocTypeId=25&ObjectId=27203&URLBack=%2Ftemplates%2FTemplateWBCSD2%2Flayout.asp%3Ftype%3Dp%26MenuId%3DMjY2

CHAPTER 3

Water Quality

Meena Palaniappan, Peter H. Gleick, Lucy Allen, Michael J. Cohen, Juliet Christian-Smith, and Courtney Smith

Every day, millions of tons of inadequately treated sewage and industrial and agricultural wastes pour into the world's waters. Every year, lakes, rivers, and deltas take in the equivalent of the weight of the entire human population—or the weight of nearly seven billion people—in the form of pollution. Every year, more people die from the consequences of unsafe water than from all forms of violence, including war. And, every year, water contamination of natural ecosystems affects humans directly by destroying fisheries or causing other impacts on biodiversity that affect food production. In the end, most polluted freshwater ends up in the oceans, causing serious damage to many coastal areas and fisheries and worsening the challenge of resource management.

Clean, safe, and adequate freshwater is vital to the survival of all living organisms and the smooth functioning of ecosystems, communities, and economies. But the quality of the world's water is increasingly threatened as human populations grow, as industrial and agricultural activities expand, and as climate changes threaten to cause major alterations to the hydrologic cycle. Poor water quality threatens the health of people and ecosystems, reduces the availability of safe water for drinking and other uses, and limits economic productivity and development opportunities. Water quality is as important as water quantity for satisfying basic human and environmental needs, yet it has received far less investment, scientific support, and public attention in recent decades than water quantity, even though the two issues are closely linked. There is an urgent need for the global community—both the public and private sectors—to join together to take on the challenge of improving the quality of water in our rivers, lakes, aquifers, and taps. To do so, we must commit to preventing future water pollution, treating waters that are already contaminated, and restoring the quality of rivers, lakes, aquifers, wetlands, and estuaries; this enables these waters to meet the broadest possible range of human and ecosystem needs. These actions will be felt all the way from the headwaters of our watersheds to the oceans, fisheries, and marine environments that help sustain humanity.[1]

1. This chapter draws on work done by the authors and the Pacific Institute for the United Nations Environment Programme (Palaniappan et al. 2010).

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_3,

Current Water-Quality Challenges

Contaminants in Water

Both human activities and natural activities can change the physical, chemical, and biological characteristics of water, and they have specific ramifications for human and ecosystem health. Water quality is affected by changes in nutrients, sedimentation, temperature, pH, heavy metals, nonmetallic toxins, persistent organics and pesticides, and biological factors, among many other factors (Carr and Neary 2008). Following are brief discussions of these major contaminants. Many contaminants can also combine synergistically to cause worse, or different, impacts than the cumulative effects of a single pollutant. Continued inputs of contaminants will ultimately exceed an ecosystem's resilience, leading to dramatic, nonlinear changes that may be impossible to reverse (MA 2005b).

Nutrients

Nutrient enrichment has become the planet's most widespread water-quality problem (UN WWAP 2009). Most often associated with nitrogen and phosphorus from agricultural runoff, but also caused by human and industrial waste, nutrient enrichment can increase rates of primary productivity (the production of plant matter through photosynthesis) to excessive levels, leading to overgrowth of vascular plants (e.g., water hyacinth), algal blooms, and the depletion of dissolved oxygen in the water column, which can stress or kill aquatic organisms. Some lakes and ponds have become so hypereutrophic (nutrient rich and oxygen poor) due to excess nutrient inputs that all macro-organisms have been eliminated.

Erosion and Sedimentation

Erosion is a natural process that provides sediments and organic matter to water systems. In many regions, human activities have altered natural erosion rates and greatly altered the volume, rate, and timing of sediments entering streams and lakes, affecting physical and chemical processes and species' adaptations to natural sediment regimes. Increased sedimentation can decrease primary productivity, decrease and impair spawning habitat, and harm fish, plants, and benthic (bottom-dwelling) invertebrates. For example, the construction of major dams on the Yangtze River has noticeably affected sediment load reaching the East China Sea, according to Chinese scientists. In recent years, sediment reaching Datong, near the Yangtze's delta, dropped to only 33 percent of the 1950–1986 levels (Xu et al. 2006). Among the consequences of this drop in sediment are growing coastal erosion and a change in the ecological characteristics and productivity of the East China Sea (Xu et al. 2006).

Water Temperature

A wide range of human activities alter natural water temperatures, including large withdrawals of water, impoundments and releases from reservoirs, industrial and thermoelectric cooling systems, and even large-scale climate change. Water temperature plays an important role in signaling biological functions such as spawning and migration and in affecting metabolic rates in aquatic organisms. Altering natural water temperature cycles can impair reproductive success and growth patterns, leading to long-term population declines in fisheries and other classes of organisms. Warmer water holds less oxygen, impairing metabolic function and reducing fitness. Such impacts can be especially severe downstream of thermal or nuclear power generation facilities or industrial activities, where the return of water to the streams may be substantially warmer than ecosystems are able to absorb (Carr and Neary 2008).

Acidification

The pH is a key factor in determining the health and biological characteristics of aquatic ecosystems. A range of industrial activities, including especially mining and power production from fossil fuels, can cause localized acidification of freshwater systems. Acidification disproportionately affects young organisms, which tend to be less tolerant of low pH. Lower pH can also mobilize metals from natural soils, such as aluminum, leading to additional stresses or fatalities among aquatic species. According to the U.S. Environmental Protection Agency, for example, more than 90 percent of the streams in the Pine Barrens, a wetlands region in the eastern United States, are now unnaturally acidic as a result of emissions from upwind energy systems, particularly coal-fired power plants (US EPA 2009a).

Salinity

Freshwater plant and animal species typically do not tolerate high salinity. Various actions, often but not exclusively anthropogenic, can cause salts to build up in the water. These include agricultural drainage from high-salt soils, groundwater discharge from oil and gas drilling or other pumping operations, various industrial activities, and some municipal water-treatment operations. These may increase salt loading and also alter the natural salt balances (for example, altering the ratio of potassium to sodium).

Pathogenic Organisms

One of the most widespread and serious classes of water-quality contaminants, especially in areas where access to safe, clean water is limited, is pathogenic organisms: bacteria, protozoa, and viruses. These organisms pose direct threats to human health. The greatest risk of microbial contamination comes from consuming water contaminated with pathogens from human or animal feces (Carr and Neary 2008). In addition to microorganisms introduced into waters through human or animal fecal contamination, a number of pathogenic microorganisms are free-living in certain areas or, once introduced, are capable of colonizing a new environment. These free-living pathogens, including some *Vibrio* bacterial species and a few types of amoebas, can cause major health problems in those exposed, including intestinal infections, amoebic encephalitis, amoebic meningitis, and occasionally death (WHO 2008). Viruses and protozoa, including *Cryptosporidium* and *Giardia*, Guinea worm, and others, also pose human health risks.

Trace Metals

Trace metals, such as arsenic, zinc, copper, and selenium, are naturally found in many different waters. Some human activities, such as mining, industry, and agriculture, can lead to an increase in the mobilization of these trace metals out of soils or waste products into fresh waters. Even at extremely low concentrations, such additional materials can be toxic to aquatic organisms or can impair reproductive and other functions. In the early 1980s, high concentrations of selenium in agriculture drainage water that was discharged to the Kesterson National Wildlife Refuge in California extirpated all but one species of fish and caused widespread bird die-offs, as well as severe deformities in several bird species (Ohlendorf 1989).

Human-Produced Chemicals and Other Toxins

Diverse human-produced organic chemicals can enter surface and groundwater through human activities, including pesticide use and industrial processes, and as breakdown products of other chemicals (Carr and Neary 2008). Many of these pollutants, including pesticides and other nonmetallic toxins, are used globally, persist in the environment, and can be transported long distances to regions where they have never been produced (UNEP 2009).

Organic contaminants (sometimes called persistent organic pollutants, or POPs), such as certain pesticides, are commonly found to be contaminating groundwater by leaching through the soil and surface waters through runoff from agricultural and urban landscapes. DDT, a pesticide that has been banned in many countries but is still used for malaria control in countries throughout Africa, Asia, and Latin America (Jaga and Dharmani 2003), remains persistent in the environment and is resistant to complete degradation by microorganisms (WHO 2004a). For some of these materials, nonlethal doses may be ingested by invertebrates and stored in their tissues, but as larger organisms consume contaminated prey species, the amounts of pesticides and other materials bioaccumulate, eventually to toxic levels. Other organic pollutants, such as dioxins, furans, and polychlorinated biphenyls (PCBs), are the by-product of industrial processes and enter the environment both through their use and disposal (UNEP 1998). Such materials have become an emerging threat, with possible long-term degradation of freshwater and other ecosystems.

Introduced Species and Other Biological Disruptions

Invasive species displace endemic species and alter water chemistry and local foodwebs. More experts explicitly consider this to be a water-quality problem (Carr and Neary 2008). In many instances, these introductions have decimated endemic fish and other aquatic organisms, and they can also degrade local watersheds. In South Africa, invasive plant species have altered local water quality and reduced water availability as well by increasing evapotranspiration rates in watersheds. In the United States, the invasion of some species of mussels has led to additional costs exceeding a billion dollars annually to the water power industry and in impacts on local ecosystems (De Leon 2008). According to the South African Department of Water Affairs and Forestry, invasive alien species are causing billions of rands of damage to the country's economy every year and are the single biggest threat to the country's biodiversity. In response, the country launched the Working for Water program to remove invasive plants, restore local watersheds, provide community jobs and job training, and reduce risks to local biodiversity.

Emerging Contaminants

About 700 new chemicals are introduced into commerce each year in the United States alone (Stephenson 2009), and worldwide, vast quantities of chemicals with unknown health and environmental impacts are used for a wide range of industrial and agricultural purposes. In just one example, pesticide application is estimated to be approximately five billion pounds (over two million metric tonnes) per year (PAN 2009). Despite their widespread use, the prevalence, transport, and fate of many of these new chemicals remain largely unknown because, until recently, testing techniques were unable to detect contaminants at the low concentrations at which they are present in the environment (Carr and Neary 2008).

Another new threat has recently been identified for surface water and groundwater: endocrine disruptors. These are chemicals that can interfere with hormone action, and they have now been identified among chemicals used in agriculture, industry, and households, and for personal care, including pesticides, disinfectants, plastic additives, and pharmaceuticals like birth control pills. Many of these endocrine disruptors mimic or block other hormones in the body, disrupting the development of the endocrine system permanently and irreversibly (Colborn et al. 1993). The effects of endocrine disruptors on wildlife include the thinning of eggshells in birds, inadequate parental behavior, cancerous growths, and other effects (Carr and Neary 2008). For example, the feminization of fish living downstream from wastewater treatment plants has been linked to estrogenic pharmaceuticals (Sumpter 1995), and new studies link the observed feminization of amphibians to endocrine-disrupting pesticides such as atrazine (Hayes et al. 2006).

The growing presence of pharmaceuticals and personal care products in water systems is also of increasing concern. These chemicals originate from products like cosmetics, toiletries, and detergents, as well as from medical treatments ranging from painkillers and antidepressants to hormone-replacement therapies and chemotherapy agents (Carr and Neary 2008). As an example, one study found measurable adverse impacts on aquatic bacteria from the antibiotic tetracycline, even at concentrations as low as micrograms (or a few millionths of a gram) per liter of water (Verma et al. 2007).

In addition to emerging chemical contaminants, there is also the threat of emerging waterborne pathogens. Several studies have confirmed that the variety of disease is expanding and the incidence of many water-related microbial diseases is increasing (WHO 2003b). Pathogens can emerge as a result of environmental conditions, from the use of new technologies, and from scientific advancements, such as the inappropriate use of antibiotics, insecticides, and pesticides creating resistant pathogen strains (WHO 2003b). In recent years, 175 species of infectious agents from 96 different genera have been classified as emerging pathogens (WHO 2003b).

Human Activities that Affect Water Quality

A wide range of human activities affect water quality. Below, four major categories are discussed—agricultural production, industrial and mining activities, water infrastructure, and the direct disposal of untreated or partly treated human wastes into water systems—along with the impacts these activities have on water quality. Three other key processes that have affected and will continue to affect water quality—population growth, urbanization, and climate change—are also described below.

Agriculture

The vast extent of agricultural activities, and the methods used for increasing agricultural productivity around the world, contribute to both economic productivity and water-pollutant loads. Since the 1970s, concern has grown over the increases in nitrogen, phosphorus, and pesticide runoff into surface water and groundwater. Intensive cultivation, increasing dependence on artificial fertilizers, and growing concentrations of "factory" animal or aquaculture operations generate large nonpoint source contributions of pollutants (Ignazi 1993). A comparison of domestic, industrial, and agricultural sources of pollution from the coastal zone of Mediterranean countries found that agriculture was the leading source of phosphorus compounds and sediment (UNEP 1996b).

Furthermore, nitrate is the most common chemical contaminant found in the world's groundwater and aquifers (Spalding and Exner 1993). According to surveys in India and Africa in the 1990s, 20 to 50 percent of wells contained nitrate levels greater than 50 milligrams per liter, and in some cases as high as several hundred milligrams per liter (cited in FAO 1996). More recent data from the United Nations Environment Programme's Global Environment Monitoring System/Water Programme (UNEP GEMS/Water) shows that mean nitrate concentrations have increased in the last decade in watersheds in the Americas, Europe, Australasia, and most significantly, Africa and the eastern Mediterranean (Figure 3.1) (UNEP 2008).

Beyond nitrate contamination, agricultural activities are also linked to the salinization of surface water, eutrophication (excess nutrients), pesticides in runoff, and altered erosion and sedimentation patterns.

Industry and Energy Production

Industrial activities are a significant and growing cause of poor water quality. Industry and energy production use accounts for nearly 20 percent of total global water withdrawals (UN WWAP 2009), and this water is often returned to its source in a degraded condition. Wastewater from industrial facilities, including power plants, paper mills, pharmaceutical manufacturers, semiconductor fabrication plants, chemical plants, petroleum refineries, and bottling facilities, and processes such as mining and drilling all contribute to poor water quality around the world (Figure 3.2). Industrial wastewater can contain a number of different pollutants, including:

- Microbiological contaminants, such as bacteria, viruses, and protozoa;
- Chemicals from industrial activities, such as solvents and organic and inorganic pesticides, PCBs, asbestos, and many more;
- Metals, such as lead, mercury, zinc, copper, and many others;
- Nutrients, such as phosphorus and nitrogen;

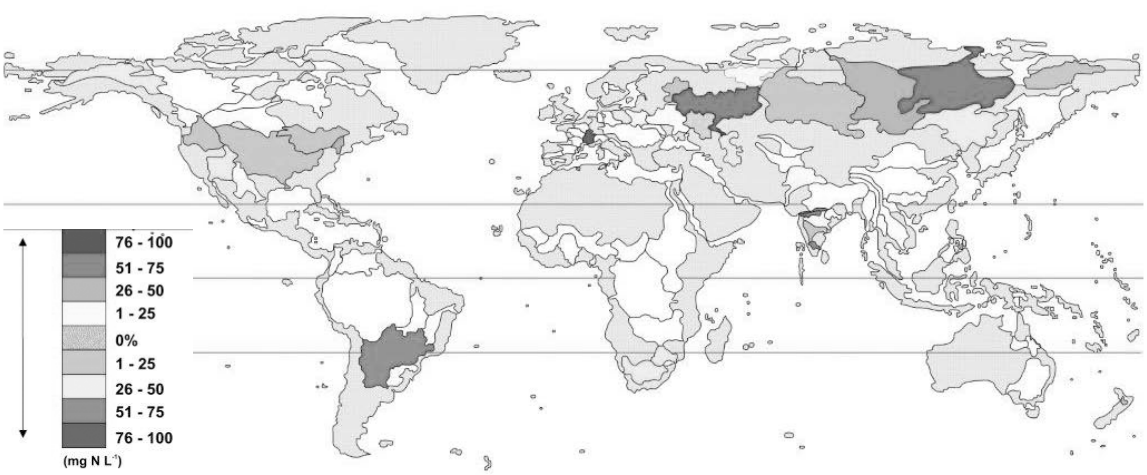

FIGURE 3.1 CHANGES IN NITROGEN CONCENTRATIONS FOR SIGNIFICANT GLOBAL WATERSHEDS BY REGION 1990–1999 AND 2000–2007.

Source: UNEP 2008

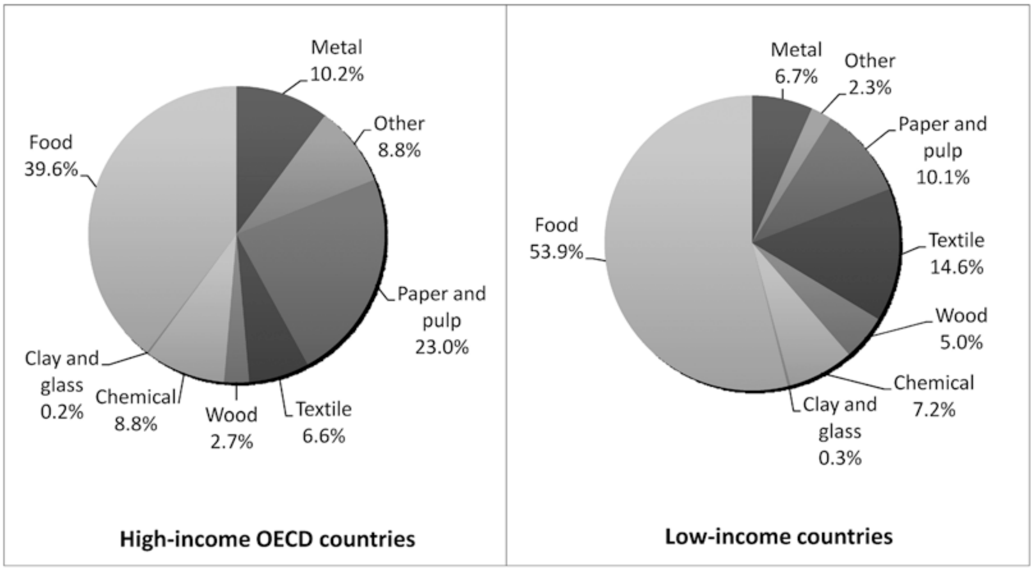

Figure 3.2 Contribution of Main Industrial Sectors to the Production of Organic Water Pollutants.
Source: UN WWAP 2003.

- Suspended matter, including particulates and sediments;
- Temperature changes through the discharge of warm cooling-water effluent; and
- Pharmaceuticals and personal care products.

The production of energy also affects water quality mostly because of the vast quantities of water required for power-plant cooling and the extensive risk of contamination during the search for and production of fossil fuels. Three major impacts prompt concern: (1) the production of vast quantities of contaminated groundwater during the drilling of oil and gas wells, (2) the withdrawal of water for power-plant cooling that reduces water available for ecosystems, and (3) the heating and subsequent discharge of cooling water, which raises the ambient water temperature in rivers, streams, and lakes, with effects on natural ecosystems. Some wastewater is also produced by certain power plants, with concomitant impacts on water quality.

Worldwide, it is estimated that industry is responsible for dumping 300–400 million tons of heavy metals, solvents, toxic sludge, and other waste into waters each year (UN WWAP undated). The amount of industrial water pollution in different countries varies greatly, based both on the amount of industrial activity in the country and the types of pollution-prevention and water-treatment technologies used by industrial facilities.

Mining

Mining activities have long been known to cause significant water-quality impacts. Mining and drilling for minerals and fossil fuels bring to the surface materials long buried in the earth, including water. They also tend to generate large quantities of waste materials or by-products relative to the target resource, creating large-scale waste disposal challenges, some of which are directly dumped into streams. Additionally, surface water may drain into mine openings, even those abandoned for over a century, and groundwater frequently accumulates in mines. Mine drainage waters can be extremely polluted by salts in the groundwater itself; metals such as lead, copper, arsenic, and zinc present in the source rock; sulfur compounds leached from rock; and mercury or other materials used in extraction and processing. Some mine drainage is extremely acidic, with a pH of 2–3; other source materials can lead to very alkaline discharges. These contaminated drainage waters can devastate local waterways, eliminating fish and rendering streams unfit for human use. In the U.S. state of Colorado alone, some 23,000 abandoned mines have polluted 2,300 kilometers of streams (Banks et al. 1997). In 1979, the Church Rock uranium mill tailings breached a containment dam, releasing over 1,000 tons of radioactive wastes and approximately 93 million gallons of radioactive effluent. The contamination traveled 80 miles downstream in the Puerco River and is reported as one of the largest radioactive accidents in U.S. history. Even today, portions of the river are too contaminated to use.

Water-System Infrastructure

All human-built systems can lead to the introduction of non-native species, altered water quality (nutrients, oxygen, and temperature), changes in system dynamics (flow size, duration, and timing), and the health of ecosystems. Water-supply infrastructure, including irrigation systems and dams, affects water quality through a number of mechanisms. These impacts are sometimes classified as follows (WCD 2000): (1) first-order impacts that involve modifying the physical, chemical, and geomorphological characteristics of a river and streamflow, including altering the natural quantity, distribution, and timing of water; (2) second-order impacts that involve changes in the biological productivity and characteristics of riverine ecosystems and downstream habitats such as wetlands and deltas; and (3) third-order impacts that affect flora or fauna (such as fish, amphibians, or birds) caused by a first-order effect (such as destruction of spawning habitat) or a second-order effect (such as decrease in a food source, or mobilization of a contaminant). Third-order impacts can also include effects on human health, industrial or agricultural productivity, or even politics.

A classic example of a water system severely affected by human development is the Aral Sea, fed by the Amu Darya and Syr Darya, where a series of dams and irrigation structures have shrunk the sea to one-fourth of its original size, killing off all 24 endemic fish species. The Colorado River in the United States and Mexico now has dams that can hold five years of average annual runoff, and almost the entire flow is allocated to human urban and agricultural uses in the U.S. and Mexico. The Orange-Vaal River in South Africa has 24 dams of various sizes and a severely modified temperature and sediment regime (WCD 2000). Many other examples exist of comparable modification of riverine systems by water infrastructure.

Uncontrolled Disposal of Human Wastes

A major activity that leads to widespread water-quality problems is the disposal of human waste. Fecal contamination often results from the discharge of raw sewage into natural waters—a method of sewage disposal common in developing countries, and even in more advanced countries, such as China, India, and Iran (Carr and Neary 2008). Even in developed countries, partially or inadequately treated sewage remains a major source of water-quality contamination.

Worldwide, 2.5 billion people live without improved sanitation (UNICEF and WHO 2008). Over 70 percent of these people, or 1.8 billion people who lack sanitation, live in

Asia. The amount of fecal coliform bacteria (associated with fecal matter) detected in Asia's rivers is sometimes measured at 50 times the WHO guidelines, indicating a high level of dangerous microbial contaminants (UNEP 2000). Even improved sanitation does not guarantee the protection of water quality; often there is no wastewater treatment to protect water bodies from receiving collected sewage. Over 80 percent of the sewage in developing countries is discharged untreated into receiving water bodies (UN WWAP 2009).

Open defecation poses an extreme human health risk and significantly compromises quality in nearby water bodies. Eighteen percent of the world's population, or 1.2 billion people, defecate in the open (UNICEF and WHO 2008). UNEP GEMS/Water provides in their Global Water Quality Outlook an assessment of the extent of fecal coliform contamination (an indicator of human or animal sewage contamination) downstream of major cities.

Population Growth, Urbanization, and Development

The pace of urbanization is increasing globally, putting more pressure on local water quality. According to the United Nations, the fraction of the world's urban population rose from 13 percent in 1900 to 29 percent in 1950 to 49 percent in 2005. The United Nations predicts that the proportion of people living in urban areas by 2030 will rise to 60 percent (UN-DESA 2008). In addition to discharges of urban and industrial wastewater, urban areas add to poor water quality other ways. Large areas of impervious surfaces increase runoff from roads and increase the flows of numerous pollutants, such as oils, heavy metals, rubber, and other automobile pollution, into waterways and streams. The reduction of water percolation into the ground can also affect the quantity and quality of groundwater, and stormwater runoff can overwhelm wastewater treatment systems when high volume flows exceed treatment capacities.

Climate Change

Climate change has a major impact on the world's freshwater resources, water quality, and water management (Pachauri and Reisinger 2008, Bates et al. 2008). Increases in water temperature and changes in the timing and amount of runoff are likely to produce unfavorable changes in surface-water quality, which will in turn affect human and ecosystem health. Global surface temperatures are rising, and evidence shows that the rate of warming is accelerating. By 2100, current climate models project that rising greenhouse gas concentrations will "likely" increase global mean surface air temperature between 1.1˚C and 6.4˚C relative to a 1980–1999 baseline (Meehl et al. 2007).[2] Water temperature is an important determinant of surface-water quality, as it controls the types of aquatic life that can survive, regulates the amount of dissolved oxygen in the water, and influences the rate of chemical and biological reactions. Among the consequences, higher surface-water temperatures from climate change will accelerate biological productivity, increase the amount of bacteria and fungi in the water, and promote algal blooms (Kundzewicz et al. 2007).

Many regions may see an increase in the intensity of precipitation events, which will likely result in increasing sedimentation and leaching of solid mine wastes, among other off-stream contaminants. Pollutants associated with human activity, including pesticides,

2. Terms such as *likely* and *very likely* have a very specific meaning associated with the expected probability of occurrence, given current knowledge. A likely outcome has more than a 66 percent probability of occurrence. A very likely outcome has more than a 90 percent probability of occurrence.

heavy metals, and organic matter, may flow into surface water faster and with less time for natural water filtration and groundwater infiltration (Kundzewicz et al. 2007). However, in some regions, this same increase in water flow could potentially dilute these contaminants, improving water quality (Carr and Neary 2008). However, in areas that are projected to become drier, the increase in intensity may be offset by a reduction in the frequency of precipitation events (Meehl et al. 2007). Increased drought conditions in these regions could both concentrate pollutants and lead to growing water scarcity.

A rise in sea level will further accelerate seawater intrusion into coastal aquifers and affect coastal ecosystems and drinking water supplies (Jacobs et al. 2001, Burns 2002). Coastal regions, particularly small islands, are especially vulnerable to these changes. If surface waters that empty into the ocean, such as estuaries and inland reaches, suffer from a decrease in their streamflow, more saline ocean water can penetrate farther upstream (Kundzewicz et al. 2007). Groundwater pumping from coastal aquifers, when increased to meet the demands of a growing population and increased development, can further reduce the recharge of aquifers, worsening the problem. Finally, water quality will be affected, both positively and negatively, by the decisions society makes in the face of climate change. Water management decisions, such as building large-scale hydropower dams and utilizing wastewater reuse on crops, have implications for local and regional water quality and for ecosystem and human well-being. With scarce water supplies combined with increased human use, a need arises to manage the allocation of water, often requiring greater transboundary management and collaboration.

Consequences of Poor Water Quality

Poor water quality affects human life and the environment in numerous ways. In the following sections we document the effects of poor water quality on the environment, including on lakes, waterways, groundwater, coasts, and wetlands, as well as the consequences for biodiversity. Humans, particularly the poor and marginalized, are negatively affected by the health impacts of poor water quality and the impacts it has on limiting economic and educational opportunities for women and children. Polluted water affects livelihoods and imposes significant economic costs on human health, ecosystem services, agriculture, and industry.

Effects of Poor Water Quality on the Environment

Freshwater ecosystems are among the most degraded on the planet by worsening water quality and quantity (UN WWAP 2009). They have suffered proportionately greater species and habitat losses than terrestrial or marine ecosystems, from factors that will likely grow worse in coming years (Revenga et al. 2000). In addition to irreversible species loss, impaired water quality reduces the economic value of services provided by freshwater systems, including their ability to treat and clean water for human uses and to provide important habitat for aquatic species.

Rivers and Streams

Despite humanity's reliance on flowing water, human activities have severely degraded the quantity and quality of rivers and streams worldwide, diminishing their ability to provide valuable ecosystem services and driving species to extinction. Factors as diverse as nutrient enrichment from agricultural runoff and domestic wastes, acid mine drainage, invasive species, dams, and diversions have radically altered rivers and streams across the planet, from the smallest ephemeral tributaries to the world's largest rivers. Sixty percent of the world's 227 biggest rivers have interrupted streamflows due to dams and other infrastructure (UN WWAP 2003). Interruptions in stream flow dramatically decrease sediment and nutrient transport to downstream stretches, reducing water quality and impairing ecosystem health. Widespread water-quality problems degrade ecosystem services, imposing costs on local populations and governments. For example, more than 90 percent of China's rivers are polluted, prompting a recent commitment from the Chinese government to invest 13.5 billion (US$) in wastewater treatment infrastructure and other pollution control projects (Li 2009).

Lakes

The world's lakes contain the vast majority of the planet's accessible freshwater—an estimated 91,000 cubic kilometers of freshwater (far more freshwater is estimated to reside in groundwater reserves, but this water is far less accessible) (Shiklomanov 1993). Lakes are vulnerable to a wide range of water-quality threats, including increased salinity, changes in temperature, and contamination by industrial and agricultural chemicals. For example, excessive nutrients can lead to eutrophication—the overproductivity of organisms in water—resulting in the creation of algal blooms and the depletion of oxygen concentrations, which threatens many animal and plant species (Carr and Neary 2008).

Groundwater

Some 30 percent of the world's freshwater stocks are found underground, supplying drinking water for an estimated two billion people and irrigation for an estimated 40 percent of the world's food. By virtue of its location, groundwater typically enjoys greater protection from pollutants than do surface waters, though several kinds of practices and a wide range of contaminants degrade groundwater and diminish its utility. Because of the slow movement of contaminants and subsurface water, it may take years for a contaminant plume to pollute a groundwater source. This slow movement and the fact that groundwater and subsurface contaminants are not readily detected also challenge efforts to determine and control pollution sources. Once contaminated, groundwater is difficult and expensive to remediate (UNEP 1996a). Global data on groundwater quality are very limited, due to the cost of monitoring and analysis (Revenga et al. 2000). Salinization has also become an important threat to groundwater quality, especially in coastal areas where groundwater extraction at unsustainable rates has led to seawater intrusion. In Chennai, India, overextraction of groundwater has resulted in saline groundwater nearly 10 kilometers inland from the sea (UNEP 1996a), and similar problems can be found in populated coastal areas around the world. In some areas, most notably Bangladesh, natural factors have contaminated groundwater supplies with elevated levels of arsenic, with widespread threats to human health.

Coastal Zones

Nations around the world, particularly "developing" economies in tropical regions, often have an especially high concentration of industry and population along their coasts. Common sources of this pollution in coastal zones include industrial waste, urban waste, land construction, dam development, mangrove conversion, coral mining, and canalization in wetlands (UN WWAP 2009). These activities can be extremely destructive to both freshwater and marine habitats. As the end point of most river systems, coastal zones receive much of the water pollution in rivers as it accumulates over the course of a river. Cities or areas of high industrial activity often discharge large amounts of untreated sewage and industrial wastes, which flow into the sea, destroying fisheries and affecting public health of fishers and bathers. The impacts of this pollution can be severe. Not only does it lead to massive destruction of ecosystems and habitats, but it affects humans who rely on these ecosystems for their livelihoods and results in substantial human health problems, especially among the young and among tourists, who have not developed immunity to endemic diseases found in these waters (ENHIS 2007).

Vegetated Wetlands

Wetlands provide several critical ecosystem services. They filter and improve water quality, attenuate and moderate floodwater flows, help recharge underlying aquifers, and support extensive biodiversity. In some parts of the world, more than half of natural wetlands have disappeared completely as their water sources have been diverted or as they have been converted to agricultural uses or developed for other purposes (Mitch and Gosselink 2000). Other wetlands have been degraded by excessive volumes of contaminants, diminishing their capacity to improve water quality and provide other services. For example, in Egypt, the seasonal flooding of riparian wetlands has sustained the population for millennia, but water-related infrastructure projects have threatened this natural dynamic. Similarly, riparian wetlands in South America's Amazon River basin have historically provided spawning habitat for fishes upon which local populations depend for protein. Inundation of these areas for hydropower production, deposition of silt from mining and agricultural activities, and human migration patterns that modify demands for water, transportation, and energy all threaten the integrity and sustainability of these critical systems.

Biodiversity

Freshwater ecosystems boast a disproportionately large share of the world's biodiversity. Although they comprise less than 1 percent of the planet's surface, some 12 percent of described species live in freshwater and more than 25 percent of the world's described vertebrate species depend on freshwater ecosystems at some point in their life cycle. Freshwater ecosystems also suffer from a disproportionate loss of and threats to biodiversity, partly due to the water-quality degradations described earlier. In the last three decades of the twentieth century, populations of freshwater species fell 50 percent on average, a rate two-thirds greater than the rate of change of terrestrial and marine species. Among the most endangered mammals on Earth are the Yangtze dolphin, the Ganges dolphin, and the Amazon dolphin; additionally, the entire crocodilian assemblage in the Yangtze and Ganges rivers is also threatened or endangered (Dudgeon et al. 2005). In the United States, nearly 40 percent of freshwater fish species, more than two-thirds of freshwater mussel species, half of all crayfish species, 40 percent of stonefly species, and 40 percent of amphibians have gone or may soon go extinct (US EPA undated). In Europe, more than 40 percent of freshwater fish species are in imminent danger of extinction; in South Africa, nearly two-thirds of freshwater species are threatened or endangered (Revenga et al. 2000). Nearly half of all amphibian species have experienced population declines, and nearly a third face extinction (Dudgeon et al. 2005). Since amphibians are indicator species and are especially sensitive to water-quality perturbations, their decline points to the widespread adverse impacts of pollution on global freshwater ecosystems (MA 2005b).

Effects of Poor Water Quality on Human Health

Unsafe or inadequate water, sanitation, and hygiene cause approximately 3.1 percent of all deaths worldwide, and 3.7 percent of DALYs (disability-adjusted life years) worldwide (WHO 2002). Worldwide, unsafe or inadequate water, sanitation, and hygiene cause approximately 1.7 million deaths a year (WHO 2002). While the majority of the health threats posed by poor water quality is the result of microbial contaminants and subsequent disease in developing countries, the historical and current use of chemicals for industrial and agricultural purposes, along with the chemical by-products of waste management, are also compromising water quality, leading to other serious health problems for wildlife and humans around the world. This section addresses the impacts of poor water quality on human health, focusing on water-related diseases and other direct human health impacts.

Water-Related Diseases

Worldwide, waterborne diseases are among the leading killers of children under five years old, and more people die from unsafe water annually than from all forms of violence, including war (WHO 2002). There are four main classes of water-related disease: waterborne (fecal-oral), water-washed, water-based, and water-related insect vector. Many water-related diseases are the result of poor-quality water that is used for drinking, washing, and other uses. Two classes of water-related disease that are directly related to poor water quality are described in more detail below.

Waterborne diseases. Waterborne diseases include those for which water is the agent of transmission, particularly those pathogens transmitted from excreta to water to humans. These include most of the enteric and diarrheal diseases caused by bacteria, parasites, and viruses, such as cholera, Giardia, typhoid, and rotaviruses. Drinking water contaminated by human or animal excreta is the main cause of water-related diseases. The first such diseases identified were typhoid and cholera, and both remain a serious problem in many regions of the world.

The most common causes of severe diarrheal disease include Rotavirus, Pathogenic E. coli, *Campylobacter jejuni*, and protozoan parasites. The leading cause of severe diarrhea in children is Rotavirus, and almost every child who reaches the age of five will have an episode of rotavirus gastroenteritis (UNICEF 2008). Epidemic diarrheal diseases are caused by *Shigella* and *Vibrio cholera*. Both are highly infectious and can lead to severe epidemics.

Every year, around 1.8 million people die from diarrheal diseases, 88 percent of which are attributed to unsafe water supply or inadequate sanitation and hygiene (WHO 2004b). In Southeast Asia and Africa, diarrhea is responsible for as much as 8.5 percent and 7.7 percent of all deaths, respectively. Severe and repeated cases of diarrhea contribute extensively to childhood malnutrition. Malnutrition, often caused by diarrhea that is in turn the result of unsafe water, causes 35 percent of all deaths worldwide of children age five or younger. Fifty percent of this malnutrition is associated with diarrhea or intestinal nematode infections from unsafe water (Prüss-Üstün et al. 2008).

Over the past 50 years, some progress has been made in reducing deaths from diarrhea, from an average of 4.2 million deaths per year between 1955 and 1979 to 2.5 million deaths per year from 1992 to 2000 (UNICEF 2008). But diarrheal morbidity appears to be increasing: every year, children in developing countries suffer from four to five debilitating episodes of diarrhea (UNICEF 2006). Recurring bouts of diarrhea exacerbate malnutrition and can result in long-term debilitating effects, such as stunting and wasting. Recently studies have also made the link between chronic diarrheal disease and long-term cognitive impairment. Studies found lasting impacts in terms of reduced ability to perform on standardized tests years after the diarrheal episodes (UNICEF 2008).

There are also non-diarrheal waterborne diseases, including typhoid fever, which causes 600,000 deaths per year. Two forms of hepatitis, hepatitis A and hepatitis E, are waterborne diseases caused by ingestion of fecally contaminated water.

Water-based diseases. Water-based diseases come from hosts that either live in water or require water for part of their life cycle. These diseases are passed to humans when the hosts are ingested or come into contact with skin. The two most widespread examples in this category are schistosomiasis, which results from contact with snails that serve as hosts, and dracunculiasis (Guinea worm), which results from ingesting contaminated host zooplankton. About 160 million people in 74 countries are infected with schistosomiasis, a tenth of whom suffer severe effects (UNICEF 2008), and schistosomiasis could be responsible for 200,000 deaths per year in sub-Saharan Africa alone (Zhang et al. 2007). The disease continues to spread where irrigation projects produce habitat that favors the host snails. Major outbreaks of schistosomiasis often follow the construction of large dams. In the Sudan, the construction of Sennâr Dam led to the infection of nearly the entire nearby population.

Health Effects of High Concentrations of Nutrients

High concentrations of nutrients can pose serious risks to human health. The potential health effects of nitrates are numerous and include methemoglobinemia (infant blue-baby syndrome), cancers, thyroid disruptions, and birth defects. Blue-baby syndrome occurs when the oxygen-carrying capacity of hemoglobin is blocked by nitrites (caused by the conversion of nitrates in the stomach), leading to oxygen deprivation and suffocation. Infants are especially susceptible because their stomachs easily convert nitrates to nitrites (Harte et al. 1991). High levels of nutrients like nitrates have also been linked to stomach cancer and negative reproductive outcomes (Carr and Neary 2008). Nitrites react with both natural and synthetic organic compounds to produce N-Nitroso compounds in the human stomach.[3] Many of these compounds are carcinogenic in humans (IARC 1978, US NAS 1977), and a substantial body of literature suggests that high nitrate levels in drinking water may increase cancer risks (Mirvish 1983, 1991). To date, most water agencies have not adequately addressed the contribution of nitrate in drinking water to the human cancer risk from N-Nitroso compounds.

Epidemiological evidence also points to a risk to thyroid function from drinking high concentrations of water with nitrates. One study shows an increase in hypertrophy, a condition marked by enlargement of the thyroid, the gland responsible for many of the

3. Nitrosamines are produced from *nitrites* and secondary *amines*. Their formation can occur under certain conditions, including strongly *acidic* conditions such as that of the human *stomach*. Many of these compounds have been found to be carcinogenic in laboratory animals.

body's endocrine and hormonal functions (Van Maanen et al. 1994). Other studies have indicated a possible link between exposure to nitrites, nitrates, and N-Nitroso compounds and birth defects. The effects of exposure were first observed in animal studies but have since been seen in human epidemiological studies (Dorsch et al. 1984, Knox 1972, Super et al. 1981, Ward et al. 2005).

Other Health Impacts of Water-Quality Contaminants

A range of other contaminants are known to have direct and indirect impacts on human health, including nonorganic and organic contaminants. Metals, such as mercury, copper, and zinc, are naturally found in the environment; at low concentrations, they are essential for ecosystem and human health. However, extended exposure or exposure at high levels can have serious consequences for humans as these metals tend to bioaccumulate in tissues (UNEP GEMS/Water 2007). Human activities, particularly the increase in mining and industrial processes since the 19th century, have increased the concentration of metals in the environment (Carr and Neary 2008). For example, mercury, which is largely a by-product of fuel combustion, mining, and waste incineration (Pacyna et al. 2006), is highly toxic. Since some fish bioaccumulate metals, they can contain high concentrations of mercury and expose people to concentrations sometimes tens of thousands of times higher than that found in the water source, posing a serious threat to human health (WHO 2005). The mercury found in fish and shellfish is most often methyl mercury, which is particularly toxic. Consumption of methyl mercury, especially by small children and pregnant women, can lead to developmental and neurological damage. In adults, it has been linked to coronary heart disease (Mozaffarian and Rimm 2006). Inorganic mercury also poses a range of acute and chronic health effects, with long-term oral exposure to low amounts potentially leading to renal damage and immunological effects (WHO 2003a).

Arsenic is a semi-metallic element that is highly toxic and carcinogenic (IARC Working Group 2004). Naturally occurring in subsurface formations, arsenic can readily leach into groundwater. Naturally occurring minerals are, of course, a human health concern only when humans rely on those sources for drinking, cooking, or bathing. But millions of individuals are exposed to drinking water contaminated with inorganic arsenic (Smedley and Kinniburgh 2002). Exposure to arsenic through drinking or bathing in contaminated water can lead to the development of skin lesions and cancers (Carr and Neary 2008). While evidence suggests arsenic levels in groundwater aquifers in many parts of the world are acceptably below WHO drinking water guidelines, it remains a serious health threat in some areas, including Bangladesh, India, and, to a lesser extent, Cambodia and Vietnam (Charlet and Polya 2006) (see the case study later in this chapter). Arsenic-contaminated groundwater has also been found in Argentina, Chile, China, Mexico, Thailand, and the United States (WHO 2004b). As of 2004, 28 to 35 million Bangladeshis were consuming water with elevated arsenic levels; the subsequent number of cases of skin lesions related to drinking water in Bangladesh is about 1.5 million (WHO 2004b).

Other metals present in drinking water also pose serious health risks. Lead exposure can cause brain damage, nervous damage, blood disorders, kidney damage, and developmental damage to the fetus. Acute exposure can cause vomiting or death. While natural waters contain almost no lead, it can be leached into water supplies from distribution systems and pipes. Copper, while an essential mineral, can cause stomach irritation, nausea, vomiting, and diarrhea in relatively high concentrations (ATSDR 2004). Cadmium is also of concern because long-term, low-level ingestion is associated with kidney damage and can cause bones to become fragile and break easily (ATSDR 2008).

A wide range of persistent organic pollutants can bioaccumulate through the food chain, with serious health and environmental impacts. These impacts often include disruption of developmental function, making small children and the developing fetuses of pregnant woman particularly vulnerable. Recognizing the threat of POPs, the Stockholm Convention on Persistent Organic Pollutants has identified an initial 12 POPs—the "dirty dozen"—that pose extreme danger to environmental and human health. Exposure to POPs, either acute or chronic, can lead to a wide range of adverse health effects in both animals and humans, including endocrine disruption, reproductive and immune system problems, cancer, and death (Ritter et al. 1996).

Nine of the twelve POPs identified by the Stockholm Convention to be permanently phased out of use are pesticides. In humans, DDE, which accumulates in fatty tissue, has been linked to endocrine disruption and reproductive problems (Jaga and Dharmani 2003) and has been classified as possibly carcinogenic by the International Agency for Research on Cancer (ATSDR 2002). Three other POPs of serious human health concern are dioxins, furans, and polychlorinated biphenyls, unwanted by-products of industrial processes and incineration. Dioxins and furans are found throughout the world in practically all media (UNEP 1999). Dioxins are very stable chemicals, and with a half life estimated to be seven to eleven years, they bioaccumulate in fat tissue and breast milk and endure in the body for a long time. Due to the ubiquity and stability of dioxins, all people have background exposure and a certain level of dioxins in their body (UNEP 1999). Long-term exposure to dioxins and furans is linked to damage to the immune system, developing nervous system, endocrine system, and reproductive functions; chronic exposure has resulted in several types of cancer (UNEP 1999). PCBs have been classified as a probable human carcinogen (UNEP 2009). It is also linked to such health problems as low birth weight, thyroid disease, and learning, memory, and immune system disorders. PCBs in the river sediment also affect fish and wildlife (US EPA 2009b).

Effects of Poor Water Quality on Water Quantity

Direct connections exist between water quality and water quantity. Polluted water that cannot be used for drinking, bathing, industry, or agriculture effectively reduces the amount of water available in a given area, directly affecting water quantity. The more polluted water is, the more difficult it is to treat it to usable standards. Generally, treatment processes for polluted water remove pollutants through creation of a waste sludge. The poorer the water quality of the source water, the greater the level of treatment that will be required to bring it to a usable standard, or the less clean will be the water that results from treatment. Also, more-polluted water requires a significant amount of energy to treat—and energy use in turn has implications for water use and availability. Numerous characteristics of the built environment affect water quantity and water quality. For example, impervious surfaces reduce the quantity of water that infiltrates to groundwater, affect the base flow of streams, and also increase the volume of water that runs off the land surface, creating more erratic streamflows and conveying greater amounts of contaminants. Both reduce the quality of water. At the same time, actions that improve water quality can also increase the quantity of water that watersheds produce. Forested areas help to filter water and enhance water quality prior to runoff entering into waterways.

Effects of Poor Water Quality on Vulnerable Communities

Some communities are disproportionately affected by poor water quality. These communities include those that live near waterways of compromised quality, are forced to travel long distances to reach safe water supplies, and suffer the most from diseases caused by unsafe water. Poor water quality has the greatest impact on marginalized communities and those that lack political and economic power. Groups that are most affected by poor water quality include women, children, and the poor in developed and developing countries.

Women

Women are the primary managers of water in most developing countries. The UN Development Report estimates that 40 billion mostly woman-hours per year are spent collecting water in sub-Saharan Africa alone (UNDP 2006). Because women and children supply most water for the household, polluted water affects them the most because of the increased contact they have with unsafe water (Cap-Net/GWA 2006). Women also bear the primary responsibility of caring for sick children and family members who fall ill due to unsafe water. Some researchers estimate that this “time poverty” may far outweigh even the amount of time women spend to collect safe water. The lack of safe sanitation not only affects water quality but also severely compromises the safety and security of women. In developing countries, 1.3 billion women and girls live without access to a private, sanitary toilet, forcing them to go to the toilet in the open and under the cover of night, often risking rape and violence in the process (WHO and UNICEF 2004). The lack of safe sanitation at school also dissuades girls from attending school after menstruation, further limiting educational equality for girls. Unequal power relations within families and in communities directly affect the health of women and girls. The United Nations Human Development Report found that in India reduced rainfall is more strongly associated with deaths among girls than deaths among boys (UNDP 2007).

Children

Children are by far the most affected by the lack of clean water and have the least power to effect improvements in water quality. The overwhelming majority of deaths from water-related diseases, over 90 percent, are the deaths of children under age five. Every year 1.5 million children die as a result of unsafe water (UNICEF 2006). Worldwide, more than 125 million children under age five live in households without access to improved drinking water, and 280 million children under age five live in households without safe sanitation (UNICEF 2006). Unsafe water and lack of sanitation and hygiene account for 18 percent of under-age-five deaths and are a leading cause of mortality among children in developing countries.

The future opportunities of children are also limited by the lack of safe water and sanitation. Children, particularly girls, who spend hours each day seeking sources of clean water for the household, do not have time left for education. The lack of toilets in schools prevents girls from attending, and water-related diseases affect the ability of children to attend and succeed in school. In addition to carrying the threat of falling ill from diarrhea, the lack of clean water leads to intestinal worm diseases that primarily affect school-age children, impairing cognitive functions and reducing physical growth and fitness (UNICEF 2006). Every year, 133 million cases of hookworm, roundworm, and whipworm are discovered. Many more are often undiagnosed and untreated. These worms significantly affect development in childhood. Children in poor environments can carry 1,000 parasitic worms in their bodies at any time. A typical roundworm infection consumes one-third of the food a child eats. This further leads to malnutrition, which is implicated in 50 percent of childhood illnesses (UN-Water 2008). Every year, 443 million school days are lost due to water-related illnesses (UNDP 2006).

Economically Disadvantaged

The very poor in urban areas often live along the banks of waterways, because this land commonly is in public ownership. Lacking other options, the dwellers in these informal settlements use the waterways to directly discharge sewage, sullage, and solid waste. Slum dwellers and others without adequate access to safe and affordable water often use these same polluted water systems for washing, bathing, and drinking and are thus at high risk for waterborne disease. A UNICEF/WHO study in developing countries found that the richest 20 percent were four times more likely to have access to sanitation than the poorest 20 percent. And while fewer than 4 in 10 of the poorest households had access to improved water, 9 in 10 of the richest households did (WHO and UNICEF 2004). Poor water quality feeds the cycle of poverty. Those who have the least access to water and sanitation are also often the least likely to have health care and stable jobs. Bouts of waterborne disease reduce income further and, for the most vulnerable, often lead to death.

Effects of Poor Water Quality on Livelihoods

The need for adequate *quality* of water to support livelihoods has been emphasized less than the need for adequate *quantity* of water. In reality, both are necessary, and polluted water can reduce or eliminate the viability of many livelihoods. A study compared two villages in Andra Pradesh, one that was polluted by nearby industries and one that was not. In the polluted village, water contained very high levels of arsenic and had abnormally high chemical oxygen demand, total dissolved solids, and other contaminant levels. The amount of land under cultivation in the polluted village declined by 88 percent over nine years after being affected by water pollution directly as a result of polluted water (Reddy and Behera 2006). In the affected village, 149 animals died over five years from drinking polluted water.

A 2000 assessment by the World Resources Institute concluded that water pollution was a major threat to inland fisheries in nearly all regions of the world (Revenga et al. 2000). In Lake Manzala in the northeastern Nile Delta in Egypt, which once provided 30 percent of all fish consumed in Egypt, fish began to have a high incidence of organ malformation and discoloration due to pollution. This has reduced demand for Manzala fish, and reduced fishing in the lake. Another study quantified the effects on local livelihoods of water pollution from a large-scale mining spill in the Philippines, using surveys before and after the spill to quantify impacts. The spill, which released 1.6 million cubic meters of mine tailings into the Boac River, found that for 10 years after the spill, a total of US$7 million (in 1996 dollars) was lost in income from coastal and river fishing, crop farming, and farm trading. The amount offered as compensation from the mining company was less than half of what was lost in the year 1996 alone (Bennagen 1997).

Economic Costs of Poor Water Quality

Poor water quality has many economic costs associated with it, including degradation of ecosystem services; health-related costs; impacts on economic activities, such as agriculture, industrial production, and tourism; increased water treatment costs; and reduced property values. In some regions, these costs can be significant, but effective quantification in economic terms is rarely possible. For example, the estimated costs of poor-quality water in countries in the Middle East and North Africa range between 0.5 and 2.5 percent of gross domestic product (GDP) per year (WB 2007). Additionally, poor countries with access to clean water and sanitation services experienced faster economic growth than those without: one study found an annual economic growth rate of 3.7 percent among poor countries with better access to improved water and sanitation services, whereas similarly poor countries without access to improved water and sanitation had annual growth of just 0.1 percent (Sachs 2001). These numbers, however, rarely include all of the adverse impacts of poor water quality described throughout this chapter.

Ecosystem Services

Ecosystems provide humanity with a broad range of fundamental market and non-market benefits, including provisioning services such as food, water, and fiber; regulating services such as wastewater treatment; cultural services that include recreational, spiritual, and aesthetic; and supporting services such as photosynthesis and nutrient cycling (MA 2005a). One influential study estimated the global value of ecosystem services at roughly double the gross national product of the global economy (Costanza et al. 1997). The Millennium Ecosystem Assessment (MA 2005b) found that the total economic value of unconverted wetlands was often greater than that of converted wetlands. The greatest single service freshwater ecosystems—marshes, in particular—provide is water purification and the assimilation of wastes, valued at US$400 billion (2008 dollars) worldwide (Costanza et al. 1997). For example, Uganda's Nakivubo swamp bestows an estimated US$363 million worth of wastewater treatment services annually to the citizens of Kampala (UN WWAP 2009). Degradation of water quality has economic impacts as well. Eutrophic (or nutrient-rich) waters are more expensive to treat to drinking water standard, produce fewer fish, suffer decreased amenity and recreational values, and pass greater nutrient loads downstream. In the 1990s, freshwater eutrophication in England and Wales imposed damage and remediation costs of some US$200 million annually (MA 2005a).

Human Health–Related costs

Economic benefits of improved health as a result of better water quality can be measured in a number of different ways but typically take into account such parameters as productivity loss, treatment costs, and the value of prevented deaths (SIWI 2005). Human health–related costs can be significant—for example, economic losses as a result of the mortality and morbidity impacts from the lack of water and sanitation in Africa are estimated at US$28.4 billion annually, or about 5 percent of GDP (UN WWAP 2009). As water-quality degradation continues, the prevalence and impacts of disease will increase, particularly among the poor and vulnerable (MA 2005b). And, sanitation and drinking water investments are found to have high rates of return: for every US$1 invested, there is a projected $3 to $34 economic development return (UN WWAP 2009). By one estimate, meeting the

UN Millennium Development Goals to halve the proportion of people without safe water and sanitation will save 322 million working days (lost to sickness) per year, the value of which is nearly US$750 million (SIWI 2005), save US$7 billion in health sector costs, and provide an overall economic benefit of US$84 billion (SIWI 2005).

Agriculture

Water pollution affects the economic productivity of agriculture by destroying crops, reducing crop and soil quality, and diminishing yields. Throughout history, societies have collapsed due to decreased crop yields associated with increased salinity and irrigation (Postel 1999). It has been estimated that land degradation of irrigated lands, particularly from salinization, has resulted in the loss of US$11 billion from decreased agricultural productivity worldwide each year (Postel 1999). In addition, as the quality of surface water and groundwater is degraded, farmers often must find new sources of water, which are typically expensive and contentious, commonly leading to significant political and military transboundary conflict (see, for example, Cooley et al. 2009).

Industrial Production

While industrial production can affect water quality, industrial production can also be negatively affected by poor water quality. Water is critical to many industrial processes, such as heating and cooling, generating steam, and cleaning, and as a constituent part of some products, such as beverages. Most industrial uses require water of a certain quality, and some have higher quality requirements than others. Poor-quality water may force an industrial facility to relocate, find a new source of water, halt production, decrease the quality of the product, or increase expenditures to clean up water prior to use. Each of these impacts has associated costs. In 1992, China's industrial sector lost approximately US$1.7 billion as a result of water pollution (SIWI 2005). As examples of the kinds of impacts that result, a study of the Tongliang County Silk-making Plant found that decreased quality of silk due to water pollution reduced the plant's production value by 3.1 percent in one year, and the municipality of Chongquing estimated the cost of water shortages due to pollution to be US$21 million (Yongguan et al. 2001).

Tourism and Recreation

Tourism has grown quickly in recent decades and is now a major source of employment worldwide. Tourism directly or indirectly supports an estimated 8.1 percent of all jobs worldwide and accounts for 10.4 percent of total world GDP (UNEP and UN-WTO 2005, quoting the World Travel and Tourism Council). Water pollution can result in large losses in tourism revenue. In the Philippines, tourism losses due to water pollution represent around 70 percent of the total US$1.3 billion annual economic losses from water pollution (WB 2003). In South Africa, where ecotourism has become one of the country's largest income generators, pollution on the Olifants River has resulted in wildlife mortality, which will likely have a negative impact on the tourism economy (Oberholster 2009). In the United States, loss of recreational use of freshwaters due to eutrophication alone is estimated to cost between US$0.37 and $1.16 billion per year (Dodds et al. 2008).

Mining

Mining operations frequently require extensive and expensive waste treatment, and degradation of water resources can have long-term negative impacts on economic opportunities in the surrounding areas. For example, acid mine drainage in South Africa "threatens the scarce water resources of South Africa, and as a result also human health and food security in mining areas" (EAT 2008). Unfortunately, few studies quantify the costs of these externalities. The aforementioned Philippines mine spill, in which 1.6 million cubic meters of mine tailings were released into the Boac River, was estimated to cost US$7 million (in 1996 dollars) in forgone income in the 10 years following the spill, more than twice the amount offered in compensation from the mining company (Bennagen 1997). In 1998, a mining-related accident in Spain, in which a dam failure caused the release of approximately 5 million cubic meters of toxic sludge into the River Agrio, cost US$44 million in regional governments' clean-up costs, plus another US$53.3 million in government acquisition of land polluted by the spill (UNECE 2007). In the U.S. alone, there are an estimated 500,000 abandoned mines (Abandoned Mines Portal n.d.). Managing and remediating the pollution caused by these abandoned mines will cost more than US$20 billion, and many of these sites will require management in perpetuity (Septoff 2006).

Moving to Solutions and Actions

Effective solutions to water-quality challenges exist and have been implemented in a number of places. It is time for an expanded global focus on protecting and improving the quality of the world's freshwater resources. There are three fundamental solutions to water-quality problems: (1) prevent pollution, (2) treat polluted water, and (3) restore ecosystems.

Focus on Pollution Prevention

Pollution prevention is the reduction or elimination of contaminants at the source before they have a chance to pollute water resources—and it is almost always the cheapest, easiest, and most effective way to protect water quality. Pollution prevention strategies reduce or eliminate the use of hazardous substances, pollutants, and contaminants; modify equipment and technologies so they generate less waste; and reduce fugitive releases and water consumption. Pollution prevention will also require better design of human settlements to improve water infiltration and reduce non-point source pollution. As the world takes on the challenge of improving water quality, pollution prevention should be prioritized in international and local efforts.

Expand and Improve Water and Wastewater Treatment

Many water sources and watersheds are already of poor quality and require remediation and treatment. Both high-tech, energy-intensive technologies and low-tech, low-energy, ecologically focused approaches exist to treat contaminated water. More effort to expand the deployment of these approaches is needed: they need to be scaled up rapidly to deal with the tremendous quantities of untreated wastes entering waterways every day, and water and wastewater utilities need financial, administrative, and technical assistance to implement these approaches.

Restore, Manage, and Protect Ecosystems

Healthy ecosystems provide important water-quality functions by filtering and cleaning contaminated water. By protecting and restoring natural ecosystems, broad improvements in water quality and economic well-being can occur. In turn, ecosystem protection and restoration must be considered a basic element of sustainable water-quality efforts.

Mechanisms to Achieve Solutions

Mechanisms to organize and implement water-quality solutions include (1) better understanding of water quality through improved monitoring; (2) more effective communication and education; (3) improved financial and economic tools; (4) deployment of effective methods of water treatment and ecosystem restoration; (5) effective application and enforcement of legal and institutional arrangements; and (6) political leadership and commitment at all levels of society.

Improve Understanding of Water Quality

Ongoing monitoring and good data are the cornerstones of effective efforts to improve water quality, but the current state of water-quality data collection and monitoring is poor. Addressing water-quality challenges will mean building capacity and expertise in developing countries and deploying real-time, low-cost, rapid, and reliable field sampling tools, technologies, and data-sharing and management institutions. The UN GEMS/Water program is an effort to do this at the international level, but it has never had sufficient resources or acceptance by national water-quality agencies. Resources are needed to build international, national, and regional capacity to collect, manage, and analyze water-quality data.

Improve Communication and Education

Education and communication are among the most important tools for solving water-quality problems. Water plays key cultural, social, economic, and ecological roles. Demonstrating the importance of water quality to households, the media, policy makers, business owners, and farmers can have a tremendous impact in winning key improvements, driving policy changes, and mobilizing community support for actions. A concerted global education and awareness-building campaign around water-quality issues is needed, with targeted regional and national campaigns that connect water quality to issues of cultural and historical importance.

Use Effective Legal, Institutional, and Regulatory Tools

New and improved legal and institutional frameworks to protect water quality are needed from the international level down to the watershed and community level. As a first step, laws on protecting and improving water quality should be adopted where they are lacking or adequately enforced where they are present. Model pollution prevention policies could be disseminated more widely, and guidelines should be developed and applied to protect ecosystem water quality as well as drinking water quality. Planning at the watershed scale is also needed to identify major sources of pollution and appropriate interventions, especially when watersheds are shared by two or more political entities. Standard methods to characterize instream water quality, international guidelines for ecosystem water quality, and priority areas for remediation need to be developed and deployed globally.

Deploy Effective Technologies

Many effective technologies and approaches, ranging from ecohydrology and distributed/decentralized approaches to conventional centralized wastewater treatment, are available to improve water quality through pollution prevention, treatment, and restoration. A focus on deploying appropriate approaches to collect, transport, and treat very diverse wastewater streams is critically important. This will require connecting communities, governments, and businesses with effective water-quality technologies and approaches, developing new technologies when needed to meet specific environmental or resource needs, and providing technical, logistical, and financing support to help communities and governments implement projects to improve water quality.

Improve Financial and Economic Approaches

Many water-quality problems are the result of inadequate access to financing to develop water-treatment or restoration programs, or inappropriate pricing and subsidy programs. Better understanding of the economic value of maintaining ecosystem services and water infrastructure is required, as are more effective water-pricing systems that permit sufficient cost recovery, ensure adequate investments, support sustainable long-term operation and maintenance, and recognize concerns around poverty and inequitable access to services. Innovative regulatory approaches and standards are needed, for example, to entail payments for ecosystem services or to require polluters to internalize the costs of pollution, and to provide subsidized alternatives to populations unable to pay the full cost of basic services.

Conclusion

Water has always been at the center of healthy ecosystems and human societies, yet the freshwater resources on which we all depend are becoming increasingly polluted. As a global community, we need to refocus our attention on improving and preserving the quality of our water. The decisions made in the next decade will determine how we address the global water-quality challenge. That challenge requires bold steps internationally, nationally, and locally to protect water quality. Developing a broad range of funding tools, technological options, and community policies to improve water quality can ensure that our global water resources can once again become a source of life. As the United Nations observed in 2010: “Clean water is life.” Achieving clean water as a global priority will improve the health of communities, ecosystems, and children—today and for the future.

References

Abandoned Mines Portal. N.d. http://www.abandonedmines.gov/ep.html

Agency for Toxic Substances and Disease Registry (ATSDR). 2002. ToxFAQs for DDT, DDE, and DDD. http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=80&tid=20

Agency for Toxic Substances and Disease Registry (ATSDR). 2004. ToxFAQs for Copper. http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=205&tid=37

Agency for Toxic Substances and Disease Registry (ATSDR). 2008. Public Health Statement for Cadmium. http://www.atsdr.cdc.gov/PHS/PHS.asp?id=46&tid=15#bookmark05

Banks, D., Younger, P.L., Arnesen, R.T., Iversen, E.R., and Banks, S.B. 1997. Mine-water chemistry: The good, the bad and the ugly. *Environmental Geology* 32: 157–174.

Bates, B., Kundzewicz, Z.W., Wu, S., and Palutikof, J. 2008. *Climate Change and Water.* Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Bennagen, M.E. 1997. Estimation of Environmental Damages from Mining Pollution: The Marinduque Island Mining Accident. http://www.idrc.ca/eepsea/ev-8430-201-1-DO_TOPIC.html (accessed December 16, 2009).

Burns, W.C.G. (2002). Pacific island developing country water resources and climate change. In: *The World's Water 2002–2003*. P.H. Gleick (editor). Island Press, Washington D.C., pp. 113–132.

Cap-Net and Gender and Water Alliance (Cap-Net/GWA). 2006. Why Gender Matters: A Tutorial for Water Managers. Multimedia CD and booklet. Delft, Netherlands: CAP-NET International Network for Capacity Building in Integrated Water Resources Management.

Carr, G.M., and Neary, J.P. 2008. Water Quality for Ecosystem and Human Health. 2nd Edition. United Nations Environment Programme Global Environment Monitoring System. http://www.gemswater.org/publications/pdfs/water_quality_human_health.pdf (accessed July 14, 2009).

Charlet, L., and Polya, D.A. 2006. Arsenic in shallow, reducing groundwaters in southern Asia: An environmental health disaster. *Elements* 2: 91–96.

Colborn T., Soto, A., and F. vom Saal. 1993. Developmental effects of endocrine-disrupting chemicals in wildlife and humans. *Environmental Health Perspectives* 101(5): 378–384.

Cooley, H., Christian-Smith, J., Gleick, P.H., Allen, L., and Cohen, M. 2009. *Understanding and Reducing the Risks of Climate Change for Transboundary Waters.* Oakland, California: The Pacific Institute and United Nations Environment Program.

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Suttonkk, P., and van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 353–360.

De Leon, R. 2008. Testimony before the U.S. House of Representatives Committee on Natural Resources, Subcommittee on Water and Power. Hearing on "The Silent Invasion: Finding Solutions to Minimize the Impacts of Invasive Quagga Mussels on Water Rates, Water Infrastructure and the Environment." June 24, 2008. http://www.usbr.gov/lc/region/programs/quagga/testimony/MWD.pdf (accessed December 16, 2009).

Dodds, W.K., Bouska, W.W., Eitzmann, J.L., Pilger, T.J., Pitts, K.L., Riley, A.J., Schloesser, J.T., and Thornbrugh, D.J. 2008. Eutrophication of U.S. freshwaters: Analysis of potential economic damages. *Environmental Science andTechnology* 43(1): 12–19.

Dorsch, M.M., Scragg, R.K.R., McMichael, A.J., Baghurst, P.A., and Dyer, K.F. 1984. Congenital malformations and maternal drinking water supply in rural South Australia: A case control study. *Journal of Epidemiology* 119: 473–485.

Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z.I., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L.J., and Sullivan, C.A. 2005. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews* 81: 163–182.

Environmental Affairs and Tourism, Republic of South Africa (EAT). 2008. Emerging Issues Paper: Mine Water Pollution. http://soer.deat.gov.za/dm_documents/Mine_Water_Pollution_fPA1A.pdf (accessed December 17, 2009).

European Environment and Health Information System (ENHIS). 2007. Bathing Water Quality. Fact sheet No. 1.4. http://www.euro.who.int/Document/EHI/ENHIS_Factsheet_1_4.pdf (accessed July 28, 2009).

Food and Agriculture Organization (FAO). 1996. Control of Water Pollution from Agriculture. Food and Agriculture Organization of the United Nations, Irrigation and Drainage Paper 55.

Harte, J., Holdren, C., Schneider, R., and Shirley, C. 1991. *Toxics A to Z: A Guide to Everyday Pollution Hazards*. Berkeley: University of California Press.

Hayes, T.B., Stuart, A.A., Mendoza, M., Collins, A., Noriega, N., Vonk, A., Johnston, G., Liu, R., and Kpodzo, D. 2006. Characterization of atrazine-induced gonadal malformations in African clawed frogs (*Xenopus laevis*) and comparisons with effects of an androgen antagonist (Cyproterone Acetate) and exogenous estrogen (17 -estradiol): Support for the demasculinization/feminization hypothesis. *Environmental Health Perspectives* 114(S-1): 134–141.

Ignazi, J.C. 1993. Improving nitrogen management in irrigated, intensely cultivated areas: The approach in France. In: *Prevention of Water Pollution by Agriculture and Related Activities.* Proceedings of the FAO Expert Consultation, Santiago, Chile, October 20–23, 1992. Water Report 1. Rome, Italy: Food and Agriculture Organization of the United Nations, pp. 247–261.

International Agency for Research on Cancer (IARC). 1978. *Some N-Nitroso Compounds.* IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans Lyon, France: International Agency for Research on Cancer, p. 17.

International Agency for Research on Cancer (IARC) Working Group on the Evaluation of Carcinogenic Risks to Humans. 2004. *Some Drinking-Water Disinfectants and Contaminants, Including Arsenic*. Lyon, France: IARC Press.

Jacobs, K., Adams, D.B., and Gleick, P.H. (2001). Potential Consequences of Climate Variability and Change for the Water Resources of the United States. The Potential Consequences of Climate Variability and Change, U.S. Global Change Research Program. http://www.usgcrp.gov/usgcrp/Library/nationalassessment/14Water.pdf

Jaga, K., and Dharmani, C. 2003. Global surveillance of DDT and DDE levels in human tissues. *International Journal of Occupational Medicine and Environmental Health* 16(1): 7–14.

Knox, E.G. 1972. Anencephalus and dietary intakes. *British Journal of Preventive and Social Medicine* 26: 219–223.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P. Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z., and Shiklomanov, I.A. 2007. Freshwater resources and their management. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, editors. Cambridge, United Kingdom: Cambridge University Press, pp. 173–210.

Li, J. 2009. Govt invest 13b to fight water pollution. *China Daily,* December 2, 2009. from http://www.chinadaily.com.cn/bizchina/2009-12/02/content_9100720.htm (accessed December 16, 2009).

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., and Zhao, Z.-C. 2007. Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (editors). New York: Cambridge University Press.

Millennium Ecosystem Assessment (MA). 2005a. *Ecosystems and Human Well-Being: Synthesis.* Washington, D.C.: Island Press.

Millennium Ecosystem Assessment (MA). 2005b. *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*. Washington, D.C.: World Resources Institute.

Mirvish, S.S. 1983. *Journal of the National Cancer Institute* 71: 629–647.

Mirvish, S.S. 1991. The significance for human health of nitrate, nitrite, and N-nitroso compounds. In: *Nitrate Contamination.* I. Bogardi and R.D. Kuzelka, editors. Berlin, Germany: Springer, pp. 253–266.

Mitch, W.J., and Gosselink, J.G. 2000. *Wetlands.* 3rd ed. New York: John Wiley and Sons.

Mozaffarian, D., and Rimm, E.B. 2006. Fish intake, contaminants, and human health: Evaluating the risks and the benefits. *Journal of the American Medical Association* 296(15): 1885–1899.

Oberholster, P.J. 2009. Impact on ecotourism by water pollution in the Olifants River catchment, South Olifants River catchment. *SIL News* (55): 8–9. http://researchspace.csir.co.za/dspace/bitstream/10204/3841/3/oberholster4_2009.pdf (accessed January 28, 2010).

Ohlendorf, H.M. 1989. Bioaccumulation and effects of selenium in wildlife. In: *Selenium in Agriculture and the Environment*. L.W. Jacobs, editor. Soil Science Society of America and American Society of Agronomy. SSSA Special Publication no. 23, pp. 133–172.

Pachauri, R.K., and Reisinger, A., eds. 2008. *IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the*

Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change.

Pacyna, E.G., Pacyna, J.M., Steenhuisen, F., and Wilson, S. 2006. Global anthropogenic mercury emission inventory for 2000. *Atmospheric Environment* 40(22): 4048.

Palaniappan, M., Gleick., P., Allen, L., Cohen, M., Christian-Smith, J., Smith, C. 2010. *Clearing the Waters: A Focus on Water Quality Solutions*. Nairobi: United Nations Environment Programme.

Pesticide Action Network (PAN). 2009. PAN Pesticides Database. http://www.pesticideinfo.org/ (accessed July 28, 2009).

Postel, S. 1999. *Pillar of Sand: Can the Irrigation Miracle Last?* New York: W.W. Norton.

Prüss-Üstün A., Bos, R., Gore, F., and Bartram, J. 2008. *Safer Water, Better Health: Costs, Benefits and Sustainability of Interventions to Protect and Promote Health*. Geneva, Switzerland: World Health Organization.

Reddy, V.R., and Behera, B. 2006. Impact of water pollution on rural communities: An economic analysis. *Ecological Economics* 58: 520–537.

Revenga, C., Brunner, J., Henninger, N., Kassem, K., and Payne, R. 2000. *Pilot Analysis of Global Ecosystems: Freshwater Systems*. Washington, D.C.: World Resources Institute. http://www.wri.org/wr2000 (accessed January 28, 2010).

Ritter, L., Solomon, K.R., Forget, J., Stemeroff, M., and O'Leary, C. 1996. Persistent Organic Pollutants. The International Programme on Chemical Safety (IPCS). http://www.chem.unep.ch/pops/ritter/en/ritteren.pdf (accessed January 28, 2010).

Sachs, J.D. 2001. Macroeconomics and Health: Investing in Health for Economic Development. Report of the Commission on Macroeconomics and Health, prepared for the World Health Organization.

Septoff, A. (2006). Predicting Water Quality Problems at Hardrock Mines. Earthworks. http://www.earthworksaction.org/publications.cfm?pubID=213

Shiklomanov, I.A. 1993. World fresh water resources. In: *Water in Crisis: A Guide to the World's Fresh Water Resources*. P.H. Gleick, editor. New York: Oxford University Press, pp. 13–24.

Smedley, P.L., and Kinniburgh, D.G. 2002. A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry* 17(5): 517–568.

Spalding, R.F., and Exner, M.E. 1993. Occurrence of nitrate in groundwater: A review. *Journal of Environmental Quality* 22: 392–402.

Stephenson, J. 2009. Testimony Before the Subcommittee on Commerce, Trade, and Consumer Protection, Committee on Energy and Commerce, House of Representatives: Options for Enhancing the Effectiveness of the Toxic Substances Control Act. U.S. Government Accountability Office.

Stockholm International Water Institute (SIWI). 2005. Making Water a Part of Economic Development: The Economic Benefits of Improved Water Management and Services. http://www.siwi.org/documents/Resources/Reports/CSD_Making_water_part_of_economic_development_2005.pdf (accessed December 16, 2009).

Sumpter, J.P. 1995. Feminized responses in fish to environmental estrogens. *Toxicology Letters* 82/83: 737–742.

Super, M., Heese, H., MacKenzie, D., and Dempster, W. 1981. An epidemiological study of well-water nitrates in a group of south west African/Namibian infants. *Water Research* 15: 1265–1270.

United Nations Children's Fund (UNICEF). 2006. Progress for Children: A Report Card on Water and Sanitation. No 5, September 2006.

United Nations Children's Fund (UNICEF). 2008. *UNICEF Handbook on Water Quality*. New York: United Nations.

United Nations Children's Fund and World Health Organization Joint Monitoring Programme for Water Supply and Sanitation (UNICEF and WHO). 2008. *Progress on Drinking Water and Sanitation: Special Focus on Sanitation*. New York: UNICEF; Geneva, Switzerland: WHO.

United Nations Department for Economic and Social Affairs (UN-DESA). 2008. *World Urbanization Prospects: The 2007 Revision Highlights*. February. New York: United Nations.

United Nations Development Program (UNDP). 2006. *Beyond Scarcity: Power, Poverty and the Global Water Crisis*. Human Development Report 2006. New York: UNDP.

United Nations Development Program (UNDP). 2007. *Fighting Climate Change: Human Solidarity in a Divided World*. Human Development Report 2007/2008. New York: UNDP.

United Nations Economic Commission for Europe (UNECE). 2007. Transboundary Accidental Water Pollution, Liability and Compensation: Challenges and Opportunities. Background document for the UNECE Workshop held in Budapest, Hungary, May 21–22, 2007.

United Nations Environment Programme (UNEP). 1996a. *Groundwater: A Threatened Resource.* Environment Library 15. Nairobi, Kenya: UNEP.

United Nations Environment Programme (UNEP). 1996b. *The State of Marine and Coastal Environment in the Mediterranean Region.* MAP Technical Series No. 100. Athens, Greece: UNEP.

United Nations Environment Programme (UNEP). 1998. Inventory of World-wide PCB Destruction. UNEP Chemicals. http://www.chem.unep.ch/POPs/pdf/pcbrpt.pdf (accessed December 16, 2009).

United Nations Environment Programme (UNEP). 1999. Information on Dioxins. http://www.chem.unep.ch/pops/infosheets/is1-pdf/fact1.pdf (accessed December 16, 2009).

United Nations Environment Programme (UNEP). 2000. GEO-2000: Global Environment Outlook. http://www.unep.org/geo/geo2000/english/0067.htm (accessed December 16, 2009).

United Nations Environment Program (UNEP). 2008. *Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters.* 2nd ed. Nairobi, Kenya: UNEP.

United Nations Environment Programme (UNEP). 2009. Persistent Organic Pollutants. http://www.chem.unep.ch/pops/ (accessed December 9, 2009).

United Nations Environment Programme Global Environment Monitoring System/Water Programme (UNEP GEMS/Water). 2007. Water Quality Outlook. http://esa.un.org/iys/docs/san_lib_docs/water_quality_outlook.pdf (accessed July 28, 2009).

United Nations Environment Programme and World Tourism Organization (UNEP and UN-WTO). 2005. Making Tourism More Sustainable: A Guide for Policy Makers. http://www.unep.fr/shared/publications/pdf/DTIx0592xPA-TourismPolicyEN.pdf (accessed February 2, 1010).

United Nations–Water (UN-Water). 2008. Tackling a Global Cisis: International Year of Sanitation 2008.

United Nations World Water Assessment Programme (UN WWAP). Undated. Water and Industry. http://www.unesco.org/water/wwap/facts_figures/water_industry.shtml (accessed December 16, 2009).

United Nations World Water Assessment Programme (UN WWAP). 2003. The 1st UN World Water Development Report: *Water for People, Water for Life*. http://www.unesco.org/water/wwap/wwdr/wwdr1/ (accessed February 5, 2010).

United Nations World Water Assessment Programme (UN WWAP). 2009. The World Water Development Report 3: *Water in a Changing World*. Paris, France: United Nations Educational, Scientific and Cultural Organization. http://www.unesco.org/water/wwap/wwdr/wwdr3/ (accessed December 17, 2009).

United States Environmental Protection Agency (US EPA). Undated. Freshwater Ecosystems. http://www.epa.gov/bioiweb1/aquatic/freshwater.html (accessed February 28, 2011).

United States Environmental Protection Agency (US EPA). 2009a. Effects of Acid Rain. http://www.epa.gov/acidrain/effects/surface_water.html (accessed December 17, 2009).

United States Environmental Protection Agency (US EPA). 2009b. Hudson River PCBs: Background and Site Information. http://www.epa.gov/hudson/background.htm (accessed February 5, 2010).

United States National Academy of Sciences (US NAS). 1977. *Drinking Water and Health.* Washington, D.C.: US NAS.

Van Maanen, J., van Dijk, A., Mulder, K., de Baets, M.H., Menheere, P.C.A., van der Heide, D., Mertens, P.L.J.M., and Kleinjans, J.C.S. 1994. Consumption of drinking water with high nitrate levels causes hypertrophy of the thyroid. *Toxicology Letters* 72(1–3): 365–374.

Verma, B., Robarts, R.D., and Headley, J.V. 2007. Impacts of tetracycline on planktonic bacterial production in prairie aquatic systems. *Microbial Ecology* 54: 52–55.

Ward, M.H., deKok, T.M., Levallois, P., Brender, J., Gulis, G., Nolan, B.T., and VanDerslice, J. 2005. Workgroup report: Drinking-water nitrate and health—recent findings and research needs. *Environmental Health Perspectives* 113(11): 1607–1614.

The World Bank (WB). 2003. Philippines Environment Monitor 2003. Water Quality. http://www.worldbank.org

The World Bank (WB). 2007. Making the Most of Scarcity Accountability for Better Water Management Results in the Middle East and North Africa. http://siteresources.worldbank.org/INTMENA/Resources/00a-Front-Scarcity.pdf (accessed February 2, 2010).

World Commission on Dams (WCD). 2000. *Dams and Development: A New Framework for Decision-Making.* London: Earthscan.

World Health Organization (WHO). 2002. World Health Report: Reducing Risks, Promoting Healthy Life. http://www.who.int/whr/2002/en/whr02_en.pdf (accessed July 14, 2009).

World Health Organization (WHO). 2003a. Elemental Mercury and Inorganic Mercury Compounds:

Human Health Aspects. http://www.who.int/ipcs/publications/cicad/en/cicad50.pdf (accessed December 10, 2009).

World Health Organization (WHO). 2003b. Emerging Issues in Water and Infectious Disease. http://www.who.int/water_sanitation_health/emerging/emerging.pdf (accessed December 10, 2009).

World Health Organization (WHO). 2004a. DDT and Its Derivatives in Drinking-Water. http://www.who.int/water_sanitation_health/dwq/chemicals/ddt.pdf (accessed December 10, 2009).

World Health Organization (WHO). 2004b. Water, Sanitation and Hygiene Links to Health: Facts and Figures Updated November 2004. http://www.who.int/water_sanitation_health/publications/facts2004/en/index.html (accessed December 9, 2009).

World Health Organization (WHO). 2005. Mercury in Drinking Water. http://www.who.int/water_sanitation_health/dwq/chemicals/mercuryfinal.pdf (accessed December 9, 2009).

World Health Organization (WHO). 2008. Guidelines for Drinking-Water Quality: Incorporating the First and Second Addenda Volume 1, Recommendations. 3rd ed. http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ (accessed May 24, 2011).

World Health Organization and United Nations Children's Fund (WHO and UNICEF). 2004. *Meeting the MDG Drinking Water and Sanitation Target: A Mid-Term Assessment of Progress.* Geneva, Switzerland, and New York: United Nations.

Xu, K., Milliman, J.D., Yang, Z., and Wang, H. 2006. Yangtze sediment decline partly from Three Gorges Dam. *Eos* 87(19): 185–190.

Yongguan, C., Seip, H.M., and Vennemo, H. 2001. Policy options: The environmental cost of water pollution in Chongquing, China. *Environment and Development Economics* 6: 313–333.

Zhang, Y., Koukounari, A., et al. 2007. Parasitological impact of 2-year preventive chemotherapy on schistosomiasis and soil-transmitted helminthiasis in Uganda. *BMC Medicine*. http://www.pubmedcentral.nih.gov/picrender.fcgi?artid=2014753&blobtype=pdf (accessed July 20, 2009).

C H A P T E R 4

Fossil Fuels and Water Quality

Lucy Allen, Michael J. Cohen, David Abelson, and Bart Miller

Fossil fuels are essential to the global economy—for electricity production, transportation, plastics and chemicals manufacturing, heating, and many other purposes. However, the extraction and processing of fossil fuels, in addition to their use, have profound impacts on the environment and natural resources, including water. Large oil spills—such as the recent Deepwater Horizon drilling rig spill, which leaked over 4.9 million barrels (780,000 cubic meters) of crude oil into the Gulf of Mexico—have focused attention on the potential for disasters associated with oil drilling to cause contamination of the natural environment (Lubchenco et al. 2010). The growing recognition of the serious risks to surface-water and groundwater quality from natural gas fracking operations also raises new questions. And even normal fossil-fuel extraction and refining processes pollute the environment.

The connections between water and energy have been studied in recent years, with growing recognition of how closely the two are linked. Water is used, in varying quantities and ways, in every step of fossil-fuel extraction and processing (Ptacek et al. 2004). For example, the amount of coal produced worldwide in 2009 required an estimated 1.3 to 4.5 billion cubic meters (m^3) of water for extraction and processing.[1] Oil refining requires approximately 4 to 8 million m^3 of water *daily* in the United States alone (the amount of water that two to three million U.S. households use daily) (US DOE 2006). But while interest has grown in the volume of water required for energy production, the water-quality impacts have been given much less attention.

Because water is used in so many ways during fossil-fuel extraction and processing (see Table 4.1), there are also many ways in which it can become contaminated with a wide variety of pollutants, from sediment to synthetic chemicals. Additionally, nearby water bodies and groundwater may become contaminated by solid or liquid wastes created by the extraction process. Mining and drilling for fossil fuels bring to the surface materials long buried in the Earth, including water, and generate large quantities of waste materials or by-products, creating large-scale waste disposal challenges. Water brought to the surface through mining or drilling, called "produced water," can contain dissolved salts, trace metals, hydrocarbons, and radionuclides (USGS 2010). Spills and other disasters associated with the extraction process, such as the spill of over one million m^3 of coal slurry in Kentucky in 2000 when a containment dam failed, are another source of contamination (US DOE 2006). Finally, surface water may drain into mine openings, and groundwater frequently accumulates in mines, leading to the creation

1. Based on estimated water use for underground mining plus beneficiation from Gleick 1994 (7 m^3 to 24 m^3 of water per 10^{12} joules) and EIA coal production data. Energy contained in 1 metric ton of coal is assumed to be 27 $*10^9$ joules.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_4,

Table 4.1 Connections Between Water and Fossil-Fuel Extraction and Processing

	Process	Connection to Water Quality	Connection to Water Quantity
Energy Extraction & Production	**Oil and gas exploration**	Impact on shallow groundwater quality	Water for drilling, completion, and fracturing
	Oil and gas production	Produced water can affect surface and groundwater	Large volume of produced, impaired water
	Coal and uranium mining	Tailings and drainage can affect surface water and groundwater	Mining operations can generate large quantities of water
Refining & Processing	**Traditional oil and gas refining**	End use can affect water quality	Water needed to refine oil and gas
	Biofuels and ethanol	Refinery wastewater treatment	Water for growing and refining
	Synfuels and hydrogen	Wastewater treatment	Water for synthesis or steam reforming

Source: Modified from US DOE 2006.

and possible release of acid mine waters. These impacts can make water unsuitable for other purposes, such as supporting ecosystems or domestic human uses, and in some cases degradation continues for decades or centuries after the fuel is extracted. While the total volume of water contaminated by fossil-fuel production is not known, widespread cases of contamination indicate that it poses a significant, large-scale water-quality problem.

Fossil-Fuel Production and Associated Water Use

Fossil fuels are produced, in varying quantities, in every major region of the world (see Table 4.2). The water-related impacts of fossil-fuel extraction and refining in a given region are a function of multiple factors, including the amount and type of fossil fuel produced, the extraction methods used, physical and geological conditions, and regulatory requirements (Mielke et al. 2010). In some cases, social conditions such as political stability also influence the links between water and energy. In Nigeria, for example, political corruption and social tensions have contributed to a high incidence of oil spills because oil companies are often not held accountable for polluting, and because of vandalism of oil pipelines.

At the global scale, 22 percent of all water used is for industrial purposes, including mining and fossil-fuel extraction and power generation (UN WWAP n.d.). Estimates for the amount of water used globally specifically for fossil-fuel extraction are not well developed, and many are based on water-intensity estimates from one article (Gleick 1994) that is over 15 years old. Data on the water-quality impacts of fossil-fuel extraction and processing are even more poorly developed than those on water quantity and in many cases are not available at all, as water quality is not well monitored in many regions of the world.

One estimate for global water use for oil production, produced by applying water intensities per unit of oil extracted to global oil production figures, puts total water use at 13 billion m^3 of water for oil production worldwide in 2006 (Maheu 2009). This estimate takes into account the differing water intensities of oil produced in different

Table 4.2 Top Ten Fossil Fuel–Producing Countries (2008)

	Total Oil Supply			Dry Natural Gas			Primary Coal Production		
Rank	**Country**	**Thousand Barrels /Day**	**% of world**	**Country**	**Thousand Cubic Feet**	**% of world**	**Country**	**Thousand Short Tons**	**% of world**
1	Saudi Arabia	10,782.1	13%	Russia	23,385.6	21%	China	2,847,983.4	39%
2	Russia	9,792.3	11%	United States	20,377.0	19%	United States	1,171,808.7	16%
3	United States	8,514.2	10%	Canada	6,036.6	5%	India	568,323.1	8%
4	Iran	4,175.4	5%	Iran	4,107.1	4%	Australia	438,506.1	6%
5	China	3,982.7	5%	Norway	3,503.2	3%	Russia	356,185.5	5%
6	Canada	3,331.6	4%	Algeria	3,054.9	3%	Indonesia	313,231.7	4%
7	Mexico	3,186.7	4%	Netherlands	2,990.9	3%	South Africa	259,596.5	4%
8	United Arab Emirates	3,050.0	4%	Saudi Arabia	2,840.7	3%	Germany	214,351.1	3%
9	Kuwait	2,726.2	3%	Qatar	2,718.6	2%	Poland	157,881.9	2%
10	Venezuela	2,639.7	3%	China	2,685.4	2%	Kazakhstan	119,808.0	2%
	World	**85,459.7**		**World**	**109,788.5**		**World**	**7,271,748.6**	

Source: US EIA 2010a.

Table 4.3 Typical Energy Content of Fossil Fuels and Unit Conversions

Fossil Fuel	**Typical Energy Content**
Petroleum	6.1 gigajoules per barrel (GJ/bbl)
Natural Gas	1.1 megajoules per cubic foot (MJ/ft^3)
Coal	26 gigajoules per metric ton (GJ/te)
Tar Sands	6.1 GJ/bbl
Oil Shale	6.1 GJ/bbl

Unit Conversions
1 barrel (bbl) = 42 gallons = 0.159 cubic meters (m^3)
1 cubic foot (ft^3) = 0.0283 m^3
1 British Thermal Unit (Btu) = 1055 joules

regions and with different extraction techniques. As noted previously, global coal production in 2009 required an estimated 1.3 to 4.5 billion m^3 of water for extraction and processing. Global production of natural gas in 2009 required an estimated 840 million m^3 of water.[2] This water use is attributed exclusively to processing of natural gas since traditional extraction methods require negligible quantities of water. However, with the increasing use of hydraulic fracturing (often called "fracking,") water use and water-quality impacts related to natural gas extraction are likely to increase greatly. While these coal and natural gas estimates do not take into account differences in the water intensity of extraction between regions, they provide a rough approximation. Table 4.3 offers the typical energy content of fossil fuels for different reporting units along with unit conversions.

2. Based on water use data in Gleick 1994 (6 m^3 of water per 10^{12} joules) and EIA natural gas production data. Energy contained in 1 trillion cubic feet (TCF) of natural gas is assumed to be 1.05 * 10^{18} joules.

Fossil Fuels and Water Quality: Direct Impacts

Petroleum

From extraction to end use, petroleum products affect surface water and groundwater, impairing water quality with hydrocarbons, salts, nutrients, a host of organic compounds, and various heavy metals. In many areas around the world, oil spills and stormwater runoff containing oil derivatives have degraded ecosystems and human water supply.

Petroleum, also known as crude oil, comes from the remains of prehistoric life subjected to heat and pressure for millions of years. Over time, petroleum accumulated in oil fields, between layers of impermeable rock. Crude oil is extracted from these fields through a series of recovery methods that run from tapping into the fields' initial pressure (known as primary recovery) to pressurizing the fields with water or steam or other gases to force the oil to the surface (known as secondary and tertiary, or enhanced, recovery). Total daily global crude oil production (extraction) runs about 85 million barrels, equivalent to about 12 million metric tons (US EIA 2010a). In 2009, Russia accounted for 12.9 percent of total global production, followed by Saudi Arabia at 12 percent, the U.S. at 8.5 percent, Iran at 5.3 percent, and China at 4.9 percent (see Table 4.2 for 2008 production values) (BP 2010). In the United States, about one-quarter of domestic production comes from offshore wells, but global offshore oil production is only about 6 percent of total global production. Producers convey crude oil from the well via pipelines or ships to refineries, where crude oil is distilled into a variety of petroleum products, including gasoline, kerosene, fuel oils, liquefied petroleum gas, various lubricants, asphalt, and precursors to plastic and pharmaceutical products, among others. These petroleum products are then distributed via various modes to other manufacturers and to end users.

Each of these steps requires or can affect water. Oil fields themselves usually contain large volumes of salty water. The water that comes to the surface along with extracted crude oil is known as produced water. Produced water can contain hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. The ratio of produced water to crude oil tends to rise with the age of the well. Khatib and Verbeek (2003) estimated that oil production generates roughly three times as much produced water as crude oil, equivalent to about 15 billion m^3 of produced water annually worldwide. Historically, producers disposed of this waste stream with direct disposal into the environment or into evaporation pits that were often little more than holes in the ground that allowed produced water to infiltrate into local aquifers and contaminate groundwater sources or streams fed by these aquifers (Pettyjohn 1971). Khatib and Verbeek (2003) estimated that about 55 percent of one major oil company's produced water was re-injected into the ground. Clark and Veil (2009) found that some 98 percent of produced water from onshore wells in the United States was re-injected but that 91 percent of produced water from offshore wells was simply discharged into the ocean. Assuming that the 2 percent rate of U.S. onshore-produced water that is not re-injected can be applied globally—probably an optimistic assessment—yields an annual worldwide total of 300 million m^3 of produced water remaining on the surface.

The large volumes of produced water are the greatest single connection between oil production and water quality, but each step of the oil extraction and refining process has led to contamination of water resources. Oil spills from wells are not uncommon and can pollute vast areas both offshore and onshore, generating clear and measurable environmental impacts. Spills during the conveyance of crude oil from the point of extraction to refineries also occur with some regularity. The Exxon Valdez oil tanker spill, which garnered significant public attention, is only one example of many and in fact does not rank among the top 25 largest oil spills worldwide (O'Rourke and Connolly 2003). In Nigeria, an estimated 260,000 barrels of oil (41,000 m^3) spill each year into the Niger Delta and surrounding areas, with devastating impacts on people, plants, and wildlife (Vidal 2010, Nassiter 2010). Marine spills such as these can lead to freshwater system contamination when the oil hits the shoreline and drifts up through estuaries into streams. In the U.S., spills into freshwater systems occur more frequently than marine spills; between 1995 and 1996, 77 percent of all spills greater than 1,000 gallons and 88 percent of spills greater than 10,000 gallon were inland spills. The majority of these spills were from oil pipelines (Yoshioka and Carpenter 2002).

After production, crude oil is refined through a series of water-intensive processes: water is used for steam, as part of the refining process, as wash water, and for cooling. Process water typically becomes contaminated with sulfur and ammonia, requiring treatment. Cooling system water has little direct contact with petroleum products, though trace contaminants may appear in cooling system water. Such cooling water is the largest consumptive water use in refining, at a rate of three to four units of cooling water per unit of crude oil, depending on the type of cooling system. Because of the large volumes of water required for operation, refineries are often located adjacent to water sources. The sheer size of many refineries—often covering square kilometers of land—means that, in some countries, precipitation on the refinery grounds must be captured and treated so as not to contaminate adjacent water bodies.

Refined petroleum products continue to affect water quality, though their impacts typically become more diffuse once the products are refined and distributed. In the United States, the Environmental Protection Agency has recorded more than 490,000 confirmed leaks from underground storage tanks (USTs), which are generally used to store petroleum products. As of March 2010, there were more than 600,000 active USTs and more than 1,734,000 closed USTs in the country (US EPA 2010). The total number of USTs worldwide is not known. Leaking USTs can contaminate groundwater resources with gasoline, diesel fuel, and related compounds, such as benzene and toluene. The total volumes leaked from USTs, and the total volume of groundwater affected by such leaks, is not known.

In the U.S., more than 75 percent of refined petroleum becomes gasoline, diesel, and jet fuel (Teufel and Azelton 2008). The distribution and combustion of these fuels also affect surface water and groundwater. Once the refined gasoline and diesel fuels reach motor vehicles, spills and combustion by-products can become non-point sources of pollution, washed by stormwater runoff into streams or infiltrating into groundwater. Combustion of these fuels discharges nitrogen and other contaminants to the atmosphere, which in turn can be carried back to the earth in precipitation, increasing pollution loadings to lakes and streams. Incompletely combusted fuels and minor spills and leaks from motor vehicles also generate contaminants. One study found that runoff from one square kilometer of roads and parking lots carried the equivalent of more than 180 barrels of oil annually (NRDC 2001). Although there do not appear to be any estimates of the total volume or impacts of such end-use impacts on even a local scale, much less any global estimates, extrapolating from this one estimate suggests that stormwater runoff carries the equivalent of almost 20 million barrels of oil (more than 3 million m^3) annually nationwide (about 0.8 percent of total annual motor fuel consumption), though this should be considered little more than an order of magnitude estimate. Total global runoff from contaminated surfaces could not be estimated from available data.

Unconventional Petroleum

Unconventional petroleum, which includes tar sands and oil shale, is not extracted with conventional wells. Unconventional petroleum requires more complex extraction and processing than does crude oil, and its water-quality impacts are potentially many times greater than those of conventional crude.

Tar Sands

Tar sands, sometimes known as oil sands, are a mix of clay, sand, water, and bitumen. Bitumen is a thick, tarlike substance that can be processed into "synthetic crude," which can then be further processed by an oil refinery. Bitumen is also used directly in asphalt and other applications. Almost half of Canada's total oil production comes from the Alberta tar sands, equivalent to about 1.5 million barrels of oil per day, or 86.4 million m^3 total in 2009 (Gosselin et al. 2010). The total recoverable oil equivalent in Alberta's tar sands may exceed 27 billion m^3, second only to Saudi Arabia's oil reserves (Gosselin et al. 2010). Venezuela has a small commercial tar sands operation, and small deposits have been found in the Middle East. In eastern Utah, in the U.S., a controversial effort to develop tar sands is now under way (WRA 2010). Tar sands production is more complicated and capital intensive than typical petroleum production. Companies extract bitumen either via surface mining or in situ, which typically involves injecting steam into the tar sands deposits to decrease bitumen's viscosity and enable it to flow into pools, where it can be extracted.

Tar sands mining operations use large volumes of water to separate the bitumen from parent materials. Roughly two-and-a-half units of water are required to extract and process one unit of bitumen by surface mining, yielding an annual water-use volume of roughly 100 million m^3 (Gosselin et al. 2010). This processing water, as well as water released from the tar sands as the bitumen is refined, and water produced by the formations themselves, contains high concentrations of hydrocarbons and other contaminants and must be treated or contained. The large volumes of material mined from the surface to extract bitumen—as much as two tons of tar sands per barrel of oil—generates massive volumes of waste materials, which can then leach hydrocarbons, heavy metals, arsenic, selenium, and other hazardous materials into surrounding waterways. Typically, tailings are mounded to create retaining ponds for contaminated water.

Oil Shale

For the past 100 years, oil shale has periodically been promoted as the fuel of the future—a future that has never been realized. Despite federal and private investments of hundreds of millions of dollars, research and development efforts have yielded limited results. Commercial development remains a distant goal. In the United States, the federal government is again trying to jumpstart this nascent industry. Oil shale deposits are found worldwide, with some of the richest formations located in the Green River

Formation underlying Colorado, Utah, and Wyoming (US BLM 2008). A fundamental problem with developing these oil shale deposits is the thermodynamics of the resource. There is no oil in oil shale. Instead, the shale rocks contain kerogen, a waxy substance that liquefies when heated, producing a precursor to crude oil. Kerogen must be further processed and refined before it is suitable for use as transportation fuel. Extraction and refining will both require large quantities of energy and water, though, to date, the actual amounts of energy and water required have not been determined.

There are two primary methods to extract kerogen, neither of which has proven commercially viable: mining and retort, and in situ. Mining and retort requires mining the shale, crushing it, and heating the rock to separate the kerogen. This requires huge quantities of energy and water. There are various technologies under development for in situ extraction. One such process requires heating the shale rock in place to 370°C for three years and using wells to extract the kerogen. Another in situ method being explored is separating the kerogen via chemical processes.

Of the many anticipated environmental impacts from oil shale, perhaps the most serious are impacts to water quality. Mining operations, such as retort operations proposed for Utah, would leave large piles of spent shale, which could leach hydrocarbons, salts, trace metals, or other minerals, including nitrate, arsenic, boron, barium, iron, lead, selenium, and strontium, into surface-water and groundwater supplies (US BLM 2008, WRA 2010). Further, water extracted during processing may also be filled with metals and organic materials that can significantly degrade water quality in the region (US BLM 2008). Development would also disturb soils and ground surfaces, thereby increasing rates of erosion and the amount of sediment washed into streams and rivers. Traffic on rural, dirt access roads would add to this problem (US BLM 2008). Oil shale extraction could generate large quantities of produced water that must be re-injected or held in retention ponds, where it could leak or otherwise contaminate surface water and groundwater. Some oil shale processing methods use alkaline water that could mobilize toxic materials such as arsenic and selenium (Hanson and Limerick 2009).

Natural Gas

Like petroleum, natural gas comes from organic matter subjected to intense heat and pressure for millions of years. Natural gas can be produced from dedicated wells or coproduced with oil from oil wells. Most commonly, wells permit natural gas to flow to the surface naturally; however, in some geologic conditions, lifting equipment, such as rod-pumping, is required (Natural Gas Supply Association n.d.). In the U.S., roughly 22 percent of natural gas production comes from oil wells and the remainder from dedicated gas wells, including roughly 8 percent from coalbed methane (see the following section) (U.S. DOE 2010c). According to BP (2010), total global natural gas production in 2009 was 2.987 trillion m^3 (289 billion cubic feet), a decline of 2.1 percent from 2008. In 2009, the U.S. produced 20.1 percent of total global production, Russia produced 17.6 percent, Canada produced 5.4 percent, and Iran produced 4.4 percent. Table 4.4 shows natural gas consumption by end use in the U.S. in 2009. About a third of total U.S. consumption goes to electricity generation and the rest to a range of commercial, industrial, and residential purposes; end uses at the global scale were not available.

Natural gas production degrades water quality primarily at the extraction stage, though processing and combustion also affect water quality to lesser degrees. Like

Table 4.4 U.S. Natural Gas Consumption by End Use (2009)

End Use	Percent of Total
Electrical Power Generation	30.3
Industrial	26.8
Residential	20.8
Commercial	13.6
Production, Processing, and Distribution	8.3

Source: US EIA 2010b.

petroleum, natural gas extraction can generate large volumes of produced water, often contaminated by hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. Clark and Veil (2009) report that gas extraction generates about one-sixth as much produced water as petroleum extraction, at an average rate of 182 barrels of water per million cubic feet of production. Extrapolating from this figure yields an estimated three billion m^3 of produced water globally from natural gas extraction each year. In the U.S., most produced water from traditional onshore operations is re-injected; the fate of such water globally is not known.

Methane is the main compound of natural gas as used by consumers, but natural gas deposits contain a mixture of other compounds that must be removed before the methane is suitable for use by the consumer. Once extracted, gas undergoes initial processing near the wellhead. The gas is then transported, typically via pipeline, to a processing plant for further purification, to separate methane from other compounds in the raw natural gas, including propane, butane, water vapor, hydrogen sulfide, and carbon dioxide. Some of these, such as propane and butane, have commercial value. Water, hydrogen sulfide, and other compounds must be removed and treated or retained by the processing plant, to avoid environmental contamination. The purified natural gas is then delivered to end users, again typically via pipeline, though in remote areas it is often cooled and transported via tankers as liquid natural gas.

Burning natural gas leaves negligible solid waste and generates far fewer particulates than burning coal or petroleum. Like all fossil fuels, natural gas combustion generates carbon dioxide and nitrogen oxides, though at markedly lower rates than coal combustion. Methane itself is also a greenhouse gas, contributing to the heat-trapping capacity of the atmosphere, and like carbon dioxide, its concentration has risen dramatically in the past century. Per unit mass, methane traps more than 20 times as much heat as carbon dioxide, though the volumes of methane emissions are a very small fraction of total carbon emissions and methane has a shorter life span in the atmosphere. Still, methane from all sources contributed more than 10 percent of total greenhouse gas emissions in the U.S. in 2008, as measured by carbon equivalents.

Unconventional Natural Gas

The three basic forms of unconventional natural gas reservoirs are coalbed methane, tight natural gas, and shale gas. Unlike conventional natural gas, these unconventional forms are trapped in rock with very low permeability and therefore typically require stimulation in order for the gas to be extracted. Because unconventional natural gas has not been economical to extract, the extent of global resources has not been fully assessed. However, the amount of these types of gas produced are likely to increase substantially, particularly in the U.S., Canada, and China (US EIA 2010b), as conventional gas resources get more difficult and expensive to reach.

Hydraulic fracturing or fractionation, also known as fracking, is a method used to increase production of these types of natural gas wells, especially gas shales. The process forces liquids under high pressure into rock formations surrounding gas deposits, breaking up the rock and releasing the gas for capture by the well. The liquid used for fracking contains sand, to prop open the fractures, and a number of chemical additives, whose compositions are rarely disclosed to the public or regulators. Although the process was developed in the 1970s and 1980s, it is only recently emerging as a widely used recovery technique and is becoming increasingly controversial as new evidence of environmental contamination and groundwater problems emerges. It was originally used almost exclusively in North America and to some extent in Germany, primarily because it was not an economical extraction method in other areas. However, it is now in use or is planned to be used in a variety of regions, including India, the United Kingdom, and China. Fracking has dramatically increased natural gas production and has facilitated production in many areas previously considered uneconomical, but this expansion in the number of wells, and especially fracking itself, raises the scope and severity of water contamination. Fracking is a water-intensive process—each well requires two to five million gallons of water (GWPC and ALL Consulting 2009; US EPA 2010). Disposal of the recovered fracturing fluid, and the unknown amount and composition of fluid that is not recovered, could contaminate groundwater and surface-water bodies.

Shale Gas

Shale gas is trapped in the pore space of shale rocks, which have extremely small pore sizes compared to the rocks in which conventional gas is trapped. This makes them impermeable to gas flow, and they therefore require natural or artificial fractures in the rock to release the gas (Andrews et al. 2009). Shale gas wells are often drilled horizontally, and most are hydraulically fractured (GWPC and ALL Consulting 2009).

Tight Gas

Tight gas is found in low-porosity sandstones and carbonate reservoirs. Like shale gas, the relatively impermeable nature of the rock in which tight gas is found means that it generally requires hydraulic fracturing or acidizing in order to release the gas (GWPC and ALL Consulting 2009).

Coalbed Methane

Coalbed methane, or CBM, is sourced from within a coal seam or in the surrounding rock. Major CBM deposits are found in Australia, Canada, and the United States, with smaller deposits in England and South Africa. CBM is loosely bound to coal and is typically held in place by the pressure of water in the coal deposits. CBM extraction requires removing water from the coal bed, thereby decreasing pressure on the gas and allowing it to flow up the well. The extraction process can alter groundwater levels, including by decreasing pressure in local wells and, in cases where the groundwater is shallow, in surface flows. Water-quality impacts due to extraction include methane leaks (with impacts on vegetation and, in some cases, explosions), strong odors, and cloudy or slimy well water.

In some areas (e.g., the Powder River Basin in the U.S.), produced water from coal beds is discharged to the surface, where it can concentrate salts and other substances in the soil, affect land productivity, and alter water quality, including temperature. In other areas (e.g., the San Juan Basin), produced water is typically re-injected (usually into geologic formations that lie below the aquifer from which the CBM is produced). Some propose that produced water might, after proper treatment, be discharged into surface streams to help offset decreased flows due to other diversions or even climate change. A key problem with this approach is that produced water is a finite supply that would be only a temporary, stop-gap measure to address a much longer term problem.

Coal

Like petroleum and natural gas, coal comes from organic matter subjected to intense heat and pressure for millions of years. Coal, however, is a solid—a sedimentary rock—extracted through surface and underground mining. According to the U.S. Energy Information Administration (U.S. EIA), total global coal production and consumption in 2009 was about seven billion metric tons. China produced 44 percent of this amount, followed by the United States at 14 percent and India at 8 percent. In the U.S., more than 90 percent of coal consumption is used to generate electricity, producing roughly half of all electricity generated in the country. Some forms of low-sulfur coal are baked at extremely high temperatures to make coke, which is used in the production of steel. Coal is also used for cement and aluminum manufacturing, and coal by-products are used to produce fertilizers and various plastics, among other products. U.S. EIA reports that coal combustion generated 36.5 percent of the United States' annual total greenhouse gas emissions in 2008. Coal generates more carbon dioxide per unit energy than petroleum, but petroleum constituted 44.6 percent of total fossil-fuel energy production in 2008, compared to coal's 26.8 percent (US EIA 2008).

Water is used throughout coal production, from extraction to processing, and occasionally for transportation. Water is used for cooling and cutting in the mines, for suppressing dust, for irrigating as part of land reclamation efforts, and for washing coal to remove sulfur, mercury, and other impurities. Mielke et al. (2010) report the consumptive use of water for coal mining and washing at 1 to 8 gallons/MMBtu in the U.S., roughly equivalent to 80 to 650 million m^3 per year in the U.S., depending on the thermal energy per unit coal. These estimates are very dated and might not be accurate: Mielke et al. (2010) and Younos et al. (2009), among other recent reports on volumes of water embedded in energy production, cite the U.S. Department of Energy (US DOE 2006), which in turn cites Gleick (1994), who cites data from the 1970s and 1980s. Thus, current estimates are based on research that is more than 20 years old, and in some cases more than 30.

According to one estimate that converted water use per unit of energy to water use per unit of mass by calculating from a range of energy equivalents per ton of coal, from 800 to 3,000 gallons of water are used for the extraction, processing, transport, and mitigation (such as land reclamation efforts) of one short ton of coal (K. Schneider, pers. comm.). Extrapolating from these volumes suggests that on the order of 20 to 90 billion m^3 of water are used annually for coal production processes worldwide. Gleick (1994) commented on the absence of good estimates on the amount of water contaminated by coal production; nor does there appear to have been any good estimates since then.

Although volumes of water contaminated by coal production are not known, it is clear that extraction, processing, and transportation of coal and related production materials can adversely impact surface-water and groundwater quality at each step of production and use.

When coal seams lie within about 60 meters of the surface, coal is extracted using various methods of surface mining, including strip mining, mountaintop removal, and open pit mining. Surface mining typically employs massive machines or explosives to remove the "overburden"—a euphemism for the soil, vegetation, animals, and functioning ecosystems—covering the coal seam. The volume of overburden varies dramatically by region and is a key factor determining the economic productivity of the mine; Gupta (2000) reports that the ratio of overburden to coal can range from 5:1 to 27:1. In some cases, the overburden is subsequently used to fill the hole left by surface mining operations, though in other cases, especially in mountaintop removal, it is dumped into valleys, burying and blocking streams. Surface mining generally—and mountaintop removal in particular—denudes the landscapes and compacts soils, increasing runoff rates and decreasing infiltration and groundwater recharge. Palmer et al. (2010) found a number of water-quality impacts in streams affected by mountaintop removal mining, including increases in alkalinity, electrical conductivity, heavy metals, and concentrations of sulfates and other ions, as well as decreased biodiversity.

According to the World Coal Association, surface mining accounts for roughly two-thirds of U.S. coal production but only about 40 percent of global coal production; the remainder comes from underground mining. Various methods are used to extract coal from underground mines, often using sophisticated machines and monitoring equipment. Although underground mining generates less spoil material than surface mining, these mine spoils often include heavy metals, sulfurous compounds, and other materials that leach into surrounding watercourses, often generating acid mine drainage that disrupts ecological functions (as described below).

Miners move extracted coal to processing plants, often located near the mine location. Processing requirements vary markedly by location and type of coal. Coal in the eastern U.S. and in some other areas typically contains higher sulfur concentrations. Processing plants clean the coal, removing some of the impurities and extraneous materials. Some methods use large volumes of water to wash the coal, decreasing concentrations of sulfur, mercury, and other contaminants in the coal but increasing them in the wastewater. Coal-processing wastewater can be discharged into underground mines or may be discharged into surface holding ponds. Both can degrade water resources, contaminating groundwater or leaking into surface-water bodies. Retention ponds have failed on occasion, releasing large volumes of polluted water downstream, sometimes with catastrophic impacts. For example, a 29-hectare retention pond in Kentucky, U.S., failed in October 2000, releasing almost a million cubic meters of coal-processing wastewater into a nearby mine. The contaminated wastewater then drained into nearby streams, causing flooding to a depth of almost two meters, disrupting local water supplies, and causing extensive environmental damage (National Research Council 2002). One website lists 66 separate coal impoundment spills in the eastern U.S. in the years 1972–2008 (CILIS n.d.).

After processing, coal is often transported via rail or barge to the point of consumption. In one location, crushed coal was mixed with water to form a slurry and then conveyed 440 kilometers (km) via pipeline to a power plant, though this plant has since been closed. Transportation accidents and related coal spills tend to be easier to contain than spills of liquid petroleum, though spills into waterways can leach harmful materials, such as mercury, sulfur compounds, arsenic, and lead.

Most coal moves from the mine to a power plant, where it is crushed and burned to generate electricity. Combustion residues, known as coal ash, are composed of airborne particulates known as fly ash and residual materials known as bottom ash. In some countries, fly ash is now captured; some is used in the production of concrete, while the remainder is mixed with bottom ash and disposed of in landfills or stored wet in retention facilities, to minimize dust emissions. On December 22, 2008, a wet coal ash holding pond failed in Tennessee, U.S., spilling some 3.7 million m^3 of wet coal ash into the Emory River. A medium-term study of the spill impacts found high arsenic concentrations in downstream waterways, especially in protected areas with limited flows and in bottom sediments (Ruhl et al. 2010). Other users of coal products can also degrade surface-water and groundwater resources; for example, in Brazil recently, steel manufacturers were fined for discharging toxic coal residues directly into waterways (AP 2010).

Impacts on Freshwater Ecosystems

Freshwater ecosystems are affected in a variety of ways by the direct impacts of fossil-fuel extraction and mining outlined earlier. These ecosystem impacts fall into four basic categories: (1) impacts related to climate change, (2) physical impacts, (3) chemical impacts, and (4) biological impacts.

Climate Change

Fossil-fuel production and combustion generates some 90 percent of total U.S. greenhouse gas emissions; lower fossil-fuel use rates and higher rates of land-use changes in other parts of the world suggest that fossil fuels contribute a slightly lower, though still disproportionately large, share of global greenhouse gas emissions. These emissions are already changing the global climate, including temperature and precipitation, and risk dramatically altering the hydrologic cycle. The extraction and use of carbon-intensive fossil fuels generates fundamental changes in the global distribution of water, in turn affecting a host of water-quality parameters, including sedimentation, temperature, and dissolved oxygen concentrations (Fischlin et al. 2007). Projected increases in storm intensity will amplify runoff from contaminated surfaces, both in urban areas and from tailings piles, and could overwhelm efforts to retain and manage such contaminated runoff. Increased storm intensity could also affect coal ash and other retention ponds, increasing the risk of pond failure and subsequent release of contaminated materials into downstream waterways.

Decisions about current and future energy supplies present critical opportunities. Retiring aging thermoelectric power plants may create "new" water supplies that can meet growing urban demands or environmental needs while reducing greenhouse gas emissions, if their generation capacity can be offset through energy-efficiency improvements or less water-intensive energy sources. For example, recent legislation in Colorado directed Xcel Energy to replace 900 megawatts of coal-fired power plants in the Denver metropolitan region with natural gas units, energy efficiency, and other resources. This legislation will provide important (though incidental) benefits to water resources. As other plants near the end of their design life span, additional opportunities for advancing an integrated energy, climate, and water policy may arise.

Physical Impacts

Fossil-fuel production and use can create a variety of physical changes in water resources, including changes in channel structure, sediment-transport dynamics, groundwater–surface water connectivity, and subsurface water connectivity and mobility, as well as temperature changes in surface and groundwater. The most dramatic change in channel structure comes from the surface-mining method known as mountaintop removal and valley fill, in which streams are completely buried by tailings, as described earlier. Figure 4.1 shows a mining and valley fill operation in West Virginia, U.S., in 2009. Underground coal mines and surface-mining operations for coal and tar sands all generate large volumes of tailings that can wash into and choke streams, burying fish eggs and aquatic insects. Fracking can also increase groundwater mobility, connecting pockets of highly saline or otherwise contaminated groundwater with drinking-water wells and alluvial aquifers, permitting the migration of hydrocarbons, benzene, arsenic, and other contaminants into drinking water supplies and into surface waterways. Similarly, in situ methods for extracting petroleum and tar sands, such as the injection of steam or lubricants and surfactants, can increase the mobility of underground contaminants and contaminate groundwater resources. Thermal pollution occurs at a much larger scale at power plants burning fossil fuels, where cooling water absorbs excess heat from the plant and is then discharged into streams or lakes, typically increasing the chemical and biological oxygen demand in the receiving water.

Figure 4.1 Sediment Ponds, Valley Fill, and Edge of Coal Mine near Bob White, West Virginia, United States.

Source: Vivian Stockman, http://www.ohvec.org

Chemical Impacts

At every stage of their production and use, fossil fuels can create a host of adverse chemical impacts on water quality. Fossil-fuel production, transmission, and use can contaminate water resources with hydrocarbons, heavy metals, increased nutrient and salt loads, and a host of toxic compounds, including benzene, toluene, and hexavalent chromium. The ubiquity of pipelines and tanker trucks, not to mention personal and commercial vehicles, makes fuel leaks and spills a statistical certainty, as noted earlier. Coal mine tailings often leach heavy metals and acids into nearby streams, dramatically lowering pH (often to levels of 2 to 3) and decimating or even extirpating entire aquatic communities (Swer and Singh 2004). Abandoned mines themselves, common throughout many areas of the world, pose their own long-term threats to water quality: such mines often contain heavy metals and sulfur compounds and can fill and spill from surface precipitation and groundwater, generating acid mine drainage (Banks et al. 1997).

Produced water from oil, gas, and coal extraction typically contains hydrocarbon residues, heavy metals, hydrogen sulfide, and boron, as well as elevated concentrations of salts. Although most produced water is re-injected or discharged to the ocean, more than 300 million m^3 per year of such water stays on the planet's surface, stored in retention ponds or discharged generally to the land or water, where it can contaminate groundwater and surface-water resources. Processing and refining fossil fuels also generate chemical wastes that, if not properly managed, can contaminate water with petroleum wastes, heavy metals, selenium, and other contaminants. In 2008, a Texas petroleum refinery was fined for more than 2,000 unlawful discharges between 1999 and 2006 ("Refinery Water Pollution" 2008). Combustion of coal and petroleum products generates large quantities of sulfur and nitrous oxides that can generate acid precipitation and excess nutrient loadings on land and water surfaces. Coal combustion leaves coal ash, which is often stored wet in retention ponds, though such ponds have failed, discharging selenium, arsenic, and other contaminants into nearby streams. Fuel spills from personal and commercial vehicles are widespread, leaving residues on impervious surfaces that can wash into streams or lakes or percolate into the ground after precipitation events.

Ecological Impacts

Many aspects of fossil-fuel production directly affect aquatic resources and can cause mortality events or otherwise degrade ecological resilience. At the global level, the clear link between fossil-fuel combustion and climate change means that the ecological impacts of climate change can be largely attributed to fossil fuels. The scientific literature robustly describes the intersection of climate change, water quality, and ecosystems (see Fischlin et al. 2007, Meyer et al. 1999). Impacts include direct changes, such as increased temperature and carbon dioxide concentrations and habitat loss, and increased internal nutrient loadings and decreased oxygen concentrations. These in turn affect primary production, species composition, and foodwebs and likely will increase the risk of extinctions from freshwater ecosystems.

Physical and chemical impacts lead to widespread ecological impacts in aquatic communities, ranging from complete extirpation of entire aquatic communities, to periodic mortality events in response to spills and leaks, to degraded ecosystems left more susceptible to other disturbances. In the U.S., more than 1,200 kilometers of streams have been buried by coal mine operations; the total length of streams lost worldwide due to fossil-fuel production is not known. Fisheries in another 13,000 kilometers of streams in the eastern U.S. alone have been degraded by coal mining operations, hinting at the scale of the problem globally.

Morbidity and mortality resulting from direct oil spills and leaks have attracted considerable media attention over the years, but they are not the only source of petroleum-related mortality for waterbirds and aquatic organisms. Retention ponds for produced water and other wastewater discharges, such as processing, refinery, and thermal generation plant liquid wastes, can become attractive nuisances for migratory birds and other wildlife. Ducks and other birds have landed on such retention ponds, only to die in large numbers due to oil fouling or acute toxicity. Gosselin et al. (2010) provide a historical overview of environmental incidents generated by Alberta tar sands, noting that natural bitumen discharge had been recorded along a river bank in Alberta as far back as 1719. Large-scale commercial operations began more than 40 years ago, leading to spills and releases from pipelines and tailings ponds. A 1970 pipeline spill released more than 3,000 m^3 of oil, creating an oil slick that reached more than 250 kilometers down the Athabasca River, contaminating water supplies for several communities, and likely harming aquatic organisms (though such impacts were not well monitored or reported). Subsequent sampling found that drainage from tailings ponds was acutely toxic to fish. In 2008, some 1,600 ducks died after landing in a tar sands tailings pond and becoming fouled by bitumen on the water surface (Gosselin et al. 2010).

Acid precipitation causes a host of ecological impacts, especially to aquatic resources. Acid precipitation—primarily generated by coal combustion—can increase the mobility of aluminum and other metals in aquatic systems, leading to mortality of fish and aquatic invertebrates, in turn diminishing the prey base for birds and other animals. Acid precipitation—and its degradation of water quality and dependent ecosystems—occurs downwind of coal-fired power plants; adverse impacts have been reported in China, Europe, and North America (Larssen 1999, Menz and Seip 2004).

Impacts on Human Communities

Clean water is an essential component of healthy communities. In addition to the basic human need for water for drinking and sanitation, livelihoods such as agriculture, fishing, hunting, and industrial production depend on a sufficient supply and adequate quality of water. Furthermore, water, or the ecosystems that depend on it, has cultural or spiritual importance to many communities. Therefore, water-related impacts of fossil-fuel extraction and processing not only damage the environment but also adversely affect communities and public health (Table 4.5). Because of a lack of data on community impacts of fossil fuel–related water contamination, much of the information available is anecdotal; here we use case studies to illustrate the types of potential community impacts.

Table 4.5 Examples of Water-Related Community Impacts of Fossil Fuels

Location	Process	Impacts	Source(s)
Orissa, India	Coal mining & processing	Contamination of drinking water with fluoride, manganese, nickel, and sulfate; depletion of water available for drinking and bathing.	Murthy and Patra 2006
Appalachia region, U.S.	Coal mining & processing	Contamination of drinking water causing tap water to turn black, contain orange slime, or have a foul taste or odor. Increased severity and frequency of flash flooding.	Murdoch 2009, Stout and Papillo 2004
Ecuador	Oil extraction	Approximately 17 million gallons of crude oil and over 18 billion gallons of toxic produced water spilled or dumped into rivers during oil extraction, causing contamination of domestic water sources and surface waters used for fishing.	Juhasz et al. 2009
Niger Delta	Oil extraction	Contamination of rivers and ponds from oil spills and wastes from extraction and dredging and canalization related to oil extraction, leading to loss of fish and contamination of drinking water.	Amnesty International 2010, CEHRD 2008
Alberta, Canada	Tar sands extraction	Contamination of water bodies, including the Athabasca River, with polycyclic aromatic compounds, cadmium, copper, lead, mercury, nickel, silver, zinc, and other contaminants.	Reuter et al. 2010
U.S. (multiple locations)	Hydraulic fracturing for natural gas	Contamination of drinking water wells with benzene, methane, and other contaminants—residents suspect that it is caused by hydraulic fracturing, but this link is unconfirmed. Discharge of wastewater with high concentrations of radioactivity. New research is pending.	EPA 2011, Lustgarten 2008, Urbina 2011

Drinking Water Contamination

Fossil-fuel extraction and processing can lead to contamination of sources of drinking water with a wide variety of contaminants that threaten human health. When drinking water is contaminated, communities have three basic choices: (1) find an alternative source of water, (2) treat water before drinking it, or (3) drink contaminated water and risk adverse health outcomes. Often, alternative water sources can be much more expensive; for example, in the United States bottled water can be thousands of times more expensive than tap water or may require traveling long distances at a high energy cost (Gleick and Cooley 2009). In addition to being costly, using bottled water also requires being able to lift and transport the bottles, resulting in disproportionate hardship for the elderly, disabled, and poor.

Coal mining has been linked to severe drinking water contamination in many coal mining regions. For example, in the state of Orissa, India, communities' drinking water was contaminated as a result of coal mining and processing activities. Women are particularly at risk for adverse health effects resulting from exposure to this contaminated water, as they are responsible for many household activities that involve contact with water, such as collecting the water, washing clothes and utensils, and bathing children (Murthy and Patra 2006). Some villages were even forced to relocate after groundwater was contaminated due to coal mining activities (Murthy and Patra 2006). In the U.S., coal mining in the Appalachian region has led to contamination of groundwater drinking supplies (see the case study later in this chapter).

Recent U.S. Geological Survey research has found evidence for a link between Balkan Endemic Neuropathy (BEN) and coal mining. BEN is a degenerative kidney disease that occurs in clusters in rural villages in the Balkan Peninsula and eventually leads to complete kidney failure. An estimated 25,000 people currently suffer from this disease, which was first described medically in 1956 (USGS 2001). However, the cause of the disease is still not known for certain. Patients with BEN also have a high occurrence of normally rare upper urinary tract cancers. Recently, a correlation was found between the location of the affected villages and lignite coal deposits. Additionally, well water in affected villages was found to contain organic compounds such as polycyclic aromatic hydrocarbons (PAHs), which can be toxic and could have been leached from the nearby coal deposits (USGS 2001). In the United States, states with the highest rates of upper urinary tract and other cancers also have similar types of coal deposits (USGS 2001, Orem n.d.).

A growing concern is the link between hydraulic fracturing, a process that injects water mixed with a complex and often proprietary blend of chemicals to enhance methane recovery, and contamination of drinking water supplies with benzene, methane, radiation, and other chemicals. Although practitioners claim there is no conclusive evidence to link fracking to contamination of surface-water and groundwater supplies, critics claim that more than 1,000 cases of such contamination can be traced to fracking, as well as to incidental surface spills and leaks of fracking chemicals (Lustgarten 2008, Urbina 2011). Fracking also can create links between natural gas itself and groundwater, in some instances increasing methane concentrations in drinking water to such an extent that tap water can be ignited. From the limited information on chemicals used in hydraulic fracturing that is available, either through voluntary disclosure or in states that require disclosure, we know that chemicals that can potentially cause respiratory problems or harm to the nervous and reproductive systems are used (Berkowitz 2009).

The major human community impacts associated with fossil-fuel refining, processing, and use are related to air quality. However, all of these processes can also contaminate drinking water sources with a variety of toxins. In the state of São Paulo, Brazil, for example, improper disposal of toxics at a petrochemical facility caused contamination of nearby drinking water wells (Harden et al. 2002). In the U.S., one estimate puts releases of petroleum by-products by oil refineries at 50,000 barrels per day; about a quarter of total petroleum refining toxic releases in the U.S. are to water systems (O'Rourke and Connolly 2003).

Case Study: Mountaintop Removal, Coal Mining, and Drinking Water in Appalachia

In the Appalachian Mountains, which run from the U.S. state of Georgia northeast into Canada, coal mining has been a central economic activity for generations. Increasingly, coal is extracted in this region using the mountaintop removal method, leading to large-scale environmental destruction (described earlier). Additionally, the practice has resulted in contamination of drinking water. This contamination is suspected to be primarily caused by coal slurry, which is disposed of in impoundments or by injecting it into abandoned mines, both of which can potentially leach contaminants into groundwater. Studies of well-water quality have found contaminants consistent with those found in coal slurry (Hendryx et al. 2007; McSpirit and Dieckmann 2003; Stout and Papillo 2004). Even after mine sites have been reclaimed (i.e., mining activities are completed and attempts are made to restore the site to previous conditions), groundwater has been found to contain elevated levels of mining-related contaminants (USGS 2006).

In many cases, this contamination has left families or whole communities without water that is safe to drink or even to use to bathe. Some communities with contaminated drinking water also suffer from elevated rates of health problems, including cancer, liver and kidney problems, and skin rashes—ailments they suspect are linked to their water (Stout and Papillo 2004, Murdoch 2009). But because it is difficult to determine for certain the causes of many of these diseases, the number of people whose health has been affected by drinking water that is polluted by coal mining is unknown. In one community in West Virginia, neighbors banded together to sue nearby coal companies for contaminating their drinking water. Evidence for the case was found in disclosure reports by the coal companies that showed the companies were pumping into the ground illegal concentrations of the same chemicals that were detected in drinking water (Duhigg 2009).

Loss of Subsistence Resources

Water is an important component of many livelihoods. Clean water and healthy freshwater ecosystems provide the basic goods and services upon which many livelihoods depend, from irrigation water to creating fertile floodplains for grazing. According to a UN Food and Agriculture report on water and livelihoods, "some 75% of the world's poorest people live in rural areas across the world, and for them, water access can literally mean the difference between life and death" (Sullivan et al. 2008). For many indigenous cultures, loss of subsistence resources results not only in economic or livelihood loss but also in cultural and spiritual loss. For example, the Columbia River Inter-Tribal Fish Commission states on its website that "salmon are part of our spiritual and cultural identity . . . without salmon returning to our rivers and streams, we would cease to be Indian people" (CRITFC 2010). Depletion or contamination of water resources can lead to ecosystem decline or collapse, resulting in a loss of subsistence resources. Alternatively, contamination of water resources can also lead to accumulation of contaminants in fish and wildlife, which can cause illness when people ingest them.

Case Study: Impacts of Oil Drilling on Subsistence Resources in Nigeria

Located on the coast of Western Africa, Nigeria is endowed with rich natural resources, particularly oil, but is also confronted with serious environmental and political challenges. The Nigerian economy relies heavily on oil: in 2008, crude oil accounted for 90 percent of the country's exports (UN Statistics Division 2009). Nigeria is the largest crude oil–producing country in Africa and the fourteenth largest worldwide (US EIA n.d.). Much of the oil production in Nigeria is done by large multinational companies, including Shell, ExxonMobil, and Chevron. Available information indicates that more than 6,800 spills, totaling about three million barrels of oil, have occurred in Nigeria between 1976 and 2001 (UNDP 2006). Oil spills happen both accidentally and due to vandalism of pipelines by local people in protest of oil companies and the government (UNDP 2006).

Oil spills have had severe impacts on natural resources in some parts of the country, limiting local people's ability to provide for themselves through subsistence farming or fishing, in a country where 34 percent of the population lives below the national poverty line and 64 percent of the population lives on less than $1.25 per day (UNDP 2010). Surface waters and wetlands have been have extensively damaged in the Niger Delta. For example, in 2008 there was an oil spill resulting from a break in the Trans-Niger pipeline that continued for weeks and contaminated Bodo Creek in Gokana, Nigeria. This contamination damaged many of the aquatic species that local people eat, leading a Nigerian nonprofit organization to conclude: "Given the overwhelming dependency of Gokana people's livelihood on mangrove and artisanal fisheries, it is safe to infer that the spillage will largely undermine food security in the locality" (CEHRD 2008).

Case Study: Impacts of Tar Sands on Health and Food Security of First Nations Communities

Alberta, Canada, contains approximately 175 billion barrels of proven oil reserves, largely in the form of tar sand. As discussed earlier, tar sand—a solid or semi-solid form of petroleum—requires large volumes of heated water for extraction that become contaminated with use and are often stored in toxic tailings ponds (Reuter et al. 2010). Contaminants can leak from these tailing ponds through the soil, causing contamination of nearby rivers. Recent research on the Athabasca River in Alberta, for example, has linked heavy and toxic metals—including mercury, arsenic, and lead—to nearby tar sands development (Kelly et al. 2010).

Such developments may have serious adverse effects on some First Nations (native Canadian) communities. In Fort Chipewyan, a village in Alberta, cancer rates are thought to be far higher than normal; there is disagreement regarding by how much rates are elevated (Brooymans 2010). In 2006, a local doctor pushed for an inquiry into what he believed were unusually high cancer rates among his primarily First Nations patients. He suspected that toxins dumped into the waterways by the tar sand project were to blame (Woodford 2007). This doctor was later accused by Health Canada of causing "undue alarm" when selected data from a study that it conducted indicated that cancer rates in the community were lower than overall rates in Alberta. When more complete data from the study were later released, however, they indicated that cancer rates were in fact elevated in Fort Chipewyan (Woodford 2007). While a link to tar sand developments has not been proven, many suspect that they are the cause, and improved, independent epidemiological surveys are needed.

Additionally, fish and wildlife in the area are increasingly being found to have large sores or other abnormalities, making people afraid to eat these traditional sources of food (Crazyboy 2010, Candler et al. 2010). Contaminant guidelines established to protect aquatic life were exceeded for 7 of 13 toxins examined in one study of the Athabasca River, indicating a threat to the health of fish and other organisms in the river (Kelly et al. 2010). As pollution makes traditional foods unsafe or undesirable to eat, native food security and traditions are put at risk. Speaking of the Athabasca River, one member of the Mikisew Cree First Nation stated: "We do lots of hunting in that river, not only for ducks, for moose and we do lots of fishing also. It's for our livelihood . . . you go out there to feed your kids, to feed the family. . . . And now, the moose is not fit to eat, the fish is not fit to eat, even ducks. What else are we to live on now? There's not anything fit to eat" (Candler et al. 2010).

Conclusion

The energy/water nexus has become a popular topic of inquiry, with a great deal written in the past several years about the amount of energy required to extract and move water, and about the large volumes of water required to extract fossil fuels and generate electricity. Yet very little has been written about the water-quality implications of fossil-fuel production and use, despite the fact that water quality can be degraded at every step of the fuel cycle. Extraction, refining, and combustion of fossil fuels pollute water in many ways, both through regular operations and through accidental releases or other incidents. Fossil fuels themselves are significant water contaminants; many of the chemicals used to process and refine these fuels also pose grave threats to water quality.

Unfortunately, reliable estimates of the total volumes or quality of water polluted by fossil-fuel production and use do not exist. However, some general estimates of total water required for production of various resources offer an order of magnitude–level appraisal of fossil fuel's global water-quality impacts. Not including the very large volumes of produced water that are re-injected or discharged into the oceans, on the order of 15 to 18 billion m^3 of freshwater resources are affected annually by fossil-fuel production. Much of this water is treated and subsequently discharged or held in retaining ponds, where it may evaporate or, in some cases, percolate through the soil and degrade groundwater. The severity of fossil fuel–generated water pollution varies tremendously. Some acid mine drainage is so toxic that it has effectively sterilized receiving waters; other impacts may be relatively minor and short-term.

Coal, natural gas, and petroleum are produced in every major region of the world. Similarly, the contamination of water due to fossil-fuel extraction and processing occurs around the globe. This contamination of water has significant implications for ecosystems and for communities that depend on the water for drinking or to support their livelihood. In some cases, accidents or other incidents can temporarily degrade water quality, with limited impacts to ecosystems or human communities. In other cases, such as unmitigated mine drainage or mountaintop removal, fossil-fuel production can generate chronic impacts that render a water source unusable. At the global level, the single greatest water-quality impact generated by fossil fuels comes from fossil-fuel combustion and subsequent climate changes, which will have major, long-term water-quality impacts across the planet.

Despite these impacts, information on global water-quality impacts of fossil-fuel production is scarce, old, incomplete, or nonexistent. As the world moves toward increased production of unconventional oil and gas, which typically require vast quantities of water and have a large potential for contaminating nearby freshwater systems and groundwater, these impacts are likely also to increase. Several relatively new methods of fossil-fuel extraction, such as fracking, can cause widespread contamination of groundwater resources, affecting drinking water systems and both surface water and groundwater. This chapter offers an initial assessment of the water-quality impacts of fossil-fuel production and use, but much more work needs to be done to better understand the scope and intensity of such impacts.

References

Amnesty International. 2009. Petroleum, Pollution and Poverty in the Niger Delta. http://www.amnesty.org/en/library/asset/AFR44/017/2009/en/e2415061-da5c-44f8-a73c-a7a4766ee21d/afr440172009en.pdf

Andrews, A., Folger, P., Humphries, M., Copeland, C., Tiemann, M., Meltz, R.,and Brougher, C. 2009. Unconventional Gas Shales: Development, Technology, and Policy Issues. http://www.fas.org/sgp/crs/misc/R40894.pdf

Associated Press (AP). 2010. Brazilian steel maker fined for toxic coal spill. December 10, 2010. http://finance.yahoo.com/news/Brazilian-steel-maker-fined-apf-2838486213.html?x=0&.v=1 (accessed May 20, 2011).

Banks, D., Younger, P.L., Arnesen, R.T., Iversen, E.R., and Banks, S.B. 1997. Mine-water chemistry: The good, the bad and the ugly. *Environmental Geology* 32: 157–174.

Berkowitz, M. 2009. Toxic Chemicals on Tap: How Natural Gas Drilling Threatens Drinking Water. Environment America Research and Policy Center. http://www.eenews.net/public/25/13089/features/documents/2009/11/04/document_gw_02.pdf

BP. 2010. "Natural Gas Production" and "Historical Data" Excel workbooks. http://www.bp.com/sectiongenericarticle.do?categoryId=9023780&contentId=7044476

Brooymans, H. 2010. Fort Chipewyan wants answers about cancer rates: Industry has no place in study of health in community, residents believe. *Edmonton Journal*. http://www.edmontonjournal.com/health/Fort+Chipewyan+wants+answers+about+cancer+rates/4038644/story.html#ixzz1Cwgmsix1

Candler, C., Olson, R., DeRoy, S., with the Mikisew Cree First Nation. 2010. As Long As The Rivers Flow: Athabasca River Use, Knowledge and Change. MCFN Community Report. http://www.prowsechowne.com/documents/Mikisew%20Cree%20First%20Nation/Appendix%20D%20-%20Expert%20Reports/Tab%2010.pdf

Centre for Environment, Human Rights and Development (CEHRD). 2008. Persistent Oil Spillage at Bodo Creek; Unprecedented Impacts on Ecosystem Stability, Biodiversity and Food Security of Ogoni Communities. www.cehrd.org/files/BODO_OIL_SPILL.doc

Clark, C.E., and Veil, J.A. 2009. Produced Water Volumes and Management Practices in the United States. Argonne National Laboratory ANL/EVS/R-09/1. http://www.osti.gov/bridge

Coal Impoundment Location and Information System (CILIS). N.d. Listing of Coal Impoundment Spills. http://www.coalimpoundment.org/aboutimpoundments/spillList.asp (accessed February 10, 2011).

Columbia River Inter-Tribal Fish Commission (CRITFC). 2010. Website. http://www.critfc.org/index.html

Crazyboy, G. 2010. The Alberta Tar Sands and First Nations eco-genocide. *YU Free Press*. http://www.yufreepress.org/?p=1123

Duhigg, C. 2009. Clean water laws are neglected, at a cost in suffering. *New York Times*, September 12, 2009. http://www.nytimes.com/2009/09/13/us/13water.html?_r=1

Fischlin, A., Midgley, G.F., Price, J.T., Leemans, R., Gopal, B., Turley, C., Rounsevell, M.D.A., Dube, O.P., Tarazona, J., and Velichko, A.A. 2007. Ecosystems, their properties, goods, and services. In: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, editors. Cambridge, United Kingdom: Cambridge University Press, pp. 211–272. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm

Gleick, P.H. 1994. Water and energy. In: *Water in Crisis: A Guide to the World's Fresh Water Resources*. New York: Oxford University Press. http://www.annualreviews.org/doi/abs/10.1146/annurev.eg.19.110194.001411

Gleick, P.H., and Cooley, H.S. 2009. Energy implications of bottled water. *Environmental Research Letters* 4. doi:10.1088/1748-9326/4/1/014009. http://iopscience.iop.org/1748-9326/4/1/014009/pdf/erl9_1_014009.pdf

Gosselin, P., Hrudey, S.E., Naeth, M.A., Plourde, A., Therrien, R., Van Der Kraak, G., and Xu, Z. 2010. The Royal Society of Canada Expert Panel: Environmental and Health Impacts of Canada's Oil Sands Industry. The Royal Society of Canada. http://www.rsc.ca/expertpanels_reports.php

Groundwater Protection Council (GWPC) and ALL Consulting. 2009. Modern Shale Gas Development in the United States: A Primer. U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory. http://www.netl.doe.gov/technologies/oil-gas/publications/epreports/shale_gas_primer_2009.pdf

Gupta, S. 2000. *Global Environment: Current Status*. New Delhi: Sarup and Sons.

Hanson, J.L., and Limerick, P. 2009. *What Every Westerner Should Know About Oil Shale: A Guide to Shale Country.* Boulder: Center of the American West, University of Colorado at Boulder. http://www.centerwest.org/publications/oilshale/0home/index.php

Harden, M., Walker, N., Griffiths, H., and Verweij, M., eds. 2002. Lessons Not Learned: The Other Shell Report 2004. http://www.foe.co.uk/resource/reports/lessons_not_learned.pdf

Hendryx, M., Ahern, M.M., and Nurkiewicz, T.R. 2007. Hospitalization patterns associated with Appalachian coal mining. *Journal of Toxicology and Environmental Health, Part A* 70: 2064–2070. DOI: 10.1080/15287390701601236.

Juhasz, A., Anderson, M., Bassey, N., Chicaia, A., Clark, V., Cotton, S.E., Cray, C., Cullen, D., Donowitz, P., Dotlich, S., Herriges, D., Kinman, M., Livoti, L., Langlois, M., Olson, B., Suzara, A., and Tovar, J. 2009. The True Cost of Chevron. http://truecostofchevron.com/2009-alternative-annual-report.pdf

Kelly, E.N., Schindler, D.W., Hodson, P.V., Short, J.W., Radmanovich, R., and Nielsen, C.C. 2010. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. *Proceedings of the National Academy of Sciences* 107(37): 16178–16183. http://www.pnas.org/content/early/2010/08/24/1008754107.abstract

Khatib, Z., and P. Verbeek. 2003. Water to value—produced water management for sustainable field development of mature and green rields. *Journal of Petroleum Technology*. http://www.spe.org/jpt/print/archives/2003/01/JPT2003_01_hse_horizons.pdf

Larssen, T., Seip, H., Semb, A., Mulder, J., Muniz, I., Vogt, R., Lydersen, E., Angell, V., Dagang, T., and Eilertsen, O. 1999. Acid deposition and its effects in China: An overview. *Environmental Science and Policy* 2: 9–24. DOI: 10.1016/S1462-9011(98)00043-4

Lubchenco, J., McNutt, M., Lehr, B., Sogge, M., Miller, M., Hammond, S., and Conner, W. 2010. BP Deepwater Horizon Oil Budget: What Happened to the Oil? http://www.restorethegulf.gov/sites/default/files/imported_pdfs/posted/2931/Oil_Budget_description_8_3_FINAL.844091.pdf

Lustgarten, A. 2008. Buried secrets: Is natural gas drilling endangering U.S. water supplies? *ProPublica*, November 13, 2008. http://www.propublica.org/article/buried-secrets-is-natural-gas-drilling-endangering-us-water-supplies-1113

Maheu, A. 2009. Energy Choices and Their Impacts on Demand for Water Resources: An Assessment of Current and Projected Water Consumption in Global Energy Production. Unisféra International Centre and McGill University. http://www.unisfera.org/IMG/pdf/Energy_demand_on_water_Finalversion.pdf

McSpirit, S., and Dieckmann, M. 2003. Response and technical assessment to ATSDR–petitioned health consultation, public comment release, Martin County slurry release, Inez, Martin County, Kentucky. Richmond, KY: Eastern Kentucky University.

Menz, F.C., and Seip, H.M. 2004. Acid rain in Europe and the United States: An update. *Environmental Science and Policy* 4: 253–265. DOI: 10.1016/j.envsci.2004.05.005.

Meyer, J. L., Sale, M.J., Mulholland, P.J., and Poff, N.L. 1999. Impacts of climate change on aquatic ecosystem functioning and health. *Journal of the American Water Resources Association* 35: 1373–1386. DOI: 10.1111/j.1752-1688.1999.tb04222.x

Mielke, E., Anadon, L.D., and Narayanamurti, V. 2010. *Water Consumption of Energy Resource Extraction, Processing, and Conversion: A Review of the Literature for Estimates of Water Intensity of Energy-Resource Extraction, Processing to Fuels, and Conversion to Electricity*. Energy Technology Innovation Policy Discussion Paper No. 2010-15. Cambridge, Massachusetts: Belfer Center for Science and International Affairs, Harvard Kennedy School, Harvard University.

Murdoch, S. 2009. Water: Coping with contamination. *The Appalachian Voice,* August/September. http://appvoices.org/thevoice/pdfs/voice_2009_04_augsept.pdf

Murthy, A., and Patra, H.S. 2006. *Ecological, Socio-Economic and Health Impact Assessment Due to Coal Mining—A Case Study of Talabira Coal Mines in Orissa.* Orissa, India: Vasundhara.

Nassiter, A. 2010. Far from Gulf, a spill scourge five decades old. *New York Times*, June 16, 2010. http://www.nytimes.com/2010/06/17/world/africa/17nigeria.html

National Research Council. 2002. *Coal Waste Impoundments: Risks, Responses, and Alternatives*. Washington, D.C.: National Academy Press. http://books.nap.edu/catalog/10212.html

Natural Gas Supply Association. N.d. Unconventional Natural Gas Resources. http://www.naturalgas.org/index.asp

Natural Resources Defense Council (NRDC). 2001. Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp

Orem, W. N.d. Coal Slurry: Geochemistry and Impacts on Human Health and Environmental Quality. U.S. Geological Survey. http://www.sludgesafety.org/misc/wm_orem_powerpoint/slide05.html

O'Rourke, D., and Connolly, S. 2003. Just oil? The distribution of environmental and social impacts of oil production and consumption. *Annual Review of Environmental Resources* 28: 587–617.

Palmer, M. A., Bernhardt, E.S., Schlesinger, W.H., Eshleman, K.N., Foufoula-Georgiou, E., Hendry, M.S., Lemly, A.D., Likens, G.E., Loucks, O.L., Power, M.E., White, P.S., and Wilcock, P.R. 2010. Mountaintop mining consequences. *Science* 327:148–149. DOI:10.1126/science.1180543

Pettyjohn, W.A. 1971. Water pollution by oil-field brines and related industrial wastes in Ohio. *Ohio Journal of Science* 71: 257–269. https://kb.osu.edu/dspace/bitstream/handle/1811/5637/V71N05_257.pdf?sequence=1

Ptacek, C., Price, W., Smith, J.L., Logsdon, M., and McCandless, R. 2004. *Threats to Water Availability in Canada.* No. 3. NWRI Scientific Assessment Report Series. Burlington, Ontario: National Water Research Institute. http://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1&offset=14&toc=show

Refinery water pollution costs ConocoPhillips $1.2 million. (2008). *Environment News Service,* April 7, 2008. http://www.ens-newswire.com/ens/apr2008/2008-04-07-091.html

Reuter, Y., Cogan, D., Sasarean, D., López Alcalá, M., and Koehler, D. 2010. Canada's Oil Sands Shrinking Window of Opportunity. Ceres. http://www.ceres.org/resources/reports/oil-sands-2010/view

Ruhl, L., Vengosh, A., Dwyer, G.S., Hsu-Kim, H., and Deonarine, A. 2010. Environmental impacts of the coal ash spill in Kingston, Tennessee: An 18-month survey. *Environmental Science and Technology* 44: 9272–9278. DOI**:** 10.1021/es1026739

Schneider, K., senior editor, Circle of Blue. E-mail communication, December 15, 2010.

Stout, B., and Papillo, J. 2004. Well Water Quality in the Vicinity of a Coal Slurry Impoundment Near Williamson, West Virginia. http://www.sludgesafety.org/what_me_worry/wju_report.pdf (accessed January 13, 2011).

Sullivan C.A., Cohen, A., Faurès, J.M., and Santini, G. 2008. The Rural Water Livelihoods Index: Working Paper. Food and Agriculture Organization. http://www.fao.org/nr/water/docs/FAOW_RWLI_paper.pdf

Swer, S., and Singh, O.P. 2004. Status of water quality in coal mining areas of Meghalaya, India. In: *Proceedings of the National Seminar on Environmental Engineering with Special Emphasis on Mining Environment*. I.N. Sinha, M.K. Ghose, and G. Singh, editors. NSEEME-2004, March

19–20, 2004. http://www.indiaenvironmentportal.org.in/files/Status%20of%20water%20quality%28meghalaya%29.pdf

Teufel, A., and Aexlton, A. (2008). Fisher Investments on Energy. Hoboken, NJ: John Wiley and Sons, Inc.

U.S. Bureau of Land Management (US BLM). 2008. Approved Resource Management Plan Amendments/Record of Decision for Oil Shale and Tar Sands Resources to Address Land Use Allocations in Colorado, Utah, and Wyoming and Final Programmatic Environmental Impact Statement. http://ostseis.anl.gov/documents/index.cfm

U.S. Department of Energy (US DOE). 2006. Energy Demands on Water Resources. Report to Congress on the Interdependency of Energy and Water. http://www.sandia.gov/energy-water/congress_report.htm

U.S. Energy Information Administration (US EIA). 2008. Emissions of Greenhouse Gases in the United States 2008. http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/0573%282008%29.pdf

U.S. Energy Information Administration (US EIA). 2010a. International Energy Statistics. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=53&aid=1

U.S. Energy Information Administration (US EIA). 2010b. International Energy Outlook 2010: Natural Gas. http://www.eia.doe.gov/oiaf/ieo/nat_gas.html (accessed February 2, 2011).

U.S. Energy Information Administration (US EIA). 2010. Natural Gas Annual 2009. http://www.eia.gov/FTPROOT/natgas/013109.pdf

U.S. Energy Information Administration (US EIA). N.d. Nigeria: Country Analysis Brief. http://www.eia.doe.gov/countries/country-energy-data.cfm?fips=NI

U.S. Environmental Protection Agency (US EPA). 2010. Underground Storage Tanks. http://www.epa.gov/oust/index.htm (accessed December 9, 2010).

U.S. Environmental Protection Agency (US EPA). 2011. Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/HFStudyPlanDraft_SAB_020711.pdf

United States Geological Survey (USGS). 2001. Health Effects of Toxic Organic Compounds from Coal—The Case of Balkan Endemic Nephropathy (BEN). http://pubs.usgs.gov/fs/fs004-01/fs004-01.pdf

United States Geological Survey (USGS). 2006. Ground-Water Quality in Unmined Areas and Near Reclaimed Surface Coal Mines in the Northern and Central Appalachian Coal Regions, Pennsylvania and West Virginia. http://pubs.usgs.gov/sir/2006/5059/pdf/sir2006-5059.pdf

United States Geological Survey (USGS). 2010. Toxic Substances Hydrology Program. http://toxics.usgs.gov/sites/ph20_page.html

United Nations Development Programme (UNDP). 2006. Niger Delta Human Development Report. Abuja, Nigeria. http://hdr.undp.org/en/reports/nationalreports/africa/nigeria/nigeria_hdr_report.pdf

United Nations Development Programme (UNDP). 2010. Report 2010. Statistical Annex, Table 5, Multidimensional Povery Index. http://hdr.undp.org/en/media/HDR_2010_EN_Table5_reprint.pdf

United Nations Statistics Division. 2009. Trade Profile. http://data.un.org/CountryProfile.aspx?crName=Nigeria#Economic

United Nations World Water Assessment Program (UN WWAP). N.d. Water and Industry. http://www.unesco.org/water/wwap/facts_figures/water_industry.shtml

Urbina, I. 2011. Regulation lax as gas wells' tainted water hits rivers. *New York Times,* February 27, 2011, p. 1. http://www.nytimes.com/2011/02/27/us/27gas.html (accessed March 3, 2011).

Vidal, J. 2010. Nigeria's agony dwarfs the Gulf oil spill. *The Guardian*, May 30, 2010. http://www.guardian.co.uk/world/2010/may/30/oil-spills-nigeria-niger-delta-shell

Western Resource Advocates (WRA). 2010. Fossil Foolishness: Utah's Pursuit of Tar Sands and Oil Shale. http://www.westernresourceadvocates.org/land/utosts/utreport.php

Woodford, P. 2007. Health Canada muzzles oilsands whistleblower: AB physician sounded cancer alarm, slapped with College complaint. *National Review of Medicine* 4 (6). http://www.nationalreviewofmedicine.com/issue/2007/03_30/4_policy_politics1_6.html

Yoshioka, G., and Carpenter, M. 2002. Characteristics of Reported Inland and Coastal Oil Spills. http://www.epa.gov/oem/docs/oil/fss/fss02/carpenterpaper.pdf

Younos, T., Hill, R., and Poole, H. 2009. *Water Dependency of Energy Production and Power Generation Systems*. VWRRC Special Report No. SR46-2009. Blacksburg: Virginia Polytechnic Institute and State University. http://www.vwrrc.vt.edu/pdfs/specialreports/sr-46_water_dependency_of_energy.pdf

C H A P T E R 5

Australia's Millennium Drought: Impacts and Responses

Matthew Heberger

As this edition of *The World's Water* goes to press in early 2011, eastern Australia is recovering from devastating floods that claimed more than 20 lives and destroyed hundreds of homes. The heavy rains of 2009 and 2010 that caused so much destruction also marked the end of Australia's decade-long Millennium Drought. Beginning in about 1997, declines in rainfall and runoff had contributed to widespread crop failures, livestock losses, dust storms, and bushfires. Such are the vagaries of water on the continent with the world's most uncertain and variable climate.

The "Big Dry," as the long drought is commonly called by Australians, has profoundly affected the continent's environment, economy, and national psyche. It has prompted changes to the way Australia manages water and has accelerated reforms that were already under way to modernize its water laws and institutions. Modern Australia, shown in Figure 5.1, is home to 22 million people, and is an industrial, developed society with among the highest standards of living in the world. Most of its citizens live in cities near the coast, and much of the food they eat and products they buy are imported from overseas, insulating them somewhat from the worst effects of drought.

Australia's farmers are even more vulnerable. Agriculture, once the country's dominant industry, now makes up only 2.5 percent of the economy, yet it uses two-thirds of the water supply. For most of the 20th century, irrigation policies were designed to encourage settlement in the dry, sparsely settled outback. As part of a sweeping package of economic reforms in the 1990s, the Australian government began signaling to farm communities that they should no longer rely on government drought relief. The duration and severity of the latest drought, however, has caused the government to soften this policy—thousands of farmers received "exceptional circumstances" payments over the past ten years.

Drought has caused many other changes over the past decade. Australia's sheep population, which once outnumbered humans 10 to 1, has been halved in the past 10 years. Other agricultural sectors were also hard hit: rice production collapsed in some years, as did cotton. City dwellers have learned to live with frequent water restrictions, prompting creative ways to reuse water and spawning new industries in water conservation technology. Drought has also increased Australians' awareness of climate change and the fragility of their country's ecosystems. The lessons learned in recent years in Australia may soon be of interest to other parts of the world as water management challenges grow.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_5,

Water Resources of Australia

It is often written that Australia is the driest inhabited continent. This simple description, correct in the aggregate, belies Australia's relative water wealth. Australia's per-capita renewable water resources average 25,000 cubic meters per year, a level higher than France, Germany, or Japan (UNESCO 2009). Surrounding Australia's vast inland deserts, where rainfall averages less than 20 centimeters per year, a variety of climates exist on and near the coasts. These range from subtropical rainforests in the northeast where rainfall can exceed 3 meters per year, to Mediterranean climates on the southwest coast marked by winter rains and hot, dry summers. Much of this precipitation is unavailable for human use—88 percent of rainfall re-enters the atmosphere via evaporation or transpiration by plants, with only 12 percent left to penetrate the ground, replenish aquifers, or flow in rivers (Cooperative Research Centre for Water Quality and Treatment 2006). In southeastern Australia, the country's most productive agricultural zone, the peak of the summer growing season in December and January coincides with the lowest streamflows under natural conditions, and hence the least water availability. Throughout this chapter, statistics are reported by Australian water years, which run from July 1 to June 30.

As Australia's first European settlers learned, averages mean far less in Australia than in the north. In temperate climes, the average tells one what to expect, while in a highly variable climate like Australia's, the calculated mean does little to indicate how much rainfall to expect in a given year. Australia's latitude means it is subject to the atmospheric phenomenon called the subtropical high (Figure 5.2). Circulation patterns create long-lasting zones of high air pressure over the continent, leading to clear skies and low rainfall. And unlike temperate regions where rain is driven by seasonal patterns that recur every year, Australia's precipitation is heavily influenced by ocean and atmosphere conditions that can persist for several years, such as the El Niño Southern Oscillation and the Indian Ocean Dipole (Verdon-Kidd and Kiem 2009). El Niño events generally coincide with low rainfall, while the associated La Niña often brings floods (Nicholls 2008). Recent work by the University of New South Wales indicates that warm sea-surface temperatures in the Indian Ocean are significantly correlated with drought in southeastern Australia and that this effect may be even more important than El Niño (Ummenhofer et al. 2009).

Since 1860, when reliable records began, Australia has had a major drought somewhere on the continent in 82 out of 150 years (Lake 2008). It is now known that drought is a normal and recurring feature of Australia's climate. The most serious droughts on record include the Federation Drought from 1895 to 1902, the World War II drought from 1937 to 1945, and the recent "Big Dry" from 1997 to 2009. Shorter droughts appear throughout Australia's recorded history, for example in 1914–1915, 1965–1968, and 1982–1983. "Australia should be used to the death and destruction of drought," wrote the newspaper *The Australian*, "but each time we are surprised by its ferocity—and every disaster seems worse than the last" (McKernan 2010).

While previous droughts were usually limited to specific regions, the Millennium Drought differed in that it covered much of the continent over the course of several years (Lloyd 2010). Each of Australia's most populous cities—Sydney, Melbourne, Brisbane, Adelaide, and Perth—has been affected (Figure 5.2), along with the nation's major food-producing regions, primarily the Murray-Darling River Basin in southeastern Australia, and the wheat belt in the southwest.

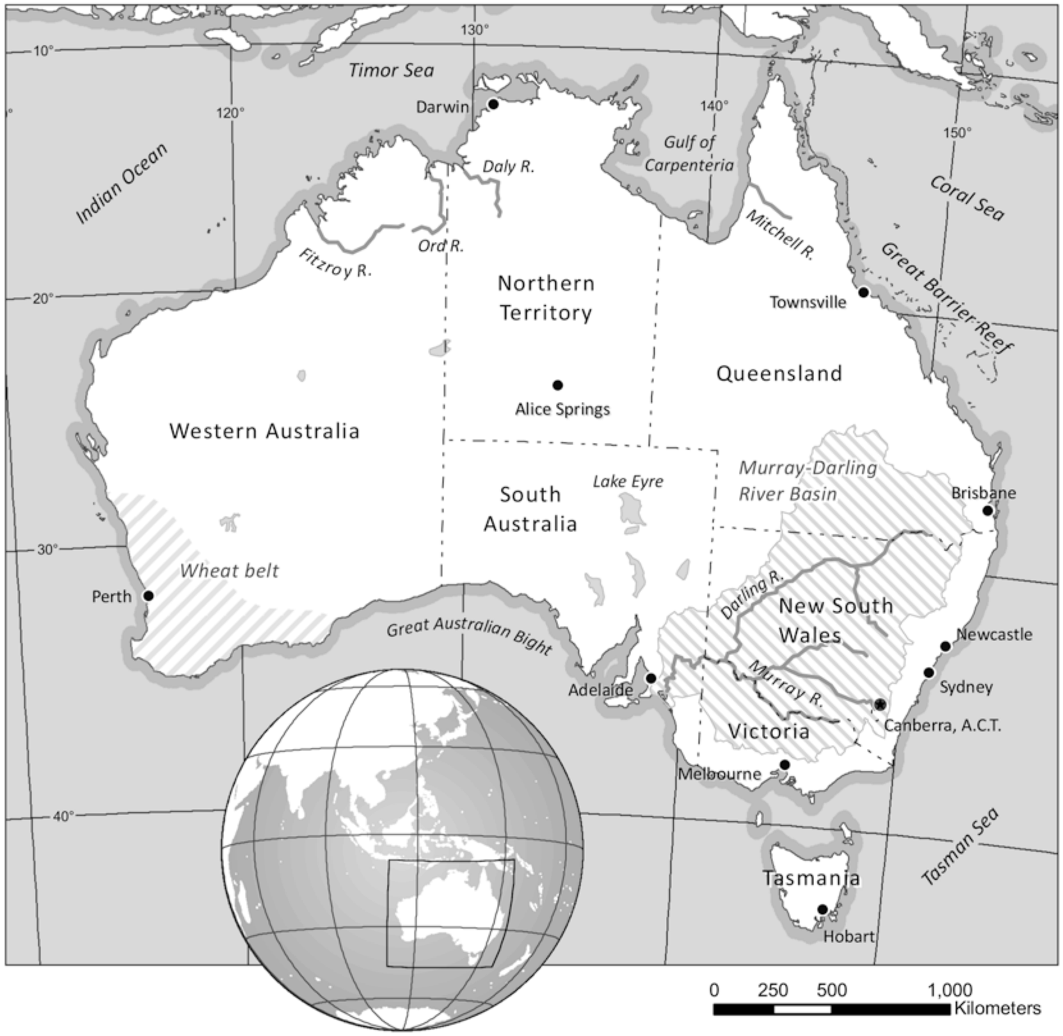

Figure 5.1 Map of Australia.
Source: Map created by the author using data from Natural Earth, www.naturalearthdata.com.

The short but acute drought of 1982–1983 was among the most damaging on record. Rainfall deficiencies (amount below the long-term average) were the greatest ever recorded (Verdon-Kidd and Kiem 2009). While rainfall deficiencies were not as severe during the Millennium Drought, climatologists have rated it even more severe in terms of its duration and spatial extent. Anecdotes abound verifying their conclusion. A grazier in Central Queensland with records going back 120 years told interviewers: "What we have just been through is more than twice as bad as the worst drought previously recorded which was in 1902. . . . [In] this drought, we have had trees dying here. Those trees were here when Captain Cook sailed up the coast [c.1770] so when you have got brigalow trees dying it is a drought—there is no doubt about it" (quoted in Stehlik 2005).

A number of definitions of drought have been put forth by different authorities, and these definitions vary depending on their purpose (Cooley 2007). Hydrologists define droughts based on changes in environmental water, such as lake levels or river flows. A meteorological drought refers to a deficit of precipitation. Agricultural droughts are declared when soil moisture is depleted below levels needed for healthy crops. A water management drought may be declared when reservoirs fall below a certain level.

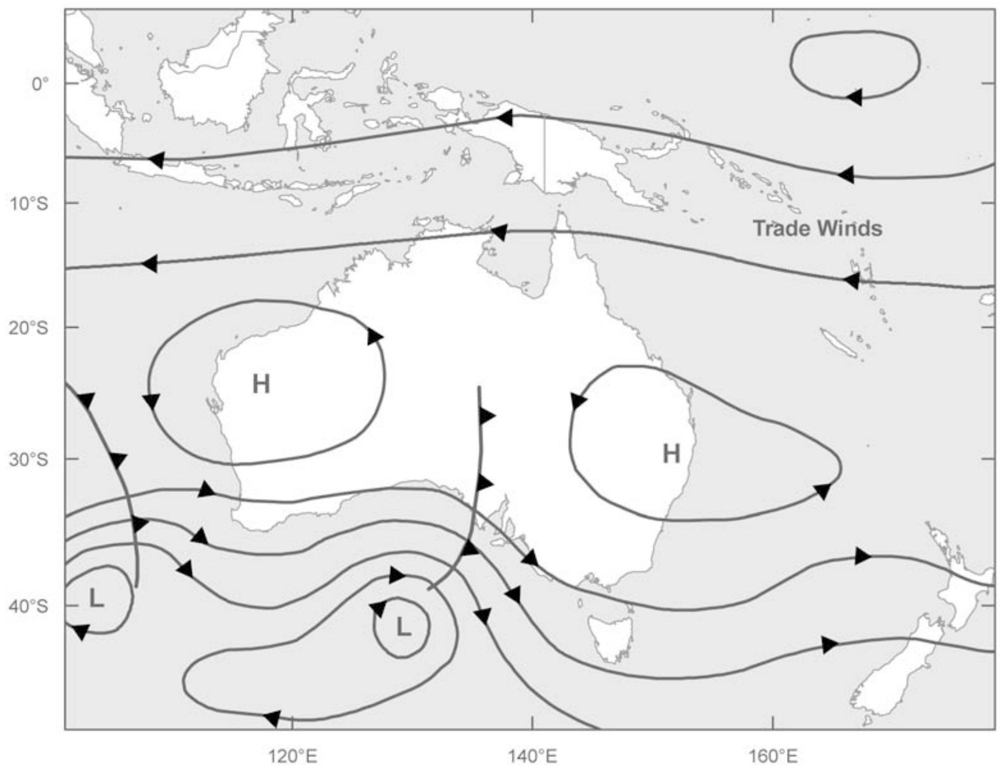

FIGURE 5.2 STABLE HIGH-PRESSURE AIR MASSES OVER AUSTRALIA LEADING TO LONG, WARM, DRY PERIODS.

Source: Redrawn from Australian Bureau of Meteorology undated

Drought relief in Australia has been tied to official drought declarations, and drought triggers were inconsistent among the states and frequently politicized. As a result, the Australian government moved to create a standard national definition of drought in the 1990s. Drought is now defined by comparing rainfall for a given period to the long-term average for that same period. Rainfall totals in the lowest decile (lowest 10 percent of records) are termed a "serious" rainfall deficiency. When rainfall is in the lowest 5 percent of observations, it is classified a "severe" rainfall deficiency. The Bureau has not, however, created a clear definition to mark the end of a drought (Botterill 2005).

Discussion of the Australia's Millennium Drought often glosses over the fact that the entire country was not in a drought for the past decade. In fact, in some years, good rains in certain regions allowed water restrictions to be lifted and some agricultural enterprises to prosper. In 2008–2009, a year before the drought lifted, planting of cotton and canola were up nearly 50 percent in response to good growing conditions in some regions. Figure 5.3 shows drought conditions in Australia indicated by rainfall deficiencies for the water years from 1997 to 2010. Rainfall in the lowest decile occurred in some regions repeatedly over the last decade, much more often than one would expect based on a 10 percent chance in a given year.

The Millennium Drought has had observable effects on much of the continent's flora and fauna. Along the Murray River, salty and acidic water is causing the death of beloved red gum trees along 1,500 kilometers of the river. The condition of the Menindee Lakes

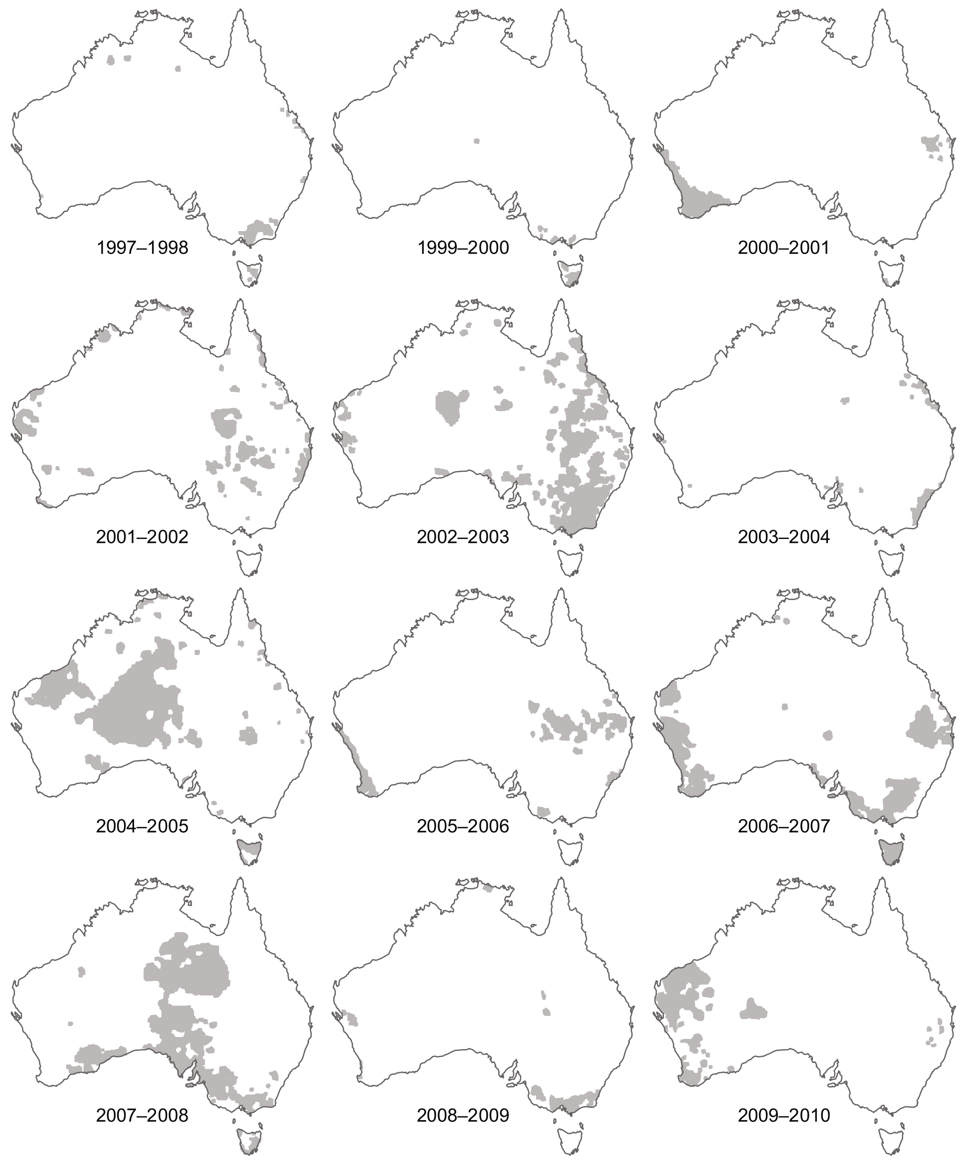

Figure 5.3 Extent of Drought in Australia During the Big Dry. Shaded regions indicate serious water deficiency (rainfall in the lowest decile) for the Australian water year July 1–June 30. (The year of 1998–1999, in which few regions experienced serious deficiencies, is not shown.)

Source: Data from the Australian Bureau of Meteorology undated

along the Murray River, and the Coorong Wetlands near its mouth, have deteriorated during the drought due to lack of freshwater inflows, causing the near disappearance of iconic shorebirds, including pelicans, black swans, and fairy terns (Ker 2009). In 2007, National Geographic noted that kangaroos had become a common sight in the parks and streets of cities in southeast Australia, "invading" cities in search of food and water (Peatling 2007). Koala are also at risk as drought is killing off several species of eucalyptus trees, the animals' main food source (Sohn 2007).

In the future, climate change is likely to exacerbate drought conditions. Some argue that it already has. Scientists at the Commonwealth Scientific and Industrial Research

Organization (CSIRO) found that, since the middle of the 20th century, rainfall has decreased by 15 percent, and temperatures in the first decade of the 2000s were 0.3–0.6°C above the long-term average. These changes combine to increase potential evaporation (Nicholls 2008, Ummenhofer et al. 2009). The combination of higher evaporation and lower precipitation depletes soil moisture and runoff and raises the prospect of more frequent and intense droughts in the future. A 2008 CSIRO report forecast a 35 to 50 percent decline in water availability in the Murray-Darling by the year 2030, and predicted that flows to the Lower Lakes near the Murray's mouth could drop by up to 70 percent (CSIRO 2008). A number of Australians now believe that their country is a "canary in the coal mine" when it comes to climate change and that drought conditions are an early indication of changes that other regions of the world are likely to experience in the future.

Impacts of the Millennium Drought

The most apparent effect of drought has been on Australia's landscape and watercourses; images of dry lake and riverbeds have become common in newspapers and on television. The drying of soils and lowering of water tables has had a discernible effect on the continent's plant and animal life, and has led to an increase in wildfires and dust storms over the past several years. Further, decreased river flows and reservoir levels have dramatically curtailed irrigation in some years, causing loss of income and economic hardship in rural communities. These impacts of the drought and others are discussed in the sections that follow.

Agriculture

Ten years of drought have affected nearly every aspect of Australia's rural economies. Considering only one of the worst years of the Big Dry, the Australian Bureau of Statistics estimated that drought in 2002–2003 caused a $7.4 billion drop in agricultural production and a loss of around 70,000 jobs (Lu and Hedley 2004).[1] For that year, losses were equivalent to 1.6 percent of Australia's gross domestic product. While some question the logic of such assessments (i.e., does it make sense to assign a theoretical value to crops never planted or harvested?), drought has clearly had a major effect on agricultural output, as shown in Figure 5.4. The figures plotted here do not paint a picture of uniform devastation. Some industries enjoyed good years in the past 10 years, while others expanded production overall. Among the hardest-hit sector has been Australia's well-known sheep industry. By the end of the drought, sheep populations declined by half, to 72.7 million, their lowest levels since 1905. The wool clip had fallen by 40 percent (Wahlquist 2010). Sheep numbers had already been declining steadily since they peaked in 1970 (at 180 million—there were 14 sheep for every person), but drought appears to have contributed to an even steeper decline in the past decade.

Australia's second-most-important livestock industry—cattle for beef and dairy—also suffered during the drought, although its decline was not as precipitous as with

1. Throughout this chapter, costs are reported in Australian dollars. In 2010, it was roughly equivalent to the US dollar.

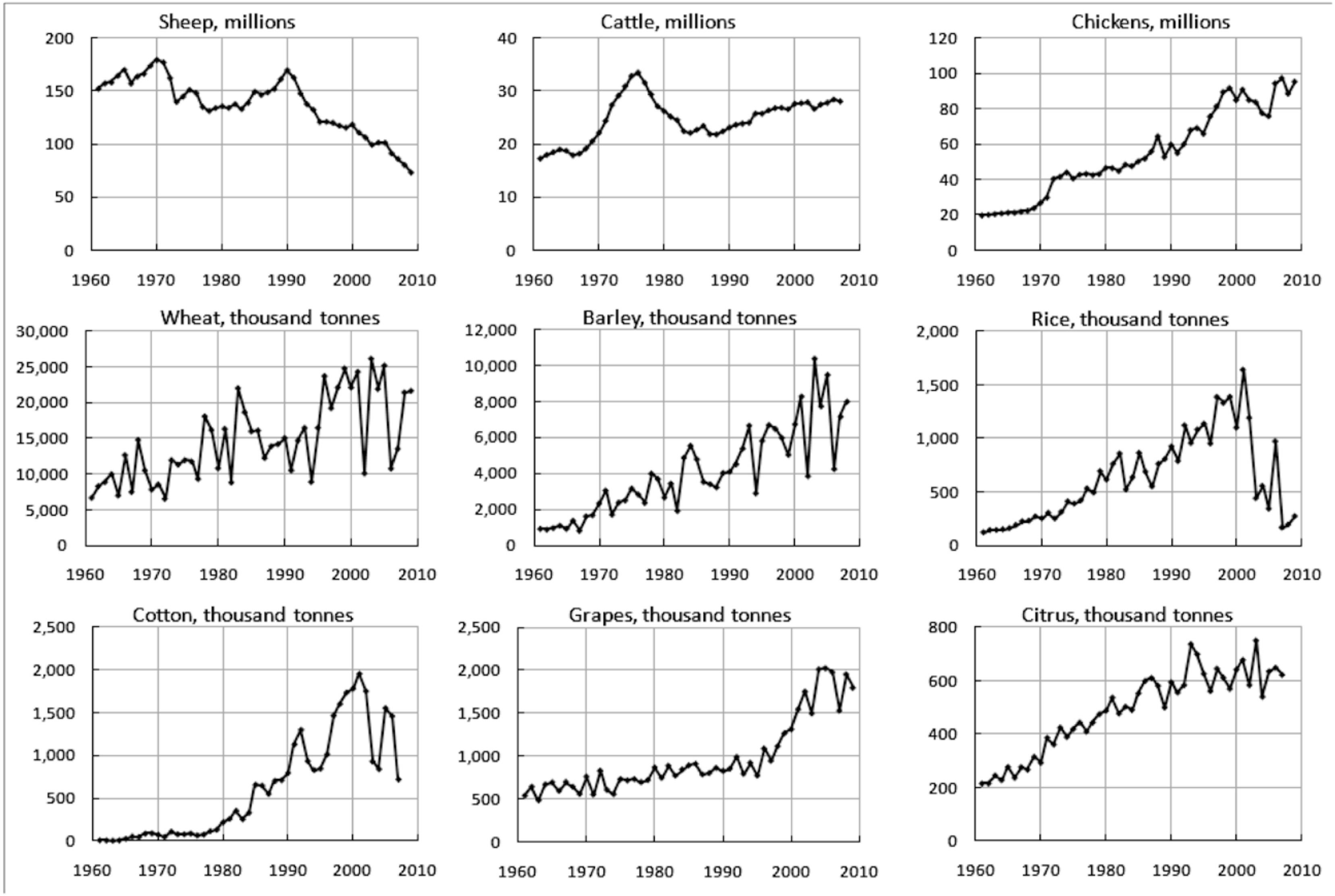

Figure 5.4 Production of Select Commodities in Australia, 1960–2009. The top graphs show the number of animals in millions, while the remaining graphs report annual harvests in thousand tonnes.

Source: Data for 2008–2009 from Australian Bureau of Statistics, publication 7121.0, Agricultural Commodities, Australia, 2008–09, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/7121.02008-09 (download link for Publication tables, .xls). Data for 1961–2007 from the UN Food and Agriculture Organization, via UNdata, http://data.un.org/Explorer.aspx?d=FAO

Datasets > FAO Data > Crops or Livestock (custom queries for various agricultural commodities, filtered to show only Australia).

sheep. The number of dairy cows decreased 25 percent during the drought. Milk production declined less due to higher milk production per cow, and the dairy industry actually increased in value. Australia's cotton production before the drought reached a high of 795,000 tonnes in 2000–2001, valued at $1.8 billion. By 2007–2008, production fell to just 133,000 tonnes, worth $254 million.

Crop production also declined during the drought. The widest fluctuations occurred among annual crops, such as rice and wheat. Rice, which is especially water intensive, saw the most dramatic declines. The start of the decade brought a record crop of 1.6 million tonnes, worth $350 million. In 2007–2008, the rice harvest contracted to the smallest levels on record, at 18,000 tonnes. Upon hearing suggestions that perhaps Australia should not grow a crop that requires flood conditions in an arid country, rice farmers are quick to point out that they achieve among the highest yields in the world, averaging 10 tonnes per hectare in 2006, and grow high-quality strains that fetch premium prices on the international market. And, as an annual crop, rice fields can be fallowed during dry years. Indeed, some rice growers took advantage of newly created water markets to sell their meager water to downstream water users.

Dry years can mean a halving of Australia's wheat production. Because it accounts for 15 percent of the world's total production, this can affect markets and food prices globally (Berry 2008), raising the prospect of food shortages. Meanwhile, Australians have discovered that grocery shopping and restaurant dining have become much more expensive, especially the cost of fruits, vegetables, and meat.

Australia's prominence as a global wine producer is also threatened by drought. In recent years, Australia has become a major wine exporter, with exports valued at $3 billion per year. The country has become the number one supplier of imported wine in England and lags only France and Italy in supplying the United States' import market. All of Australia's grape growers rely on irrigation, and as water has become more expensive, their profit margins have decreased. Wine industry groups have estimated that 1,000 out of Australia's 7,000 wine growers may leave the industry because their vineyards are no longer profitable (Thieberger 2008). Research by CSIRO indicates that climate change is likely to further stress Australia's wine-growing regions, making 44 percent of viticultural areas unsuitable for grape growing by 2050. Others suggest that people's tastes will have to adapt along with a changing climate. In the meantime, drought may end up benefiting Australia's wine industry by driving up prices and quality. Paul Dalby of Australia's Center of Excellence in Water Management says, "The drought has increased grape prices overall because supply has dropped, wiping out a glut of product that had been keeping prices low" (quoted in Beasley 2009).

The drought has accelerated major structural changes already under way in Australian agriculture. The largest and smallest farms fared best during the drought. It is estimated that the top 25 percent of producers remained profitable during the drought, while small farms with under $100,000 in sales are buffered because some of their income comes from off-farm employment. According to the director of the Australian Farm Institute, Mick Keogh, mid-size "mum and dad farms" were the most vulnerable to drought, as they are "too small to get the economies of scale they need, and too big to leave the farm to work." Mid-size farmers received the majority of the $4 billion in government drought relief since 2001 and were the most likely to quit farming altogether (Wahlquist 2010).

During the worst years of the drought from 2001 to 2006, 10,636 families gave up farming (Berry 2008). Many other farm families turned to other sources of income, taking jobs off the farm or searching for other ways to supplement their income. Farm debt has tripled over the past 10 years, to the point where the average farmer owes $400,000 (Byrnes 2007). The drought has also discouraged a generation of young, would-be farmers. Today, only 29 percent of farm families expect their children to take over the farm (Diamond 2005). A potential consequence of farm closures is to further depopulate already sparsely settled areas, making it more difficult for the government to maintain public services (Botterill and Wilhite 2005).

Bushfires and Drought

Fire has always been a feature of the Australian landscape. For thousands of years, Aboriginal Australians have practiced "firestick farming." Land was burned to clear it of tall, dry grass. New green grass that sprouted up in its place supported kangaroos and wallabies, food sources for the native hunter-gatherers (Cathcart 2010, Diamond 1999). Today, there are wildfires every year in Australia, but they are more widespread and severe during drought years. The worst fires in Australia's history have been associated with droughts, such as the Black Friday fire of 1939 and the Ash Wednesday fire of 1983 (Lake 2008). Since 1851, fires have been blamed for more than 800 deaths and damages of $1.6 billion.

Some of the most destructive fires in Australia's history have occurred in the past 10 years. The Black Christmas fire that struck New South Wales in 2001 and 2002 is blamed for the destruction of 121 homes. On the Eyre Peninsula, bushfires in 2005 were responsible for 9 deaths and the loss of 93 homes. In 2009, dry conditions and an intense heat wave contributed to the deadliest fires in Australian history. Beginning on March 7, around 400 fires raged across 450,000 hectares (450 square kilometers) in Victoria, burning more than 4,000 homes and other buildings. Most tragically, what has come to be called the Black Saturday bushfires claimed 173 lives and caused 414 injuries (Romsey Australia 2010). The proximate causes of the fires were either arson or falling power lines, but the 10-year drought contributed to their severity.

A panel of experts convened to prevent future disasters recommended against allowing residents to rebuild destroyed homes or resettle in fire-prone areas. They recommended a "large scale government buy back" of land in "areas of unacceptably high bushfire risk" (Rintoul 2010), mirroring government efforts to buy back water entitlements from irrigators to restore the health of rivers, described later in this chapter in the section on water management in the Murray-Darling.

Dust Storms

In the 1930s and 1940s, there was a widespread fear that severe droughts could cause "desert outbreaks" in Eastern Australia, what today would be called desertification. Generations of experience would reveal the true causes of soil degradation: overgrazing, deforestation, invasive rabbits, and unsuitable agricultural practices. Dry soils with no vegetative cover are liable to be carried off by wind or rain, resulting in soil erosion and dust storms. Melbourne was blanketed in dust in 1902 as thousands of tons of topsoil from hundreds of kilometers inland blew past on its way out to sea. This would be repeated in 1983 and again during the Millennium Drought.

On September 22, 2009, a massive cloud of dust 500 kilometers wide by 1,000 kilometers long spread from the outback into eastern Australia. In Sydney, it darkened skies, canceled flights, and forced people indoors for shelter from the hazardous air (Boston Globe 2009). The Bureau of Meteorology reports that it was the worst dust storm since the 1940s, with air pollution up to 10 times worse than ever recorded (O'Loughlin 2009). Across New South Wales, there were reports of people being hospitalized due to asthma (Riebeek 2009).

Responses to Drought

The Millennium Drought has prompted unprecedented changes in the way Australia manages water and has reinvigorated water reforms already under way by the states and the Commonwealth government. Recent developments in water policy grant more power to the national government and have accelerated the development of water trading and other market-based initiatives. Institutional reforms have been aimed at improving long-term water resiliency and mitigating the economic damage from drought. Meanwhile, urban water suppliers faced with dwindling supplies imposed restrictions and moved forward with projects to increase supplies, such as desalination, water recycling, and stormwater capture, and to reduce demand by improving water-use efficiency and changing water-use practices.

Water reforms have been influenced by the so-called neoliberal political philosophy that favors fiscal conservatism and application of free market economics, causing some to contend that economists have been given disproportionate influence over water policy (Thompson and Price 2009, Lockie and Higgins 2007).Throughout the 1990s, Australian policy makers pursued policies that focused on using economics and free market ideals to improve public services. This followed on a wave of privatization of government services, under the assumption that "when businesses compete, consumers get the best deal" and that enterprises will be run more efficiently and at lower cost. The water reform process has been closely tied to economic reforms designed to remove restrictions on competition. The goal has been to promote "competitive neutrality," the idea that government should not enjoy an advantage over private service providers by virtue of public sector ownership.

Development of National Water Policies

The Australian constitution vests most water management responsibility to the states: "The Commonwealth shall not, by any law or regulation of trade or commerce, abridge the rights of the States or of the residents therein to the reasonable use of waters from conservation or irrigation" (Section 100 of the Australian constitution). Yet there has been a trend toward consolidation of power, exemplified by the "new federalism" under Prime Minister Bob Hawke in the early 1990s. Much of the water reform agenda has been pursued through the Council of Australian Governments (COAG), an organization consisting of the federal government, the six states and two territories, and the Australian Local Government Association, with a stated purpose to "develop and monitor the implementation of policy reforms that are of national significance and which require cooperative action by Australian governments" (COAG 2009).

Until the 1990s, state and federal government responded to drought with emergency relief efforts and funding, in much the same way they did for other disasters, such as cyclones, earthquakes, or floods. With the realization that drought was an inevitable and recurring threat, governments at all levels agreed to a National Drought Policy in 1992, based on principles of self-reliance and risk management.

In 1994, the COAG agreed to the Water Reform Framework, a key goal of which was to establish a market-based water management system by 2005. Elements of the Framework included allowing prices to reflect the full cost of resources, ending most subsidies, and making remaining subsidies more transparent. Conflicts of interest were to be removed by taking regulatory functions away from agencies also involved with supplying water. Lastly, trading and selling of water rights was to be introduced nationally. Difficulties were encountered in implementing the ambitious reform package, in part due to lack of cooperation between states, each having separate jurisdiction over portions of watersheds and competing for the same resource (Thompson and Price 2009).

Disappointed by slow progress, governments made a new attempt to accelerate reforms with the National Water Initiative (NWI) in 2004. Under the Initiative, signed by all the states and territories between 2004 and 2006, states agreed to conduct water reforms and move toward "integrated management of water for environmental and public benefit." The agreement built on the 1994 Water Framework, and its purpose was to develop a more cohesive approach to the way that Australia manages, measures, plans for, prices, and trades water. In December 2004, the Australian government created an independent body, the National Water Commission (NWC), to oversee implementation of the NWI.

As a part of the NWI, the government also created a $2 billion Water Fund to invest in water-efficiency upgrades (discussed later in this chapter). The largest of these programs, Water Smart Australia, was a competitive grant program funded at $1.6 billion. Two smaller programs included Raising National Water Standards ($200 million) and Community Water Grants ($200 million). The NWC was given responsibility for administering the latter programs, whereas Water Smart Australia has since been transferred to the Department of the Environment, Water, Heritage and the Arts (Cull et al. 2010).

In January 2007, faced with growing water shortages and seeing a need for swift action, Prime Minister John Howard announced the National Water Plan, extending the powers of the federal government over water management and committing $10 billion to various water projects. The plan was called "hurriedly prepared and ambitious," launched during the administration's last year in a bid to be seen as taking action on water, which had proven vexing to many politicians (Connell and Grafton 2008, Watson 2007). However, the plan was enthusiastically taken up by the newly elected Labor Party administration of Kevin Rudd in 2008. Under the 2007 Water Act and amendments passed by the Parliament in 2008, Australia established a new authority to manage the waters of the distressed Murray-Darling Basin and restore water to the environment. Further, the act committed the federal government to spending $12.9 billion, with the majority of funds for infrastructure improvements and irrigation efficiency projects, and to "buy back" water from irrigators and dedicate it to the environment.

Agricultural Water Management

It has been said that Australia rose to prominence on the backs of sheep. In the 19th century and first half of the 20th century, agriculture formed the basis of the economy and wool was the number one export. In recent years, agriculture has contributed to only 3 percent of the nation's economy (Hamblin 2009). Yet agriculture takes up 54 percent of Australia's land and 65 percent of its human water use (Australian Bureau of Statistics 2010b). In his bestseller *Collapse* (2005), Jared Diamond states that "only tiny areas of Australian land currently being used for agriculture are productive and suitable for sustained agricultural operations." Behind his contention is the fact that 80 percent of agricultural profits come from only 0.8 percent of the country's agricultural lands and that up to half of farms are unprofitable (DSEWPC 2002).

In effect, government subsidies, including low-cost water, prop up an industry that would not otherwise be profitable. Diamond enumerates the environmental advantages of phasing out unprofitable agriculture but acknowledges it would be a "first" in the modern world if any government decided to do so. The debate on agricultural water use and the extent to which government should "bail out" farmers struggling due to drought illustrates the dilemmas of this policy decision. On the one hand are the neo-liberal political ideals and policies idealizing the free market and competition. On the other is Australians' deep nostalgia for their agrarian roots and sympathy for hard-working farm families.

According to the Australian Bureau of Meteorology: "The 1990s saw formal Government acknowledgement that drought is part of the natural variability of the Australian climate, with drought relief for farmers and agricultural communities being restricted to times of so-called 'exceptional circumstances.' In other words, the agricultural sector was expected to cope with the occasional drought, and relief would be available only for droughts of unusual length or severity" (Australian Bureau of Meteorology 1999). Changing attitudes have led to the gradual reversal of long-standing policies intended to increase irrigation water use and foster settlement in rural Australia. "In 1992, the Commonwealth government insisted that farming be considered a business—a central element of which has to be the ongoing management of risk—and subsequently removed farm welfare provisions from agricultural adjustment programmes" (Mercer et al. 2007).

This new policy was bound to be unpopular with farmers. A female grazier in Central Queensland told interviewers: "I think [the government's position] is absolutely stupid. It is a disaster. We haven't created it. It is the same as the cyclone or earthquake. It is the elements [that are] beyond us." Another stated: "Everybody else gets assistance if there is a flood or a fire. Why shouldn't the farmers get assistance? We are feeding the nation" (quoted in Stehlik 2005). It has been difficult for the government to maintain a disciplined stance in the face of obvious suffering. Between August 2001 to September 2010, the Australian government spent more than $4.5 billion on "exceptional circumstances" payments to support farmers and small businesses affected by the drought (Lloyd 2010). In 2007, the government doubled to $150,000 the amount it would pay to a farmer to simply leave his or her land (Hamashige 2007).

Public pressure and Australian attitudes contribute to this difficulty. Despite the fact that most Australians live in cities and suburbs, images of the outback and the hard-working farm families are an important part of the Australians' self-image. Linda Botterrill, director of the National Institute for Rural and Regional Australia, cites as an example cultural representations of the "real Australia" in the opening ceremonies of the Sydney 2000 Olympics, and the popularity of television programs with rural settings, such as *McLeod's Daughters*, *Flying Doctors,* and *Blue Heelers* (Botterill 2003). As desert specialist Mark Stafford Smith puts it, the "almost mythological place that the outback has in the heart of urban Australia enables a small rural electorate to have a disproportionate influence on the political process through the emotional ties of the urban populace" (Botterill and Wilhite 2005).

The Australian government is investing heavily in infrastructure to improve agricultural water efficiency, committing the largest portion of the $12.9 billion in the 2007 Water Act to infrastructure improvements and grants to support on-farm irrigation efficiency. Not everyone agrees with the wisdom of investing in irrigation infrastructure. A number of environmentalists and economists argue that much of Australia's irrigated agriculture harms the environment and is losing money, and that the country needs *less* irrigated land. Savings from agricultural efficiency improvements are difficult to quantify, and equivalent savings could frequently be obtained more cheaply by simply purchasing water entitlements and retiring marginal lands (Collins 2008).

At the farm-field scale, many more farmers are now using water-saving management practices, such as no-till planting and improved irrigation methods. Zero-till has been described as a revolution in wheat farming in Australia in the past decade. Using zero-till methods, farmers plant directly into undisturbed soil, leaving stubble from the previous crop in place. This method conserves soil moisture and organic matter, allowing farmers to achieve small but economic harvests with as little as 100 millimeters (4 inches) of rain (O'Neill 2010). Mick Keogh, executive director of the Australian Farm Institute, says that cropping technologies such as minimum tillage have had a huge impact: "In terms of labour and time, the technology is light years from where it was 20 or 30 years ago and with that comes flexibility" (quoted in Wahlquist 2010).

Drought forecasting is another strategy to help farmers improve water management and farm income. The variability of Australia's climate from one year to the next poses challenges to farmers in deciding what crops to plant and when to plant them. For those whose livelihoods depend on rainfall, it is troubling to find that "seasons are poorly defined" and are not "fixed in either amplitude or timing" (Botterill and Wilhite 2005). At the federal level, Land and Water Australia has conducted research to create monthly, seasonal, annual, and longer-term forecasts to help farmers make better decisions about planting and managing water (Land and Water Australia 2009). Colin Creighton, the Managing Climate Variability coordinator at Land and Water Australia, says, "Our research success will mean the agricultural sector can make better decisions on dryland production mixes and practices by linking their on-farm decisions to risk analysis and predictions for key attributes such as plant-available water, frost frequency, heat events, and forage availability."

The Australian government is also sponsoring research to develop drought-resistant varieties of important crop species. These efforts are not new: Australia's wheat industry burgeoned after introduction of early-maturing and disease-resistant Federation wheat in 1901. Today, CSIRO's Plant Industry division has an annual budget of $84.4 million and 700 staff at nine facilities around the country. Recent research there has focused on developing the world's first drought-tolerant strain of wheat, Australia's most important export crop. Progress has been slowed by the size and complexity of wheat's genome—there is no single gene that controls for drought tolerance (O'Neill 2010).

Government and corporate researchers, working in a public-private partnership dubbed "Graingene," have so far released two varieties, Drysdale and Rees. These are sold by the agribusiness company AWB and are protected by Australian intellectual property law, making it illegal for "any unauthorized commercial propagation or any sale, conditioning, export, import or stocking of propagating material" (CSIRO Plant Industry 2010). Another potential obstacle faced by plant breeders is that the Australian public is generally untrusting of genetically modified (GM) food, and several states have placed moratoriums on growing GM food crops. GM cotton, however, introduced in Australia in 1996, made up 95 percent of the cotton crop in 2010 (GMO Compass 2010).

Companies have also developed products that reduce evaporation from water surfaces such as farm ponds. Products in use in Australia include specially made shade cloths that float on top of water; a variety of floating, modular devices that are effective (and expensive); and monolayers, which are chemical films that float atop water. These chemicals need to be reapplied frequently and are less effective when wind disturbs the water surface (Short 2007). Some members of the public have also expressed concern about the safety of introducing these new, patented chemicals into the environment and food supply. Agricultural extension services recommend other practices that are more natural, such as planting trees as windbreaks or adding compartments to farm ponds to reduce the surface area when it is less than full.

The government has also invested to improve the measurement of water deliveries to irrigators. In many locales, measurement was impossible due to lack of measurement devices and staff. According to writer Michael Cathcart: "During the 1990s, I met irrigators who confessed to jamming their meters or to secretly pumping directly from the river in the dead of night" (Cathcart 2010). A portion of the government's spending under the National Water Plan has been to improve water metering. In 2008, $417 million was dedicated to begin building the Australian Water Resources Information System, which will employ 120 hydrologists and information technology professionals (Woodhead 2008). Accurate water metering is also a prerequisite to creating working water markets.

A great deal of international attention has focused on water trading in Australia. The creation of water markets has been the government's most important strategy for dealing with drought and restoring the environment in the Murray-Darling River Basin, as described in the following section.

Water Management in the Murray-Darling

The Murray River Basin in southeast Australia covers one million square kilometers (14 percent of Australia's area), a size equivalent to France and Spain combined. It is home to 39 percent of the nation's agricultural production and 85 percent of the irrigated area. The watershed also contains 30,000 wetland areas, 16 of which are recognized under the Ramsar Convention (an international treaty signed in Iran in 1971 governing the protection of wetlands of international importance, especially as waterfowl habitat). Due to overextraction and drought, the Murray River failed to flow to the sea in 2002. For decades prior, the poor health of the river and the growing environmental movement led to calls to restore the river through better water management.

In response to evidence that the river system was overallocated, governments and irrigators agreed in 1992 to cap diversions, preventing more water from being taken out of the rivers. The "Murray-Darling Cap" was meant to allow greater environmental flows (which farmers dismissively called "duck water"), but it became clear that restoring the health of the river would require much bigger cuts (Cathcart 2010). In 2002, a group of prominent environmentalists released a series of statements including the *Blueprint for* *a National Water Policy*, calling for a halving of withdrawals from the river (Cosier et al. 2003).

In 2006, flows on the Murray fell to unprecedented lows, prompting the administration of Prime Minister John Howard to come up with a plan. He tasked the Basin Authority with setting "sustainable diversion limits," the level of consumptive water use in the river system in line with restoring the health of ecosystems. The result, a draft plan released in October 2010, calls for cuts of 22 to 29 percent in water use in the basin by cities and farms. Water expert Sandra Postel called it "perhaps the boldest water reform of this type ever proposed" and one that "few in the world have had the courage to undertake: asking farmers and communities to adapt to a future with less water in order to restore failing rivers, lakes, and wetlands" (Postel 2010).

The Commonwealth government has committed $12.6 billion over the next 10 years to ease the transition. About half of the funds ($5.8 billion) are targeted toward water-efficiency projects, for example, improving on-farm efficiency by installing drip irrigation. This approach has been criticized on several grounds. On the one hand, such subsidies are at odds with the stated goals of the National Water Initiative of full-cost pricing of resources and eliminating subsidies, leading some to call water policies "schizophrenic" (Crase 2009). Others point out the unfairness to irrigators who have already invested in on-farm efficiency improvements and will not benefit from government payments, while those who lagged behind receive assistance.

Reaction to the Basin Plan among farming communities has been overwhelmingly negative, as farmers already stressed by years of drought are worried about future cuts. The plan reflects the growing political power and influence of the environmental movement in the face of what Australian economist Lin Crase has described as "the long-standing vested interest from irrigated farming to maintain the status quo," and ability to "cushion its constituents from the impacts of any reallocation of the resource" (Crase 2009).

Water Markets

Market mechanisms have been explored as a way to reallocate water use in the Murray-Darling Basin, beginning in the 1980s when water trading was introduced in the state of South Australia. Among the obstacles to more widespread trading was that entitlements (the quantity of water a farmer has a right to use) were not always well established or well documented. A second barrier was the inability to measure water deliveries and extractions in rural districts. Further, the Murray-Darling Basin is divided among four states, each with separate jurisdiction over water allocation, and often competing for use of the same resource.

Reforms in the mid-1990s and again in the mid-2000s dealt with some of these issues, clarifying and documenting entitlements and permitting interstate water trading. A key provision of the 2007 Water Act was to give the Australian Competition and Consumer Commission expanded powers to develop and enforce water charges and water-market rules. The government moved to expand water markets "based on the premise that trading provides economic benefits to buyers and sellers, and to society as a whole, by reallocating scarce water resources to higher valued uses" (NWC 2010).

As the thinking went, the "discipline of the market" would drive up the cost of water, forcing irrigators to use it efficiently and reduce waste. A farmer with a tradition of using water is granted a water-access entitlement that he can lease or "transfer" for six months to another water user. Policy makers and economists talk of "willing buyers" and "willing sellers": a farmer is motivated to trade when he believes he can make more money by selling his water entitlement rather than using it himself. Trades are usually handled through brokers, such as Adelaide-based Waterfind. Entitlements can also be sold outright, in which case the irrigation block is stripped of its water. The "unbundling" of water from the land has been a key reform at the state level—previously licenses allowed for only certain uses (e.g., irrigating a particular parcel of land). The result of reforms has been to make trading faster and easier; irrigators can now buy and sell water over the phone or even via text messaging.

Although economists admit that freer trade will not benefit everyone, they argue that "gains will outweigh losses on average and that, if necessary, losers can be compensated" (Quiggin 2006). But water markets by themselves do not necessarily benefit the environment. In order to restore water to ecosystems, the Australian government in 2008 committed $3 billion to buy back water from the overallocated Murray-Darling. It created the Commonwealth Environmental Water Holder to purchase and retire existing water rights and dedicate water to instream flow or to refill lakes and wetlands (Postel 2010). As of 2009, the government had already purchased 766 billion liters worth of entitlements. The Basin Authority estimates that water buybacks and efficiency improvements can save up to 2 trillion liters per year, or up to two-thirds of the reductions needed to meet restoration goals. Buybacks have become the main element in the government's efforts to restore aquatic ecosystems. Australia's decision to use buybacks as a strategy partly reflects the limited power granted to the federal government by the Australian constitution; with regard to water, the government's powers are generally limited to taxation and spending. However, when compared to alternatives such as desalination or funding water-efficiency upgrades, analysts have called buybacks "the cheapest and most feasible mechanism for dealing with over-allocation problems" (Crase 2007).

To date, water trading has received broad support from politicians, environmentalists, and the agricultural community in Australia, but it is not without detractors. General concerns raised by human rights campaigners condemn markets as a corporate takeover of water. Taxpayers wonder whether the only way to guarantee river flows is to spend billions in taxpayer dollars. If water is a public good, why should the public have to pay to keep rivers flowing? Another concern is that water trading could activate unused water rights (called "sleepers"), worsening the problems that markets were to help resolve (Quiggin 2006).

Many have also expressed concern about the effects of water trading on rural communities, frequently focused on the concept of "stranded assets" (NWC 2010). Within an irrigation district, each subscriber's payments help fund operations and infrastructure maintenance. When individuals sell entitlements, there are fewer subscribers in the district, placing a greater financial burden on the remaining irrigators. Government regulators have attempted to mitigate such "third-party effects" of trading by setting caps on the amount of water that can be sold outside of an irrigation district. For example, Victoria and New South Wales set a 4 percent annual limit on the volume of water entitlements that could be traded out of a district. Such limits to trading proved unpopular with irrigators, and were removed at the beginning of the 2009–2010 season. Regulators have also contemplated adding "termination fees" to compensate irrigation districts for lost revenue and help manage the stranded assets problem.

University of Queensland economist John Quiggin writes that "the idea of stranded assets may be extended further, to encompass social infrastructure such as schools, hospitals and banking services." Some economists have dismissed this argument, arguing that "sunk costs" should be disregarded in investment decisions. Regardless of this logic, it is small consolation to a farmer who has recently invested in laser leveling and drip irrigation. Quiggin argues that transitioning to a sustainable rural economy will involve adjustment costs, and "the appropriate response is to mitigate those costs rather than to prohibit trade altogether" (Quiggin 2006). Throughout the reform process, there has been pressure on government to mitigate the negative effects on rural communities. For decades, official policies encouraged irrigated agriculture that is now seen as unsustainable, and some argue that it is only fair to compensate those dealing with the results of these policies. "The persuasiveness of the stranded assets argument and the accompanying hysteria about water leaving agricultural districts undoubtedly explains the return to favor of engineering solutions in policy circles. After all, renovating irrigation districts and subsidizing on-farm capital investments is hardly likely to draw criticism from the agricultural sector" (Crase 2009).

Critics have also raised concern about manipulation of water markets and hoarding by "water barons." A recent series of articles have focused concern on the involvement of large international investors getting involved in the Murray-Darling's water markets. Regulations were written so that markets are not limited to bilateral trades among bona fide water users. In other words, third parties—even those who have no intention or ability to use Murray water—can participate in the market. This increases a market's "liquidity" and efficiency, increasing the chance that one can make a transaction quickly, rather than waiting for a willing buyer or seller to appear. However, it also sets the stage for speculation, market manipulation, and instability. Andrew Gregson of the New South Wales Irrigators Council told the *Sydney Morning Herald*, "We don't have a problem with investment, or indeed, speculation in the water market. We are concerned about market dominance. It's a recently developed, relatively fragile market" (Circle of Blue 2010).

In a review of the Murray-Darling water trading scheme, the NWC concludes that water trading has played a role in reducing financial hardships to farmers during the drought: "Although water trading out of a region may in some cases accelerate existing social and economic changes, without the financial cushioning effects of water trading the impacts of the drought would undoubtedly have been worse" (NWC 2010). The government audit found that trading resulted in the movement of water within regions, as well as transfers between states and regions, with the volume of trading increasing in 2008–2009 to the point that nearly one in four water deliveries consisted of traded water.

Since trading was initiated in 2001, it has contributed $370 million in the Southern Murray-Darling Basin. From 2001 to 2006, the value of agricultural production in the region increased by 2 percent despite a 14 percent reduction in water use. This appears to be driven by a decrease in area cultivated in rice, and by slight increases in higher-value crops such as vines and citrus. Not all regions benefited, however; the rice-growing region along the Murrumbidgee River saw decreases in water use and declines in agricultural output. On a national scale, the benefits of trading appear to have exceeded the costs, with analysts concluding that water trading contributed an additional $220 million to Australia's gross domestic product. The NWC has concluded that water trading can play an increasingly important role in mitigating the future impacts of drought, climate change, price fluctuations of agricultural commodities, and diversion limits imposed by regulators. In fact, the Commission is so confident in the benefits of trading that it has recommended expanding the system of water markets to the nation as a whole, and for the government to move forward quickly with further reforms to make water trading faster, easier, and more efficient.

Urban Water Management

Drought-induced water shortages have renewed focus on the water needs of Australia's growing cities. The Australian government has been working with states and territories to reform urban water management, with the goals of enhancing water-supply security, adapting to changes brought on by climate change, and decreasing overall water use. A number of these programs are being developed through the Council of Australian Governments—a coalition of federal, state, and local governments.

To date, most urban water suppliers have been reluctant to purchase water from irrigators to augment their supply. For example, Sydney has pursued expensive desalination, recycling, and a dam-raising project ahead of purchasing cheaper water from irrigators served by the Tantangara Dam (Collins 2008). While transfers from agriculture are feasible for many of Australia's cities, and are in many cases cheaper and more environmentally friendly than the alternatives, a range of government policies discourage such transfers (Quiggin 2006). Other reasons put forth are Australians' sympathy for farmers, and the reluctance of politicians to disrupt the status quo in the absence of a strong demand from the electorate. Ultimately, however, water suppliers have only two options for dealing with shortages: to increase supply or to decrease demand. The ways in which Australia's urban water suppliers have moved forward with both of these strategies are described in the sections that follow.

Recycling and Desalination

The use of reclaimed water, or recycled water, has become more common in the past decade. Water recycling refers to reusing treated wastewater. Depending on the level of treatment, water may be suited for nonpotable use, in irrigation or for flushing toilets. In other cases, highly treated water is suitable directly for drinking (called direct potable reuse). An example of the latter is the $90 million water recycling facility under construction in Geelong, Victoria, toward which the Australian government is contributing $20 million. The facility expected to produce 2,000 million liters a year of potable water, enough to supply about 10,000 homes, or about 5 percent of the city's annual water use. At the plant, sewage undergoes conventional wastewater treatment, followed by ultrafiltration, and passes through two rounds of reverse osmosis membranes. In pilot tests, the water removed all pathogens and viruses and passed all government regulations for Class A drinking water (Barwon Water 2010). Despite reassurances that the recycled water is fit for drinking, recycled water in Victoria will be distributed via "purple pipe" for watering gardens, washing cars, and flushing toilets. The public has been slow to accept direct potable reuse, causing suppliers to discharge recycled water to surface reservoirs or aquifers or to create "dual reticulation" systems like the one in Victoria.

Drought has encouraged more cities to consider desalination as a new source of water supply. In 2006, the city of Perth opened the Kwinana Desalination Plant, the first seawater desalination plant for urban water supply in Australia. A second plant is already under construction in Perth. A number of other plants are either being planned or already under construction in Sydney, Melbourne, Adelaide, and on the Gold Coast. Together, the country's five largest cities are spending $13.2 billion and installing sufficient capacity to meet 30 percent of their current water needs (Onishi 2010). As of 2009, there were a total of 46 desalination plants in Australia with a capacity of at least 10,000 liters per day, and by the year 2013, the total capacity is expected to double (Hoang et al. 2009).The government has also dedicated $20 million over five years to create a desalination research center in Perth and a center for research on water recycling in Brisbane (DSEWPC 2010).

While the official government policy is that 100 percent of water infrastructure and delivery costs should be passed on to customers through water rates, the Australian government has provided millions in incentives and subsidies for the construction of desalination and water recycling plants. Desalination is among the costliest of water-supply options, and critics contend that investments in water conservation and efficiency are far less expensive. To finance construction, suppliers have been forced to raise water rates, passing on the expense to customers. Others oppose desalination for its environmental impact. Up to half the cost of operating desalination plants is for the purchase of electricity. And because most of Australia's electricity is produced from coal, desalination contributes to the emission of greenhouse gases.

Restrictions

Australian cities' demand management efforts have been largely successful; between 2002 and 2008, per-capita urban water use declined by 37 percent (Kendall 2010).The predominant approach that cities have used to limit water demand has been to impose water restrictions. Restrictions can be either permanent or temporary, and they may subject certain uses to an outright ban or put in place rules to promote efficiency. An example of one such rule is requiring hoses to have a nozzle with a shutoff trigger. Another category of rules discourages watering by making it more inconvenient and time-consuming, for example, by banning sprinklers but allowing buckets for hand watering. Table 5.1 shows the drought stages in the Australian Capital Territory (ACT), home to Canberra, which is Australia's capital and eighth-largest city (ACTEW Corporation Limited 2010). Stages are tied to reservoir levels and water-supply outlooks; managers announce progressively greater restrictions as supplies dwindle.

Temporary restrictions are the most common urban drought management policy, and they have been implemented by nearly all municipalities across Australia over the past decade. Although the restrictions vary widely, authorities typically first target outdoor water uses that are most visible and consumptive, such as lawns, gardens, swimming pools and spas, car washing, and washing hard surfaces. Permanent restrictions have often grown out of temporary ones, as some districts decide to keep certain rules in place even after the drought has ended. To date, permanent restrictions have been put in place in cities in Victoria, South Australia, and the ACT. The most typical permanent restriction is on daytime sprinkler use, which utilities estimate have resulted in savings of 4 to 9 percent (Chong et al. 2009).

Restrictions on outdoor water use have made it harder to keep recreational areas green and attractive. This has been blamed for a number of social ills, including "loss of

Table 5.1 Water Restrictions in the Australian Capital Territory

	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**
Target annual reduction	10%	25%	35%	55%
Sprinklers and irrigation	Alternate days, 7–10 a.m. and 7–10 p.m.	Drippers only, 7–10 a.m. and 7–10 p.m.	No reticulation	
Hand-watering gardens and lawns	No restrictions	Alternate days, 7–10 a.m. and 7–10 p.m.	No watering lawns; watering plants alternate days, 7–10 a.m. and 7–10 p.m.	Graywater only
Swimming pools	No emptying or filling; topping up allowed		No topping up, emptying, or filling	
Car washing	Once a week, or at commercial car wash	Once a month, or at commercial car wash	Only at commercial car washes	No car washing
Window cleaning	Only with bucket or high-pressure, low-volume cleaner	No window cleaning		

The term *reticulation* refers to the use of piped irrigation systems, including sprinklers and drip irrigation systems (drippers).

Source: ACTEW Corporation Limited 2010, Wikipedia 2010.

participation in sports and associated impact on community health, community pride and spirit; rise in antisocial behaviour, and a loss of employment" (Chong et al. 2009). Australia's professional sports leagues have been latecomers to water conservation. After three years of deliberation, the Australian Football League and Cricket Australia have agreed to standards for synthetic turf, and they began constructing the first synthetic turf oval in Wyndham City, Victoria, in February 2011 (Edwards 2011).

The Australian public has been generally supportive of water restrictions. A 2008 survey of community attitudes toward water restrictions found that most Australians understood the need for restriction but noted that attitudes may change as restrictions become more severe or long-lasting, such as total outdoor watering bans that last an entire summer. Indeed, an engineering study conducted for the ACT government quoted complaints from elderly customers who had difficulty "hand watering during early morning or late evening times, particularly during winter" (Hughes et al. 2008).

In practice, some restrictions are difficult or impossible to enforce, and they rely on the cooperation and goodwill of the public for their success. One Melbourne resident explained people's cooperation as a sense that "we're all in this together." Others have suggested that this kind of social cohesion and cooperation is part of the Australian character. "Mateship" is a traditional term for friendship but also connotes a code of conduct stressing equality. The public's overall acceptance clashes sharply with the rhetoric of some politicians, who describe restrictions by water suppliers as "draconian impositions on individual freedoms":

> The simple fact is that there is little or no reason why our large cities should be gripped permanently by water crises. . . . Having a city on permanent water restrictions makes about as much sense as having a city on permanent power restrictions. (Prime Minister John Howard, July 17, 2006)

> I think Melbournians have had a great amount of goodwill in saving water but I think, with the Government threatening to introduce some very draconian measures that the Government is at risk of eroding community goodwill. (Louise Asher, member of the Victorian Legislative Assembly, Shadow Minister for Water) (each quoted in Chong et al. 2009)

So far, in spite of Australians' dislike for "pollies" (politicians), they have for the most part gone along with restrictions ungrudgingly. Perhaps cooperation is related to awareness of environmental issues; 98 percent of Australians participate in recycling programs, a far greater proportion than in either Europe or the United States. Melbourne authorities have sought to prevent water restrictions from becoming "an avenue for expression of neighbourhood disputes" by designing an enforcement program to minimize risks (Chong et al. 2009). For example, meter readers wear "water patrol" vests; even though they do not have authority to issue fines, their presence creates community confidence and provides a visual reminder of restrictions. When a neighbor calls to report a violation (a so-called "dob in" call), the city first sends an educational letter to the alleged violator. Only a second call results in a site visit. Melbourne authorities have recently stopped accepting such calls altogether, requiring complainants to fill out a witness form and provide written details of the violation.

Some states have deputized "water inspectors" to issue penalties to water wasters. On-the-spot fines range from $100 to $500 but are generally not issued until the second or third offense. Perhaps surprisingly, a government review of the program found little opposition to fines among community representatives (Chong et al. 2009). There is also anecdotal evidence of community policing, which unfortunately has led to a few instances of confrontations, violence, and even one death (Australian Broadcasting Corporation 2007).

Communicating information to customers on restrictions is obviously of prime importance. Utilities have communicated with customers mainly through mailings or inserts in water bills on restrictions, via the utilities' websites, and using public advertising. Messages encouraging compliance with restrictions are generally included in a broader campaign to promote water conservation and efficiency. Hence, messages about restrictions are accompanied by information on rebates for water-efficient appliances and devices, showerhead exchanges, and more general educational information (Chong et al. 2009).

Some analysts have urged greater use of economics, emphasizing the use of price incentives for conservation, rather than prescribing when and how people use water. One economist noted that "water restrictions are a relatively limited and inefficient method of rationing demand, imposing inconvenience costs and allocative efficiency costs and also involving significant enforcement costs" (Hughes et al. 2008). Water pricing, some argue, is a better economic tool, and that approach has also been tested in Australia.

Water Pricing

Among other reforms passed during the Millennium Drought, the National Water Commission has created a set of nationwide principles for pricing urban water. The national guidelines require utilities to put water rates for all types of customers on a rational footing, removing pressure on politicians to underprice water to win favor with voters. Reformers have stressed that consistent pricing policies would lead to efficient water use and help create more-efficient and viable markets for water trading between jurisdictions (NWC 2010). Under the NWI, the national government has directed state and local administrations to use best practices in water pricing. Broadly, rates should be set to recover costs (including mitigation of environmental harm) while precluding excessive profits by monopoly service providers.

The new policy, finalized in February 2010, stipulates that all municipalities should move to full-cost pricing of water, or "upper bound pricing," in which all aspects of water service delivery and infrastructure are covered by ratepayers, rather than through subsidies or transfers from other government revenues. Policy makers have acknowledged that, especially in rural areas, "some small community services will never be economically viable but need to be maintained to meet social and public health obligations" and will require continued subsidies, but these are to be publicly disclosed and transparent (DEWHA 2010).

The new pricing policies are intended to promote efficient, sustainable use of water and continued investment in infrastructure. The policy requires consumption-based pricing (the more you use, the more you pay) but stops short of requiring tiered rates. Many Australian cities charge two-part tariffs, where users pay a connection fee as well as volumetric water charge, but tiered rates are much less common in Australia than in other industrialized countries. Under tiered rate structures, customers pay increasingly high rates when their consumption increases to higher levels. Such rates are intended to make water service affordable to everyone while charging a premium to big consumers and discouraging waste.

The concept of "staged" scarcity pricing has also been promoted by the NWC and backed by a study from the Australian Bureau of Agricultural and Resource Economics (Hughes et al. 2008). Water rates are currently set by regulators to match estimates of the costs of running the water system. Suppliers lack the ability to quickly change prices to send economic signals for conservation when supplies are low. With scarcity pricing, water prices would go up when supplies are low, for example, by tying rates to reservoir levels. Government economists argue that scarcity pricing is more flexible and less costly than imposing restrictions, but they acknowledge that it raises equity concerns and that attention should be paid to how such schemes may affect the poor. Potential ways to address these concerns are through subsidies to low-income families, or rate designs in which the lowest tier of consumption is made very inexpensive or even free—a practice that has been implemented in other countries.

Labeling and Education

In 2006, Australia introduced the Water Efficiency Labelling and Standards (WELS) Scheme to promote water-efficient appliances and fixtures. Backers emphasize the program's financial savings and greenhouse gas reductions as well. The program's website declares: "By 2021, Australians could save more than one billion dollars through reduced water and energy bills by simply choosing more efficient products." As of July

2006, all products in the following categories must carry a WELS rating label (like the one in Figure 5.5): faucets (with some exceptions), showers, toilets, urinals and flow controllers, clothes washers, and dishwashers.

Key components of the program include a labeling scheme, product testing, and enforcement. Besides helping to reduce domestic water consumption, it also allows manufacturers to showcase their most water-efficient products. Australia has become the world leader in the labeling of water-efficient appliances. Similar systems have been adopted in the United Kingdom, New Zealand, Singapore, and Hong Kong. The program has influenced the United States' WaterSense program and has prompted discussion about creating a similar scheme for the European Union (Benito et al. 2009).

Rebates are not offered through the WELS program, but many local councils and water authorities give rebates for WELS-registered products with specific star ratings. The Australian Department of Climate Change and Energy Efficiency maintains the Living Greener website (www.livinggreener.gov.au), where residents can search for rebates and other assistance available in their area.

In addition to rebates, some utilities offer direct installations, usually of toilets, the biggest indoor water use. For example, Sydney Water offers a Toilet Replacement Service that takes up to $370 off the cost of installing a modern, efficient toilet. The program is designed to make it easy for low-income residents and renters to participate in the program. Participants choose from among three different four star–rated, water-efficient, dual-flush toilets, each of which is installed with a 10-year warranty. Residents can choose to make a single payment or have the cost spread out over several water bills.

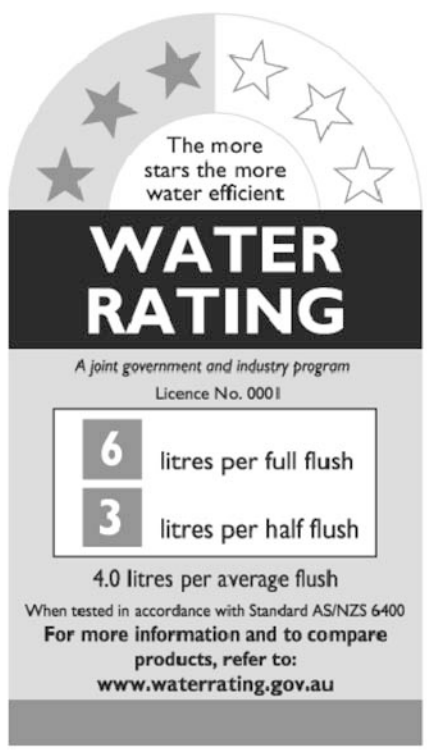

Figure 5.5 WELS (Water Efficiency Labelling and Standards) Rating Label.
Source: Courtesy of Caroma, http://www.caroma.com.au

Conservation Incentives

Many Australians have taken advantage of government incentives to purchase water-efficient appliances and fixtures in the past 10 years. According to a report by the Australian Bureau of Statistics, 251,000 households received a rebate or incentive in 2009–2010 for washing machines and dishwashers. These were followed closely in popularity by water-efficient taps and showerheads (225,000). The market for dual-flush toilets was not as robust (32,800), probably because they have already been installed in 86 percent of households. Over the past decade, the market penetration of water-efficient products has increased substantially (Australian Bureau of Statistics 2010a), as shown in Figure 5.6.

With drought-imposed water restrictions, interest in rainwater and graywater use has grown. *Graywater* refers to household water that has been used in sinks, showers, and the laundry (toilet water is referred to as *blackwater*). As of the late 1990s, graywater reuse was illegal in every state in Australia, although it was already widely used in many households (Marshall 1997). Today, graywater use has become more common and ranges from fully plumbed systems to simply placing a bucket in the shower to catch runoff for watering flowers.

As recently as the early 1990s, rainwater tanks were a common sight in Australia, where as many as 16 percent of homes had tanks and 13 percent relied on them even for drinking water. However, they had mostly disappeared by the 2000s. The drought and water restrictions renewed interest in rainwater tanks, and utilities and state governments began encouraging residents to install rainwater tanks, often with the offer of a financial rebate or incentive.

The National Rainwater and Graywater Initiative promotes these technologies and provides financial incentives to residents. Rebates can range from $150 to $1,500 for the installation of a rainwater tank, depending on the size of the tank and whether it is connected to the house's plumbing. Because the cost for an average tank is around $4,000,

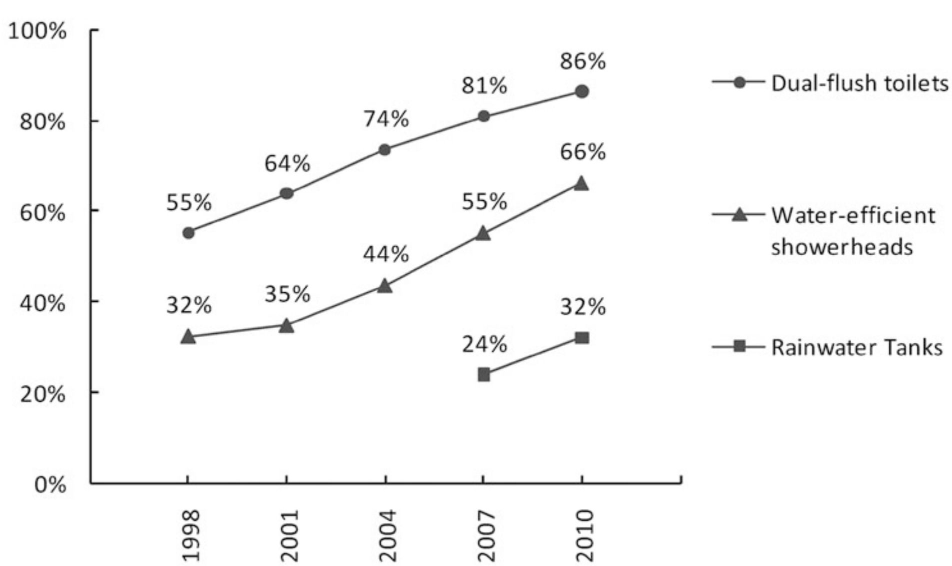

FIGURE 5.6 HOUSEHOLDS WITH WATER-SAVING PRODUCTS, 1998–2010.
Source: Australian Bureau of Statistics 2010a

it is a substantial investment for residents, yet 104,600 people received a government rebate in 2009–2010 alone.

Conclusion

Heavy rains and flooding in the austral spring of 2010–2011 prompted journalists to declare an end to the Millennium Drought. The nation's largest newspaper, the *Australian*, confidently declared, "Fresh Hope for Nation as Drought Breaks" (Lloyd 2010). Indeed, high rainfall across southeastern Australia refilled dams and restored river flows across Queensland, New South Wales, southwestern Victoria, and parts of South Australia. However, Australia's National Climate Center was more cautious, stating that "Australia's wettest September on record is not enough to clear long-term rainfall deficits" (National Climate Center of Australia 2010). Although rains restored soil moisture and give irrigators at least a temporary reprieve from drought, water suppliers' troubles have not ended, as the rains were not sufficient to restore all of the country's depleted reservoirs and aquifers. And, as history shows, droughts return.

Also worrisome, climate scientists warn that climate change will continue to worsen the risk of droughts, as temperatures rise and precipitation and water availability decrease. Some Australians speak of having already experienced a "step change" in climate and of being among the first nations to experience the negative consequences of global warming. How well Australia manages water will largely determine how well the country adapts to a warmer, drier, and more uncertain future.

The Big Dry will be remembered as the longest and most serious drought in Australian history. It has had a lasting effect on Australians' attitudes toward water, climate change, and the environment. It has profoundly affected rural economies, stimulated changes in the agricultural sector, and prompted critical thinking about how to modernize Australian agriculture and make it sustainable. The drought has set off a building spree of desalination plants on the nation's coasts and has increased Australians' awareness of water conservation. It has turned the humble rainwater tank into a fixture of more and more homes and has made newfangled dual-flush toilets the norm. Finally, it has set Australian water management on a new course, the success of which will not be fully understood until the next major drought.

References

ACTEW Corporation Limited. 2010. Scheme of Temporary Restrictions on the Use of Water from ACTEW Corporation Water Supply System. http://www.actew.com.au/publications/TemporaryWaterRestrictionsScheme.pdf

Australian Broadcasting Corporation. 2007. Man Charged with Murder After Lawn Watering Dispute. http://www.abc.net.au/news/stories/2007/11/01/2078076.htm (accessed December 30, 2010).

Australian Bureau of Meteorology. 1999. Climate Education: Drought. http://www.bom.gov.au/lam/climate/levelthree/c20thc/drought.htm (accessed January 3, 2011).

Australian Bureau of Meteorology. Undated. Drought, Dust and Deluge. Climate Education website. http://www.bom.gov.au/climate/environ/drought.shtml (accessed February 19, 2011).

Australian Bureau of Statistics. 2010a. *Environmental Issues: Water Use and Conservation, Mar 2010*. Canberra: Australian Bureau of Statistics. http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4602.0.55.003Mar%202010?OpenDocument (accessed February 5, 2011).

Australian Bureau of Statistics. 2010b. *Year Book Australia, 2009–10*. Canberra: Australian Bureau of Statistics. http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1301.0Chapter16012009%E2%80%9310 (accessed February 20, 2011).

Barwon Water. 2010. Barwon Water Northern Water Plant. http://www.barwonwater.vic.gov.au/projects/nwp (accessed February 6, 2011).

Beasley, D. 2009. Lessons From Australia: Drought Can Help Georgia Economy. http://www.globalatlanta.com/article/17131/ (accessed January 6, 2011).

Benito, P., et al. 2009. Water Efficiency Standards. Bio Intelligence Service and Cranfield University, Report for European Commission (DG Environment).

Berry, C., 2008. Australia's long drought withering wheat, rice supplies. *National Geographic News*. http://news.nationalgeographic.com/news/2008/05/080529-food-australia.html (accessed February 1, 2011).

Boston Globe. 2009. Dust storm in Australia. The Big Picture, Boston.com. http://www.boston.com/bigpicture/2009/09/dust_storm_in_australia.html (accessed February 6, 2011).

Botterill, L.C. 2003. Uncertain climate: The recent history of drought policy in Australia. *Australian Journal of Politics and History* 49(1): 61–74.

Botterill, L. 2005. Late twentieth century approaches to living with uncertainty: The national drought policy. In: *From Disaster Response to Risk Management: Australia's National Drought Policy*. L. Botterill and D.A. Wilhite, editors. New York: Springer, pp. 51–64.

Botterill, L., and Wilhite, D.A., eds. 2005. *From Disaster Response to Risk Management: Australia's National Drought Policy*. New York: Springer.

Byrnes, M. 2007. Australian farmers face bankruptcy from drought. *Environmental News Network*. http://www.enn.com/climate/article/24066 (accessed February 7, 2011).

Cathcart, M. 2010. *The Water Dreamers: The Remarkable History of Our Dry Continent*. Melbourne: Text Publishing Company.

Chong, J., et al. 2009. *NWI parties review of water restrictions*. Canberra: Australian Government National Water Commission.

Circle of Blue. 2010. Foreign Investors Are Becoming Players in Australia's Water Market. http://www.circleofblue.org/waternews/2010/business/foreign-investors-are-becoming-players-in-australia%E2%80%99s-water-market/ (accessed February 7, 2011).

Collins, D. 2008. Threats to effective environmental policy in Australia. In: *Promoting Better Environmental Outcomes, Roundtable Proceedings*. Melbourne: Australian Government Productivity Commission. http://www.pc.gov.au/research/confproc/environmental-outcomes

Commonwealth Scientific and Industrial Research Organization (CSIRO). 2008. *Water Availability in the Murray-Darling Basin Report. A Report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project*, Australia: CSIRO. http://www.csiro.au/resources/WaterAvailabilityInMurray-DarlingBasinMDBSY.html (accessed February 5, 2011).

Commonwealth Scientific and Industrial Research Organization (CSIRO) Plant Industry. 2010. Drysdale: A World's First. http://www.csiro.au/files/files/pl27.pdf

Connell, D., and Grafton, R.Q. 2008. Planning for water security in the Murray-Darling Basin. *Public Policy* 3(1): 67–86.

Cooley, H. 2007. Floods and droughts. In: *The World's Water 2006–2007, The Biennial Report on Freshwater Resources*. P.H. Gleick, editor. Washington, D.C.: Island Press, pp. 91–142.

Cooperative Research Centre for Water Quality and Treatment. 2006. *Consumer's Guide to Drinking Water*. Adelaide. http://www.wqra.com.au/_dyn/media/r396/system/attrib/file/337

Cosier, P., et al. 2003. *Blueprint for a National Water Plan*. Sydney, Australia: The Wentworth Group of Concerned Scientists.

Council of Australian Governments (COAG). 2009. Council of Australian Governments Water Reform Framework. http://www.environment.gov.au/water/australia/coag.html (accessed February 25, 2011).

Crase, L. 2007. Water markets and the chimera of price distortions. *Connections: Farm, Food and Resource Issues*. http://www.agrifood.info/connections/2007/Crase2.html

Crase, L. 2009. Water policy in Australia: The impact of drought and uncertainty. In: *Policy and*

Strategic Behaviour in Water Resource Management. A. Dinar and J. Albiac, editors. London: Earthscan, pp. 91–107.

Cull, S., et al. 2010. *Administration of the Water Smart Australia Program*. Canberra: Australian National Audit Office.

Department of Sustainability, Environment, Water Population and Communities (DEWHA). 2010. National Water Initiative Pricing Principles Regulation Impact Statement. http://www.environment.gov.au/water/publications/action/pubs/ris-nwi-pricing-principles.pdf

Department of Sustainability, Environment, Water, Population and Communities (DSEWPC). 2002. *Australians and Natural Resource Management 2002: National Land and Water Resources Audit, Commonwealth of Australia*. Canberra: DSEWPC.

Department of Sustainability, Environment, Water, Population and Communities (DSEWPC). 2010. Policy and reform in the area of urban water. *Australian Government*. http://www.environment.gov.au/water/policy-programs/urban-reform/index.html (accessed February 2, 2011).

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed*. Later printing. New York: Penguin (Non-Classics).

Diamond, J.M. 1997. *Guns, Germs, and Steel: The Fates of Human Societies*. Later printing. New York: Norton.

Edwards, N. 2011. AFL breaks ground on full-sized synthetic oval. *AFL News*. http://www.afl.com.au/news/newsarticle/tabid/208/newsid/107237/default.aspx (accessed February 22, 2011).

GMO Compass. 2010. Genetically Modified Cotton: Global Area Under Cultivation. http://www.gmo-compass.org/eng/agri_biotechnology/gmo_planting/343.genetically_modified_cotton_global_area_under_cultivation.html (accessed February 25, 2011).

Hamashige, H. 2007. Worst drought in a century hurting Australian farmers. *National Geographic News*. http://news.nationalgeographic.com/news/2007/11/071108-australia-drought.html (accessed February 1, 2011).

Hamblin, A. 2009. Policy directions for agricultural land use in Australia and other post-industrial economies. *Land Use Policy* 26(4): 1195–1204.

Hoang, M., et al. 2009. Desalination in Australia. CSIRO. http://www.csiro.au/resources/Desalination-In-Australia-Report.html

Hughes, N., et al. 2008. *Urban Water Management: Optimal Price and Investment Policy Under Climate Variability*. Canberra: Australian Bureau of Agricultural and Resource Economics.

Kendall, M. 2010. Drought and Its Role in Shaping Water Policy in Australia. http://www.nwc.gov.au/resources/documents/Kendall_International_Drought_Symposium_FINAL_mbk_260310.pdf

Ker, P. 2009. The Coorong is dead but can be revived. *The Age*. http://www.theage.com.au/environment/the-coorong-is-dead-but-can-be-revived-20090722-dtl3.html (accessed February 9, 2011).

Lake, P.S. 2008. Drought, the "creeping disaster": Effects on aquatic ecosystems. Land and Water Australia. http://lwa.gov.au/files/products/innovation/pn20677/pn20677.pdf

Land and Water Australia. 2009. Farmers beat the dry times. *Land and Water Australia*. http://lwa.gov.au/news/2009/mar/04/farmers-beat-dry-times (accessed January 10, 2011).

Lloyd, G. 2010. Fresh hope for nation as drought breaks. *The Australian*. http://www.theaustralian.com.au/national-affairs/the-drought-breaks/story-fn59niix-1225952583089 (accessed January 3, 2011).

Lockie, S., and Higgins, V. 2007. Roll-out neoliberalism and hybrid practices of regulation in Australian agri-environmental governance. *Journal of Rural Studies* 23(1): 1–11.

Lu, L., and Hedley, D. 2004. The impact of the 2002–03 drought on the economy and agricultural employment. *Economic Roundup*, pp. 25–43. http://www.treasury.gov.au/documents/817/HTML/docshell.asp?URL=03_article_2.asp (accessed May 23, 2011).

Marshall, G. 1997. Greywater re-use: Hardware, health, environment and the law. *Permaculture Association of Western Australia*. Available at: http://permaculturewest.org.au/ipc6/ch08/marshall/index.html (accessed February 3, 2011).

McKernan, M. 2010. Coming to terms with the reality of a land burnt dry. *The Australian*. http://www.theaustralian.com.au/national-affairs/coming-to-terms-with-the-reality-of-a-land-burnt-dry/story-fn59niix-1225952595679 (accessed December 30, 2010).

Mercer, D., Christesen, L., and Buxton, M. 2007. Squandering the future—climate change, policy failure and the water crisis in Australia. *Futures* 39(2-3): 272–287.

National Climate Center of Australia. 2010. Special Climate Statement 22: Australia's wettest September on record but it is not enough to clear long-term rainfalldeficits.

National Water Commission (NWC). 2010. *Impacts of Water Trading in the Southern Murray–Darling Basin: An Economic, Social, and Environmental assessment*. Canberra: Australian Government. http://www.nwc.gov.au/www/html/2816-impacts-of-water-trading-in-the-southern-murraydarling-basin.asp?intSiteID=1 (accessed January 11, 2011).

Nicholls, N. 2008. Recent trends in the seasonal and temporal behaviour of the El Niño–Southern Oscillation. *Geophysical Research Letters* 35(19): L19703.

O'Loughlin, T. 2009. Australia engulfed by dust storms. *The Guardian*. http://www.guardian.co.uk/world/2009/sep/23/australia-dust-storm-sydney (accessed February 6, 2011).

O'Neill, G. 2010. Designing drought tolerant crops. *Australian Life Scientist*. http://www.lifescientist.com.au/article/368007/feature_designing_drought_tolerant_crops/ (accessed February 7, 2011).

Onishi, N., 2010. Arid Australia turns to desalination, at a cost. *New York Times*. http://www.nytimes.com/2010/07/11/world/asia/11water.html (accessed February 7, 2011).

Peatling, S. 2007. Kangaroos invading Australian cities as drought worsens. *National Geographic News*. http://news.nationalgeographic.com/news/2007/07/070718-roos-drought.html (accessed February 1, 2011).

Postel, S. 2010. Australia takes a bold step to shape its water future. NatGeo News Watch. *National Geographic News*. http://blogs.nationalgeographic.com/blogs/news/chiefeditor/2010/10/australia-water-allocations.html (accessed February 1, 2011).

Quiggin, J. 2006. Urban water supply in Australia: The option of diverting water from irrigation. *Public Policy* 1(1): 14–22.

Riebeek, H. 2009. Dust Over Southeast Australia: Image of the Day. http://earthobservatory.nasa.gov/IOTD/view.php?id=41458 (accessed January 10, 2011).

Rintoul, S. 2010. Ban development in fire-prone areas, experts tell royal commission. *The Australian*. http://www.theaustralian.com.au/news/nation/ban-development-in-fire-prone-areas-experts-tell-royal-commission/story-e6frg6nf-1225830521084 (accessed February 6, 2011).

Romsey Australia. 2010. Summary of Major Bush Fires in Australia Since 1851. http://home.iprimus.com.au/foo7/firesum.html (accessed February 6, 2011).

Short, R. 2007. Rural Water Note: Reducing Farm Dam Evaporation. http://www.water.wa.gov.au/PublicationStore/first/76927.pdf

Sohn, E., 2007. The Big Dry: Prolonged drought threatens Australia's people, wildlife, and economy. *Science News* 172(17): 266–268.

Stehlik, D. 2005. Managing risk?: Social policy responses in time of drought. In: *From Disaster Response to Risk Management: Australia's National Drought Policy*. New York: Springer, pp. 65–97.

Thieberger, V. 2008. Drought forces wine makers in Australia to think again. *New York Times*. http://www.nytimes.com/2008/03/25/business/worldbusiness/25iht-wine.1.11395929.html (accessed January 6, 2011).

Thompson, W., and Price, R. 2009. Australia: Water reform, 1994–2004. In: *The Political Economy of Reform*. Organisation for Economic Cooperation and Development. http://www.ingentaconnect.com/content/oecd/16815378/2009/00002009/00000007/1109011ec019 (accessed February 8, 2011).

Ummenhofer, C.C., et al. 2009. What causes Southeast Australia's worst droughts? *Geophysical Research Letters* 36(4): L04706.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2009. The state of the resource. In: *The 3rd United Nations World Water Development Report: Water in a Changing World*. Chapter 4. London and Paris: UNESCO and Earthscan. http://www.unesco.org/water/wwap/wwdr/wwdr3/

Verdon-Kidd, D.C., and Kiem, A.S. 2009. Nature and causes of protracted droughts in southeast Australia: Comparison between the Federation, WWII, and Big Dry droughts. *Geophysical Research Letters* 36(22). http://www.agu.org/pubs/crossref/2009/2009GL041067.shtml

Wahlquist, A. 2010. Rural incomes rocket from reform. *The Australian*. http://www.theaustralian.com.au/national-affairs/rural-incomes-rocket-from-reform/story-fn59niix-1225952593371 (accessed December 30, 2010).

Watson, A. 2007. A national plan for water security: Pluses and minuses. *Connections—Farm, Food and Resources Issues* 7(1).

Wikipedia. 2010. Water Restrictions in Australia. http://en.wikipedia.org/wiki/Water_restrictions_in_Australia (accessed February 2, 2011).

Woodhead, B. 2008. National water plan advances. *The Australian*. http://www.theaustralian.com.au/australian-it/national-water-plan-advances/story-e6frgamf-1111115367518 (accessed February 8, 2011).

CHAPTER 6

China Dams

Peter H. Gleick

Dams are a central component of water management around the world, providing flood control, hydroelectric power, water supply, recreation, and more. There are no highly accurate estimates of the numbers of dams that have been built, but the World Commission on Dams (2000) estimated that there are around 45,000 dams larger than 15 meters in height and perhaps as many as 800,000 smaller ones. Two trillion dollars has been invested in them in the past century (Vörösmarty et al. 2005).

Dams, especially large ones, are increasingly controversial. In addition to their well-known benefits, they produce major and inadequately understood environmental, social, political, and economic risks and adverse impacts. They have altered the global water cycle, destroyed and modified aquatic habitats, fundamentally changed the suspended sediment flows in rivers and oceans, and changed the regional fluxes of carbon and other nutrients. The largest reservoirs in the world intercept 40 percent of the water that flows off the continents into oceans or inland waters, and total reservoir volume exceeds the total standing stock of water in natural river channels by a factor of between three and six (Vörösmarty et al. 2003, 2005). In addition, a small number of the world's largest dam projects have been responsible for massive social disruption and population displacements, including the Tennessee Valley Authority dams in the U.S. in the early parts of the 20th century and, more recently and on a far larger scale, in India and China.

As a result of these adverse consequences, opposition to big dams developed and grew in the latter years of the 20th century. As new information about their liabilities and adverse consequences developed, and as environmental movements against them coalesced, support for large dams began to dry up and the rate of new projects slowed dramatically. Figure 6.1 shows the cumulative capacity of large reservoirs globally from 1900 to 2010 (Vörösmarty and Sahagian 2000, updated by the author). Around the turn of the 21st century, the independent World Commission on Dams produced a comprehensive assessment of dam experience and concluded that most projects failed to produce their claimed benefits and often entailed unacceptable social and environmental costs (WCD 2000). Leading dam funders reduced the money available for international projects, and many countries began looking at alternative energy and water management options. John Briscoe, a major dam proponent and World Bank senior water advisor, observed in 2003, "Big dams account for 10 percent of our portfolio but 95 percent of our headaches" (Bosshard 2009).

Things are changing again in the world of large water infrastructure, and China is at the center of this change. China has launched a massive new effort to build dams both within China itself, on international rivers shared with its neighbors, and increasingly,

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_6,

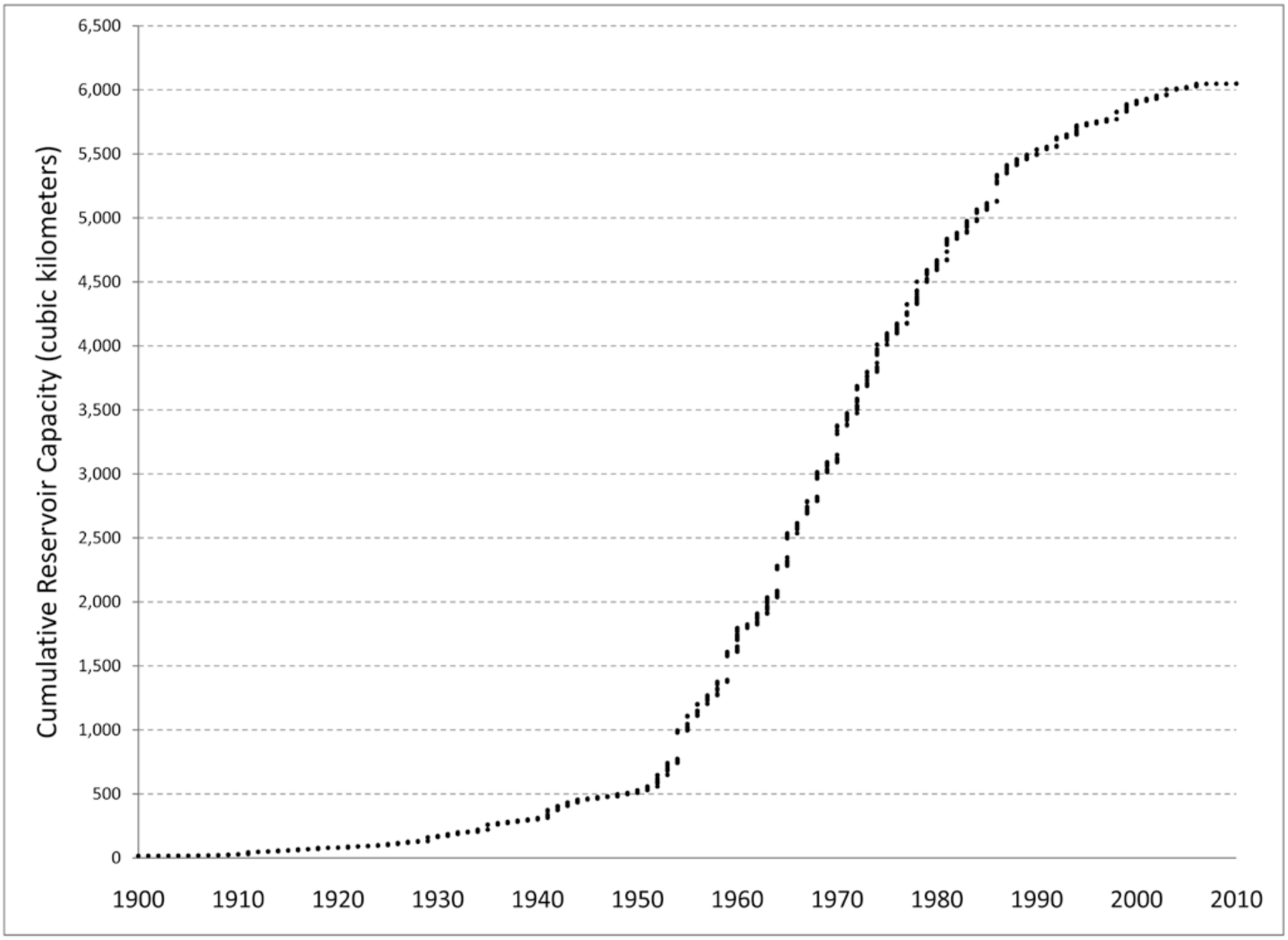

Figure 6.1 Cumulative Capacity Behind the World's Largest Dams, 1900–2010.
Source: Vörösmarty and Sahagian 2000

in other countries and regions with financial and technical support from China. These new projects are raising old and new issues around ecological destruction, transparency and openness in decision making around development approaches, ethical guidelines for dam construction and operation, and the consequences of expanding demands of China for resources, energy, minerals, and food produced outside its borders.

The new projects are also prompting questions about revisiting the explicit international guidelines for water management and for dam development produced by the United Nations and the World Commission on Dams (WCD). China was one of only three nations to vote against the UN Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention) adopting principles for international watershed management. Some observers speculate that this is due to their upstream position on so many major rivers (Loures et al. 2009) and recognition that "competition for transboundary water utilization will be fierce," as noted by He Daming, director of Yunnan University's Asian International River Centre in Kunming (Stone 2010). Guidelines developed specifically for large dam projects have mostly been ignored by the dam construction community and by countries with large dam efforts, including China and India. For example, China has long refused to provide complete hydrologic data for its rivers or dams, especially on rivers shared with neighboring countries (MacLeod 2010), a violation of general principles espoused by both the WCD and the Watercourses Convention. They rarely consult with local communities affected by their projects. And, they have shown only limited regard for ecosystem values in comparison to the purely economic benefits their projects generate. These problems seem likely to escalate in coming years, with potentially serious ecological and political ramifications.

Dams in China

China's initial focus, like most countries of the world, was on developing the hydropower potential along its own internal rivers. China's first hydropower stations were installed in Yunnan Province in the early years of the 20th century, and today the country has by far the world's largest installed hydropower capacity, around 200,000 megawatts in 2009—more than double the world's second-largest producer, Canada (Table 6.1). China has pursued a wide range of ambitious efforts to build hydroelectric plants, to dam rivers, and to transfer water from one region to another. Since 1950, almost half of the world's large dams (defined as dams higher than 15 meters) have been built in China (Fuggle and Smith 2000). On the Yangtze alone, there are an estimated 50,000 dams, including the largest in the world, the Three Gorges Dam.

Hydropower represents around one-fifth of China's total installed capacity. In 2009, China was also the world's largest producer of hydroelectricity, generating 549 billion kilowatt-hours, or 16 percent of its total electricity supply (US EIA 2011a) (Table 6.2). In early 2011, the National Energy Agency of China announced plans to build an additional 140 gigawatts-electric of hydropower in the next five years, with projects on all of their major rivers and with little apparent concern for environmental or political obstacles (Watts 2011). In a major new expansion, China has launched ambitious efforts to extend their dam-building activities on their own transboundary rivers, shared with mostly downstream neighbors, as well as in far distant countries in conjunction with their other overseas economic development projects.

Table 6.1 Total Hydroelectric Installed Capacity, 2004–2008 (2009 data for China) (million Kilowatts)

Country	2004	2005	2006	2007	2008	2009
China	105.2	117.4	128.6	145.3	171.5	197
Brazil	69.0	70.9	73.4	76.9	78.3	n.d.
United States	77.6	77.5	77.8	77.9	77.9	n.d.
Canada	70.7	71.8	72.7	73.3	74.4	n.d.
Russia	45.5	45.8	46.1	46.8	47.0	n.d.
India	32.6	34.2	36.6	38.1	39.3	n.d.
Norway	26.1	26.4	27.5	27.8	28.2	n.d.

The abbreviation "n.d." means "no data."

Source: US EIA 2011b.

Table 6.2 Total Hydroelectricity Generation, 2005–2009 (billion kilowatt-hours per year)

Country	2005	2006	2007	2008	2009
China	393.0	431.4	430.0	522.4	549.0
Brazil	334.1	345.3	370.3	365.9	387.1
Canada	360.0	351.8	367.0	378.6	363.2
United States	270.3	289.2	247.5	254.8	272.1
Russia	171.0	171.6	175.3	163.1	162.3
Norway	134.3	118.2	132.3	138.2	125.0
India	100.7	112.6	119.4	113.2	104.4

Source: US EIA 2011b.

Dams on Chinese International Rivers

China is a vast nation. As a result, many of its watersheds lie wholly within its own borders, as is the case in the United States. But China also shares many major rivers with neighboring countries, especially in the wetter southern part of the region. More than a third of the entire area of China is in an international river basin, and the country shares 18 rivers with its neighbors, including some of the world's largest and most contentious ones. Table 6.3 lists the major international rivers shared by China.

China's ongoing dam construction efforts have extended to Chinese projects within China's borders (or on the border) on international rivers as well as inside neighboring countries on rivers shared by China. These projects are sometimes, but not always, pursued with the support and collaboration of their neighbors. And at times, there is explicit opposition to Chinese projects in their shared international watersheds. Given the geographical location of China at the headwaters of so many major rivers, and their unabashed efforts to build dams to control, manage, and redistribute these waters, China will be at the center of new transboundary water competition in the region, and at the center of rising water-related tensions. Such tensions are already appearing.

Chinese Dams on the Mekong (Lancang) River

The Mekong River, one of the great rivers of the world, flows through China (where it is known as the Lancang River), Myanmar, Laos, Thailand, Cambodia, and Vietnam. It is vital to the region's economy and ecology. Eighty million people live within the Mekong watershed or depend on its waters (Goh 2004). In recent years, the Mekong has become a focus of concern on the part of the major downstream countries of the basin as China rapidly expands its dam-building and river-development programs. There is worry that these activities will affect water availability, fish health and productivity, silt and nutrient loads, agricultural production, transportation, and more. The Mekong is one of the last of the world's great rivers to have been completely explored—its source headwaters were only identified in 1994 in the glaciers of eastern Tibet (Peissel 1997). About half of its nearly 5,000-kilometer length is located in China, and the river drains an area of around 800,000 square hectares, emptying into the South China Sea. A unique characteristic of the river is the dynamics of flow in the rainy season, when so much water

Table 6.3 International River Basins Shared by China

Basin Name	Watershed Area Within China (km^2)	Percent of Total Watershed Within China
Amur	849,900	45.11
Aral Sea	40	negligible
Beilun	700	73.61
Ganges-Brahmaputra-Meghna	320,400	19.12
Har Us Nur	120	0.06
Hsi/Bei Jiang	351,700	97.28
Ili/Kunes He	55,300	34.31
Indus	111,000	10.22
Irrawaddy	18,600	4.6
Mekong	168,400	21.58
Ob	50,400	1.84
Pu-Lun-To	76,300	86.27
Red/Song Hong	84,400	51.28
Salween	128,000	52.43
Sujfun	9,800	58.39
Tarim	901,700	94.9
Tumen	22,600	68.56
Yalu	31,200	49.59

Source: OSU 2011.

flows down the river that it backs up into the Tonle Sap River and Lake, providing nutrients and habitat for enormous fish productivity (Osborne 2000).

Although a major international effort is under way to evaluate how best to manage the Mekong among the different nations and competing priorities, China has not been a significant, or even official, participant. In the 1980s, China began construction of eight hydroelectric dams on the Mekong. As of 2010, four were completed, including the massive Xiaowan Dam (292 meters tall)—the largest arch dam in the world (MacLeod 2010). These four new Chinese dams impound part of the flow of the upper Mekong, and locals believe that these dams are already adversely affecting water conditions in downstream nations. Like all major dam projects, the Chinese projects on the Mekong are controversial. Some environmental groups argue that the Mekong flow regime has already been changed by dredging and dam construction, decreasing fish catches. Pro-dam advocates argue that only wet-season flows will be captured by the dams, which could reduce flood risks, while additional dry-season water releases would actually increase. One of the biggest ecological impacts could be a reduction in sediment and nutrients that flow downstream, leading to erosion of downstream riverbanks and the Mekong Delta and a decrease in fish productivity. Similar problems have been documented for the massive Three Gorges Dam on the Yangtze River (Gleick 2008b). Scientific evidence indicates that dam development in the Mekong will adversely affect fisheries in the lower part of the basin and will hurt rural livelihoods, but the impacts are not being adequately addressed in regional policy processes (Baran and Myschowoda 2009).

In 2010, the Mekong suffered from severe drought, perhaps the worst in the region since the Chinese revolution in 1949. In southern China's Yunnan Province, as many as six million people were reported short of drinking water and the drought caused an estimated $1.5 billion in crop losses (Stone 2010). Because the Mekong is an international river, the drought in the headwaters also had severe effects downstream among China's neighbors, increasing tensions and debate about water development. Rice yields in Thailand dropped, and navigation was disrupted by low water levels, affecting commerce in communities depending on the river for trade and transportation. Downstream nations also expressed concern over the impacts of water shortages on local fisheries and ecosystem health. Some parties lay part of the blame for these impacts on China's water management and new dam construction. An editorial in the *Bangkok Post* was titled "China's Dams Killing Mekong," a point disputed by Chinese officials (Bangkok Post 2010).

The Salween (Nu) River

Chinese hydroelectric development along the Nu River in Yunnan Province, known internationally as the Salween (also shared by Myanmar and Thailand), is also increasingly controversial. The Salween, like the Mekong, originates in the highlands of Tibet, is relatively undammed, and has extensive hydropower potential as well as ecological and cultural value. Segments of the river are listed by UNESCO as World Heritage Sites, yet China has announced plans to build 13 large dams in a region nicknamed the "Grand Canyon of the Orient" (Watts 2011). These dams were first proposed in 2003, but China's environmental nongovernmental organizations and some academics launched a protest campaign through the Internet and media. The region where the dams would be built is home to more than 80 endangered species, including the snow leopard. Two downstream nations, Myanmar and Thailand, also expressed opposition to the dams because of concerns about their own water availability and local impacts (Watts 2011). In response, Premier Wen Jiabao twice suspended the projects (in 2004 and again in 2009) pending environmental reviews, but in early 2011 regional governments announced that they were moving forward with construction after lobbying by energy development interests and utilities (Chen 2010, Watts 2011). Huadian, one of the largest electric utilities in China, argued, along with the provincial government, that more low-carbon energy is needed to meet the climate commitments set by the government.

The Irrawady

Chinese developers are also involved in more than 20 hydropower projects within Myanmar itself or on the shared border. Myanmar does not require environmental assessments and has been accused of using forced labor for dam construction (Bosshard 2009). The Shweli River (Longjiang in China) forms part of the border between China and Myanmar before it flows into the Irrawaddy River, and a new 110-meter dam there is displacing villagers, disrupting water transportation, and affecting water quality. These unilateral developments are increasing tension and conflict between the two countries as the Chinese expand development projects. Part of the perception in Myanmar is that the dams offer an opportunity for growing Chinese cities to acquire cheap electricity while imposing negative social and environmental impacts on Myanmar (Piyathamsawat 2010, Saikia 2011).

Another project, the giant Myitsone Dam, financed by the Chinese, is one of seven others planned on tributaries of the Irrawaddy River. The project is due for completion by 2017 and would eventually displace about 10,000 people and flood an area the size of New York City. Like a number of other efforts, the impacts of Myitsone Dam would be felt in the homeland of Burma's Kachin minority and it highlights concerns over external exploitation of Burma's natural resources with little or no benefit for local populations and the rights of ethnic minorities (Christian Science Monitor 2010). As another example of the extreme uncertainty about the environmental impacts of these projects, a completely new species of monkey was found in 2010 during a review conducted by China of the possible impact of a proposed China Power Investment Corporation dam on the Irrawaddy River (Doyle 2010).

Exporting Chinese Dams

China's dam activities now extend far beyond its own borders. For much of the 20th century, China's hydropower development was supported by technology provided by Western suppliers. According to Bosshard (2009), China's first hydro turbines were installed by Siemens in Yunnan Province in 1909, and even the massive Three Gorges Dam project recently completed depended on turbines and generators from international partners, such as ABB, Alstom, General Electric, and Siemens (Gleick 1998, 2008b; Bosshard 2009). That is all changing. As in other Chinese industries, Chinese manufacturers have copied and adapted Western technology in the area of massive hydropower systems, now produce their own equipment, and are actively exporting it to other countries as part of their rapidly growing effort to tap into vital food and mineral resources that they lack domestically.

In recent years, numerous dam construction projects have been funded in developing countries by Chinese governmental interests, financial institutions, state-owned enterprises, and private firms. McDonald et al. (2008) estimated that the Chinese were involved in at least 93 major dam projects outside of their borders. Just one year later, Bosshard (2009) estimated that Chinese companies and financial interests were involved in at least 220 dam projects in 50 countries, including building 19 of the world's 24 largest hydropower stations. These projects provide jobs at home and abroad as well as energy in other countries—including the Sudan, Ethiopia, Zambia, the Congo, Gabon, and Myanmar—where the Chinese have launched economic and resource projects that serve their strategic objectives.

One factor that slowed international dam building in the 1980s and 1990s was a growing reluctance on the part of international financial institutions such as the World Bank and national Export-Import banks to get involved with controversial and risky dam efforts. China, however, has created its own export credit agency—the China Exim Bank—to support their dam expansion efforts. Its portfolio is now massive, and it often provides financing for projects that would not meet international environmental and social standards for dam construction. Bosshard (2009) describes extensive and unresolved problems with China's Merowe Dam in the Sudan along the Nile, including classic challenges of massive population dislocations, inadequate resettlement options, and little or no community engagement—all problems that have been characteristic of recent major internal Chinese projects such as Three Gorges Dam. A team from Sudan's Ministry of Agriculture visited the Merowe resettlement areas in April and May of 2009, after the dam was inaugurated, and reported a "devastating deterioration" of living conditions among displaced populations. In 2006, angry villagers in the Sudan staged protests against another proposed project largely funded by the Chinese—the 300 megawatts-electric (MWe) Kajbar Dam—and four villagers were killed by government militia (Bosshard 2009).

China continues to expand their international dam efforts. In July 2009, they signed an initial agreement with Ethiopia to build the controversial Gibe Dam on the Omo River. Gibe is a 1,870-MWe, $1.75 billion hydropower project with a 240-meter high rockfill dam, tunnel, water diversion works, and power station, now under construction by an Italian hydropower developer. It has been targeted by community and environmental groups for its potentially devastating environmental consequences. Among the major concerns are impacts to nearly 500,000 people who depend on seasonal flooding for farming or effects on fisheries in Lake Turkana in northern Kenya (Hathaway 2010). A 2009 report by the African Resources Working Group estimated that the Gibe Dam could lead to a 12-meter drop in Lake Turkana's water level due to irrigation withdrawals, upstream seepage, and evaporation losses (ARWG 2009). No assessment has been done on the potential of the project to worsen intertribal disputes among downstream indigenous ethnic groups. A 2009 report by the United States Agency for International Development, however, recommended that an assessment of these risks should be conducted (Johnston 2009).

In 2008, JPMorgan Chase and SACE, the Italian export credit agency, refused to finance the dam. In 2009 and 2010, the World Bank, the European Investment Bank (EIB), and the African Development Bank withdrew funding consideration in part over concern about the project's impacts (Shih 2010). Yet a follow-on agreement with China was signed in July 2010 for a $459 million construction loan from the Industrial and Commercial Bank of China (ICBC) (Hydroworld 2010). ICBC's chief risk officer, Wei Guoxiong, is on record as saying, "We will not support [projects with serious environmental impacts], whether domestically or abroad"; the bank has reiterated a commitment to China's Green Credit Policy, but international environmental groups have decried the decision to fund Gibe as hypocritical. Sonja Willems, campaign coordinator for BankTrack, said: "This loan makes a mockery of ICBC's actions to establish itself as a socially and environmentally responsible lender. As the world's largest bank, ICBC should strive to become an environmental leader, but instead is building a reputation of undercutting other banks' standards and financing untouchable projects" (Bosshard 2010a, Hathaway 2010).

China dam developments are also causing problems in its relations with India. Dams proposed for the Yarlung Sangpo River (Siang in India) by both countries have generated calls for a halt in construction from Indian non-governmental organizations (NGOs). In 2010, 51 NGOs from northeast India called on the Chinese premier and the Indian prime minister to halt efforts to build dams on the Yarlung Sangpo/Siang River. The river runs through the Tibet Autonomous Region and India's Arunachal Pradesh state and has spiritual and cultural importance to local communities (Mehta 2010).

In another example of the intricate links between China's overseas dam projects and their resource and development goals, a major dam in Gabon (the Belinga Dam) has been proposed as part of a project to provide power for an iron ore mine producing iron for China. The China National Machinery and Equipment Import and Export Corporation is to build the mine, China's Exim Bank agreed to provide the funding, and China's construction industry is to be the sole recipient of the ore. In 2008, the China Exim Bank began a new review of a proposed loan for the dam after it was informed by a local group that the dam was located in Ivindo National Park and that no public environmental impact statement had been prepared (Polgreen 2009, Bosshard 2009, BankTrack 2011).

The fact that these kinds of assessments and reviews are not standard, as recommended by the World Commission on Dams and other international principles, raises serious questions about countries sidestepping or weakening the already inconsistent and inadequately applied international standards. If Chinese dam builders are not adhering to accepted international standards when designing and building infrastructure, pressure increases on Western financial institutions and construction companies to sidestep or ignore them as well in order to compete. In 2006, the president of the European Investment Bank said, “Chinese banks don’t bother about social or human rights conditions,” and went on to question whether EIB could continue to impose strict constraints as well (Bosshard 2009).

Growing Internal Concern Over Chinese Dams

Opposition to big dams in the United States in the 1960s and 1970s provided a major impetus to the nascent environmental movement. A similar dynamic may be happening in China. Chinese activism around environmental concerns, and especially dams, is growing, and public protests about specific dam projects have increased. Such efforts have been mostly local, confined to narrow geographical concerns, and have not been political in nature. This has permitted significant numbers of citizens to participate (Qiang 2010). Increasing numbers of Chinese experts are also expressing criticism of China’s dam policies. “In western China, the one-sided pursuit of economic benefits from hydropower has come at the expense of relocated people, the environment and the land and its cultural heritage,” said Fan Xiao, a geologist and critic of the Three Gorges project. “Hydropower development is disorderly and uncontrolled, and it has reached a crazy scale” (Yardley 2007).

Some large infrastructure projects in China have been successfully delayed by public opposition and the intervention of Chinese scientists and policy makers (Gleick 2008a). Eng and Ma (2006) and Yardley (2007) offered a few examples:

- Local organizations and individuals worked to inform the public and media about the impacts of Yangliuhu Dam on an ancient and still functioning irrigation system that had been declared a World Cultural Heritage Site. Extensive media coverage and public dissent forced the developer to abandon the project in 2003.
- In 2004, Chinese NGOs opposed development projects on the Nujiang (discussed in more detail later in this chapter). Their efforts drew national attention and led Premier Wen Jiabao to temporarily halt the project.
- Environmentalists have been working to preserve the Tiger Leaping Gorge in a campaign to reduce the impact of a massive dam project on ecological and cultural diversity.
- A dam in Sichuan Province that would have inundated an ancient Qin Dynasty cultural site was canceled after local opponents called it an attack on China’s heritage.

Associated with growing public participation in environmental issues, government officials have occasionally permitted the creation and operation of new environmental NGOs, some of which have focused on concerns over large dams. Recently, however, even these groups have faced new constraints and government crackdowns. In 2005, more than 100,000 people protested the Pubugou Dam project in Sichuan Province, until the riot police crushed the demonstration (Yardley 2007). In 2006, a dam protester was executed for what government officials claimed was his role in the death of a policeman at this protest (BBC 2006, Haggart 2006). Yu Xiaogang directs the Green Watershed initiative in Yunnan and won the prestigious Goldman Environmental Prize in 2006. Yu has worked with local villagers to help them understand the impacts of dam construction, and yet, despite his public notoriety (or perhaps because of it), Yu had his passport taken away to limit his activities (Larson 2009).

International Principles Governing Dam Projects: The World Commission on Dams

As noted earlier, as the 20th century came to a close, an upsurge in opposition to new dam projects occurred and new construction slowed, to the delight of dam opponents and to the concern of those who felt that project benefits outweighed their costs. Out of the conflict came the World Commission on Dams, an independent body established in 1998. The commission's objective was to shed light on questions that plague the debate, to develop comprehensive recommendations and standards that could be used around the world, and to break the deadlock over new projects. Their charge was to "review the development effectiveness of dams and assess alternatives for water resources and energy development, and . . . develop internationally-acceptable criteria and guidelines to advise future decision-making in the planning, design, construction, monitoring, operation, and decommissioning of dams" (WCD 2000).

The WCD consisted of 12 commissioners and a secretariat based in Cape Town, South Africa. Professor Kadar Asmal, then minister for water affairs and forestry for South Africa, served as chair. The other commissioners were selected to represent the broad spectrum of interests in the large dams debate, ranging from Medha Patkar, leader of the Struggle to Save the Narmada River (an Indian NGO), to Jan Veltrop, honorary president of the International Commission on Large Dams. In November 2000, the World Commission on Dams concluded their work (WCD 2000).

The WCD gathered information on over 1,000 dams, produced assessments of project economics and impacts to ecosystems, and gave significant attention to the social and environmental impacts of dams. To its credit, the commission's work was also interdisciplinary, applying staff and consultant expertise in fields that included economics, marine biology, sociology, history, and engineering. Their final assessments are considered the most comprehensive, multidisciplinary post-hoc analysis of large dams to date (WCD 2000, Cushing 2002).

The commission's final objective was to propose a set of criteria and guidelines to shape future decision making related to water and energy resources infrastructure development. Such guidelines, in principle, should address the efforts of countries like China in their new international dam efforts. Although the WCD stakeholders were in broad agreement about and supportive of the ultimate goals and principles of the commission, implementation has been sidetracked by opposition from some national governments and pro-dam industry groups reluctant to accept new constraints on dam development.

WCD Major Findings and Recommendations

The World Commission on Dams produced a wide range of findings and recommendations (Cushing 2002). Two key recommendations were focused on the following issues related to risk and improved outcomes of major projects:

1. By bringing to the table all those whose rights are involved and who bear the risks associated with different options for water and energy resources development, the conditions for a positive resolution of competing interests and conflicts are created.
2. Negotiating outcomes will greatly improve the development effectiveness of water and energy projects by eliminating unfavorable projects at an early stage and by offering as a choice only those options that key stakeholders agree represent the best ones to meet the needs in question (WCD 2000).

These recommendations were based on research and case-study conclusions that pre-project water and energy development assessments traditionally focused on weighing the expected economic benefits of a project against its economic costs, while social and environmental impacts, if assessed at all, were given a much lower priority. Decision making was centralized and often rested with a few key players, such as governments, construction companies, and multilateral development banks (Cushing 2002).

In contrast, the WCD proposed using the concepts of "recognition of rights" and "risk assessment" as a more appropriate way to develop water and energy resources. Recognition of rights means acknowledging the various rights and entitlements that project-affected parties hold, including constitutional rights, local or national legal rights, customary rights, treaty rights, and concepts of common law or public trust doctrines (WCD 2000). Acceptance of this concept means that a much wider range of parties should be included in the decision-making process, most notably, directly affected or displaced communities, indigenous groups, and those representing the interests of future generations and ecosystems (Cushing 2002). The WCD also distinguished between voluntary risk *takers* (e.g., developers, industry, governments) and involuntary risk *bearers* (e.g., indigenous people, displaced communities, future generations, and ecosystems)—now considered a key element of risk assessment analysis. Assessing such risks means a far larger group of stakeholders should be involved in decisions around water infrastructure and an effort to improve a project's ability to define and evaluate the level and type of risks imposed (WCD 2000).

Finally, the WCD concluded that negotiated agreements among relevant stakeholder parties should be used to reconcile the interests of those who have a stake in the project and those who bear different kinds of risks. These agreements would be legally binding. The WCD recommended that the process used to arrive at an agreement include alternative decision-making mechanisms—such as arbitration, mediation, and judicial review—should a negotiated settlement prove infeasible, together with a mechanism for appeal (WCD 2000).

In its recommendations, the commission proposed a series of 26 "guidelines" or best practices that "describe in general terms how to assess options and plan and implement dams projects" that meet the commission's Strategic Priorities (Table 6.4).

Reaction to the WCD Report

Overall, those organizations and their representatives opposed to new dam projects or active in efforts to incorporate social and environmental factors in decisions about dam development strongly supported the report. They saw it as a way to encourage governments and lending institutions to reform their dam-building processes. A statement issued by 136 NGOs called for immediate implementation of WCD recommendations (especially those related to consent and participation of indigenous communities), the establishment of multi-stakeholder reviews of dam projects, and financial reparations for the uncompensated victims of existing and past projects. Perhaps most alarming to lending institutions, these organizations also called for a moratorium on the funding, planning, and construction of new dams until compliance with the aforementioned actions was achieved (Dubash et al. 2001, Cushing 2002). World Wildlife Fund International called for governments and the private sector to adopt the WCD's recommendations and for the OECD (Organization for Economic Cooperation and Development) governments to publicly pledge not to construct any more large dams for at least the next 20 years (Dubash et al. 2001).

The most influential and widely anticipated reactions to the commission's report came from the World Bank and other international funding agencies. As one commissioner put it: "A lot of the 'success' of the Commission will depend on how the World Bank reacts to it. A lot of organizations look to them for guidance, so if they don't like it or adopt it, that won't bode well for success. The WCD won't be considered effective if it doesn't influence Bank behavior" (Moore 2001). Although initially embracing the general principles behind the Commission's work, the World Bank's response has been to largely discount and ignore the findings, leaving decisions on standards and best practices to individual countries. In response to the request of international NGOs that they adopt the commission's recommendations, the Bank responded by saying: "Not all WCD guidelines apply in all cases and should not be taken literally, but rather as guiding principles. The decision on whether to adopt the [WCD's] guidelines lies with the respective developing countries." The World Bank will not "comprehensively adopt the 26 WCD guidelines, but will use them as a reference point when considering investments in dams" (World Bank 2001, Cushing 2002). This position effectively cut the legs out from under the "Good Practice" guidelines and let countries and dam developers move to ignore the WCD recommendations without fear of sanctions or increased financial risk.

Some lending institutions argued that they had already incorporated many of the commission's recommendations into existing policies or expressed support for the major conclusions, though no formal or mandatory new policies were implemented. For example, in a letter to commission chair Kadar Asmal, the president of the Asian Development Bank (ADB) stated: "ADB will reexamine its own procedures, including our environment and social development policies, and determine the extent to which

Table 6.4 World Commission on Dams "Good Practice" Guideline Topics

- Stakeholder analysis
- Negotiated decision-making process
- Free, prior, and informed consent
- Strategic impact assessment for environmental, social, health, and cultural heritage issues
- Project-level impact assessment for environmental, social, health, and cultural heritage issues
- Multi-criteria analysis
- Life-cycle assessment
- Greenhouse gas emissions
- Distributional analysis of projects
- Valuation of social and environmental impacts
- Improving economic risk assessment
- Ensuring operating rules reflect social and environmental concerns
- Improving reservoir operations
- Baseline ecosystems surveys
- Environmental flow assessments
- Maintaining productive fisheries
- Baseline social conditions
- Impoverishment risk analysis
- Implementation of the mitigation, resettlement, and development action plan
- Project benefit-sharing mechanisms
- Compliance plans
- Independent review panels for social and environmental matters
- Performance bonds
- Trust funds
- Integrity pacts
- Procedures for shared rivers

Source: Adapted from WCD 2000, p. 278.

the report's recommendations may necessitate changes in these procedures. We will also encourage our member countries to do the same" (Chino 2000).

As might have been expected, industry groups were even less enthusiastic and also moved to ignore or discount the WCD findings and recommendations. From the industry's perspective, the commission failed to adequately consider the benefits created by dams, focusing instead on the negative social and environmental impacts. Some industry representatives expressed concerns that the commission's 26 guidelines would lead to mandatory criteria, thus creating new regulations and restrictions at an international level. As a result, the dam industry has never tried to implement the WCD findings, though some hydropower projects, such as 46 projects supported by the Clean Development Mechanism, claim that they comply with WCD guidelines (Bosshard 2010b).

Of particular importance, the governments of India and China, now the two largest dam-building nations in the world, chose not to participate in the WCD process and subsequently rejected the validity of the commission and its findings. A session at the annual Stockholm water symposium in September 2010 offered a 10-year retrospective on the WCD report, which made it clear that the overall recommendations had largely been ignored, especially by countries, like China, with a vested interest in unconstrained and rapidly growing dam projects both internally and internationally (SIWI

2010). China, which initially had a commissioner participating in the process, withdrew its support of the WCD's investigative efforts. Some analysts suggest that China's withdrawal was due to concerns that the findings of the commission might jeopardize the monumental Three Gorges Dam project and other massive projects they were planning (Dubash et al. 2001). Whatever the reason, the Chinese reaction illustrates the difficulty of developing international standards of performance and development when those standards conflict with internal national policies. And subsequent Chinese behavior, as exemplified by both their internal and external dam policies, continues to highlight both the difficulty of implementing consistent international standards to govern dam construction and operation, and the need for such standards.

Conclusions

The end of the 20th century saw a slowdown in large dam construction worldwide as a result of growing concerns that the dams' environmental and social costs were beginning to substantially exceed their economic benefits. Increased opposition from well-organized local communities that previously had little or no voice in dam construction decisions also played a role in the slowdown. Dam construction is now on the rise again, however, in large part driven by Chinese development plans, financing, and construction. China is pushing forward with a new era of massive construction, both on Chinese or shared international rivers and in countries far distant. This global economic expansion is driven by China's growing need for food, minerals, power, timber, and other resources from outside its own borders. The expansion is being accompanied by environmental, social, and political consequences that are poorly understood, growing in scope and scale, and likely to lead to political tensions unless efforts are made to apply international standards for sustainable economic and environmental development.

References

African Resources Working Group (ARWG). 2009. A Commentary on the Environmental, Socioeconomic and Human Rights Impacts of the Proposed Gibe III Dam in the Lower Omo River Basin of Ethiopia. http://www.arwg-gibe.org

Bangkok Post. 2010. China's dams killing Mekong. Editorial. *Bangkok Post.* http://www.bangkokpost.com/opinion/opinion/33467/china-dams-killing-mekong (accessed January 31, 2011).

BankTrack. 2011. Belinga Dam Project. http://www.banktrack.org/show/dodgydeals/belinga_iron_ore_project (accessed February 4, 2011).

Baran, E., and Myschowoda, C. 2009. Dams and fisheries in the Mekong Basin. *Aquatic Ecosystem Health and Management* 12(3): 227–234.

Bosshard, P. 2009. China dams the world. *World Policy Institute*26(4): 43–51.

Bosshard, P. 2010a. The Gibe 3 Dam—A Test Case for China's Role in Africa. International Rivers Network. August 9, 2010. http://www.internationalrivers.org/blog/peter-bosshard/2010-8-9/gibe-3-dam-%E2%80%93-test-case-china%E2%80%99s-role-africa (accessed February 4, 2011).

Bosshard, P. 2010b. Of Rivers and Rights. Presentation to the Stockholm World Water Week session on the World Commission on Dams, Stockholm, Sweden. http://www.worldwaterweek.org/documents/WWW_PDF/2010/tuesday/K11/Peter_Bosshard_World_Commission_on_Dams10.pdf

British Broadcasting Corporation (BBC). 2006. China executes dam protester. December 7, 2006. http://news.bbc.co.uk/2/hi/asia-pacific/6217148.stm

Chen, M. 2010. Public Participation in Environmental Decision-making Process in China: A Case

Study of the Anti-Nu River Dam Campaign in Yunnan Province. MPP paper. Oregon State University, Corvallis, Oregon, June 4, 2010. http://ir.library.oregonstate.edu/jspui/bitstream/1957/16261/1/meian-chen.pdf

Chino, T. 2000. President, Asian Development Bank. Letter to Prof. Kadar Asmal, chair, World Commission on Dams, December 22, 2000.

Christian Science Monitor. 2010. Amid Burma (Myanmar) election, China-built dam highlights plight of ethnic minorities. *Christian Science Monitor,* November 8. http://www.csmonitor.com/World/Asia-South-Central/2010/1108/Amid-Burma-Myanmar-election-China-built-dam-highlights-plight-of-ethnic-minorities (accessed February 4, 2011).

Cushing, K.K. 2002. The World Commission on Dams report: What next? In: *The World's Water 2002–2003*. P.H. Gleick, editor. Washington, D.C.: Island Press, pp. 149–172.

Doyle, A. 2010. New monkey found in Myanmar near China dam project. *Reuters*, October 27, 2010. http://www.reuters.com/article/2010/10/27/us-monkey-idUSTRE69P5CH20101027 (accessed February 4, 2011).

Dubash, N.K, Dupar, M., Kothari, S., and Lissu, T. 2001. A Watershed in Global Governance? An Independent Assessment of the World Commission on Dams. Draft Report. July 5, 2001. Washington, D.C.: World Resources Institute. Also, the final report, released November 21, 2001. http://www.wri.org/governance/wcdassessment.html

Eng, M., and Ma, J. 2006. *Building Sustainable Solutions to Water: Conflicts in the United States and China.* China Environment Series. Washington, D.C.: Woodrow Wilson International Center for Scholars, pp. 155–184.

Fuggle, R., and Smith, W.T. 2000. Large Dams in Water and Energy Resource Development in the People's Republic of China (PRC). Hydrosult Canada Inc. and Agrodev Canada Inc. Country review paper prepared as an input to the World Commission on Dams, Cape Town, South Africa. http://www.dams.org

Gleick, P.H. 1998. The status of large dams: The end of an era? In: *The World's Water 1998-1999*. Washington, D.C.: Island Press, pp. 69–104.

Gleick, P.H. 2008a. China and water. In: *The World's Water 2008–2009*. Washington, D.C.: Island Press, pp. 79–100.

Gleick, P.H. 2008b. Three Gorges Dam project, Yangtze River, China. In: *The World's Water 2008-2009*. Washington, D.C.: Island Press, pp. 139–150.

Goh, E. 2004. China in the Mekong River Basin: The Regional Security Implications of Resource Development on the Lancang Jiang. Rajaratnam School of International Studies Working Papers 069/04. Nanyang Technological University. http://dr.ntu.edu.sg/bitstream/handle/10220/4469/RSIS-WORKPAPER_73.pdf?sequence=1 (accessed January 30, 2011).

Haggart, K. 2006. Dam protester put to death in secret, rushed execution. *Three Gorges Probe* news service. http://chinaview.wordpress.com/2006/12/13/china-dam-protester-put-to-death-in-secret-rushed-execution/

Hathaway, T. 2010. Chinese Loan Underwrites Lake Turkana Destruction, International Rivers Network. September 17, 2010. http://www.internationalrivers.org/en/node/5819 (accessed February 4, 2011).

Hydroworld. 2010. Ethiopia, China Sign Agreement for Gibe III Hydro Project Construction. May 17, 2010. http://www.hydroworld.com/index/display/article-display/0251345340/articles/hrhrw/News-2/2010/05/ethiopia_-china_sign.html (accessed February 4, 2011).

Johnston, L. 2009. *Ethiopia—Gibe III Hydropower Project Trip Report—January 12–30*. EGAT/ESP. Washington, D.C.: USAID.

Larson, C. 2009. Foreign policy: No merriness for Chinese dissidents. *National Public Radio,* December 29, 2009. http://www.npr.org/templates/story/story.php?storyId=122001021 (accessed February 6, 2011).

Loures, F., Rieu-Clarke, A., and Vercambre, M-L. 2009. Everything You Need to Know About the UN Watercourses Convention. Gland, Switzerland: World Wildlife Fund.

MacLeod, C. 2010. China's new dam seen as a water hog. *USA Today*, April 22, 2010. http://www.usatoday.com/news/world/environment/2010-04-21-china-dam_N.htm (accessed February 20, 2011).

McDonald, K., Bosshard, P., and Brewer, N. 2008. Exporting dams: China's hydropower industry goes global. *Journal of Environmental Management* 90(3): S294–302.

Mehta, S. 2010. Indian NGOs Urge China and India to Protect Himalayan Rivers. International Rivers Network. September 13, 2010. http://www.internationalrivers.org/en/2010-9-13/indian-ngos-urge-china-and-india-protect-himalayan-rivers

Moore, D. 2001. Commissioner, World Commission on Dams. Statement made at Berkeley Energy and Resources Group Spring 2001 Colloquium, "The World Commission on Dams: An Experiment in Global Policy Making," March 21, 2001, Berkeley, California.

Oregon State University (OSU). 2011. International River Basin Registry, http://www.transboundarywaters.orst.edu/publications/register/tables/IRB_asia.html (accessed February 14, 2011).

Osborne, M. 2000. The strategic significance of the Mekong. *Contemporary Southeast Asia* 22(3): 429–444.

Peissel, M. 1997. *The Last Barbarians. The Discovery of the Source of the Mekong in Tibet.* New York: Henry Holt.

Piyathamsawat, P. 2010. Activists say Chinese dam hurts Myanmar traders. *Associated Press*, December 14, 2010.

Polgreen, L. 2009. Pristine Africa park faces development. *New York Times*, February 21, 2009.

Qiang, W. 2010. China's environmental civilian activism. *Science* 328 (May 14): 824.

Saikia, P. 2011. China's Longjiang Dam: Concerns for Myanmar. *Eurasian Review News and Analysis*, January 15, 2011. http://www.eurasiareview.com/analysis/china%E2%80%99s-longjiang-dam-concerns-for-myanmar-15012011/ (accessed February 4, 2011).

Shih, T.H. 2010. Ethiopia dam blot on China's record. *South China Morning Post*, June 7, 2010. http://www.internationalrivers.org/node/5476 (accessed February 4, 2011).

Stockholm International Water Institute (SIWI). 2010. World Commission on Dams +10: Revisiting the Large Dam Controversy. September 7, 2010. http://www.worldwaterweek.org/sa/node.asp?node=750&sa_content_url=%2Fplugins%2FEventFinder%2Fevent.asp&id=3&event=319

Stone, R. 2010. Severe drought puts spotlight on Chinese Dams. *Science* 327(5971): 1411.

U.S. Energy Information Agency (US EIA). 2011a. China Electricity. http://www.eia.doe.gov/cabs/China/Electricity.html (accessed February 4, 2011).

U.S. Energy Information Agency (US EIA). 2011b. International Energy Statistics. http://tonto.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=7 (accessed 4, 2011).

Vörösmarty, C.J., Leveque, C., and Revenga, C. 2005. *Ecosystems and Human Well-Being*. Volume 1, *Current State and Trends: Freshwater Ecosystem Services.* Millennium Ecosystem Assessment. Washington, D.C.: Island Press.

Vörösmarty, C.J., Meybeck, M., Fekete, B., Sharma, K., Green, P., and Syvitski, J.P.M. 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. *Global and Planetary Change* 39 (1–2) (October): 169–190. doi:10.1016/S0921-8181(03)00023-7.

Vörösmarty, C.J., and Sahagian, D. 2000. Anthropogenic disturbance of the terrestrial water cycle. *BioScience* 50: 753–765.

Watts, J. 2011. China's big hydro wins permission for 21.3GW dam in world heritage site. *The Guardian*, February 1, 2011. http://www.guardian.co.uk/environment/2011/feb/01/renewableenergy-china (accessed February 1, 2011).

World Bank. 2001. The World Bank and the World Commission on Dams Report Q&A. http://siteresources.worldbank.org/INTWRD/903857-1112344791813/20424164/WB&WCDQ&A.pdf. March (accessed February 7, 2011).

World Commission on Dams (WCD). 2000. *Dams and Development: A New Framework for Decision-Making*. London: Earthscan Publications.

Yardley, J. 2007. Chinese dam projects criticized for their human costs. *New York Times*, November 19, 2007.

C H A P T E R 7

U.S. Water Policy Reform

Juliet Christian-Smith, Peter H. Gleick, and Heather Cooley

The United States faces a bevy of persistent and emerging water challenges in the 21st century. Many key water laws and policies are outdated or not effectively or equitably enforced. An increasing number of aquatic ecosystems are in danger of collapse. Many cities, businesses, and farms are not taking advantage of existing, cost-effective water conservation technologies and practices. Much of the nation's infrastructure is outdated and will become increasingly obsolete as climate change alters the timing and magnitude of water supplies. Rising energy demands and shifts in energy sources, such as increased ethanol and natural gas production, are putting additional pressure on the nation's water resources. In turn, increased water demand for growing populations will have important energy implications.

Although many water problems are local and must be resolved at the local and state levels, the federal government has a role in developing and implementing appropriate national policies as well. These responsibilities are not being adequately fulfilled by the diverse federal agencies responsible for different aspects of water management and regulation. One part of the problem is confusion over authority. Another part is the failure of the executive branch in recent years to request sufficient funds to protect and manage our water resources, and of the legislative branch to appropriate and allocate those funds. A third part of the problem is old ideas that do not account for the realities of the 21st century and for recent advances in our scientific and technical understanding of both water problems and solutions. Finally, part of the problem is a lack of vision.

The U.S. is not alone in having inadequate water policies—indeed, very few countries in the world are fully engaged in efforts to revamp outdated institutions, laws, technologies, and strategies for managing freshwater. But in recent years, a number of countries have, for various reasons, begun to tackle difficult questions and to put in place new and innovative approaches to sustainable water management. This chapter will look at some of these experiences and their similarities, examining lessons relevant to challenges that the U.S. now faces and offering some recommendations for a 21st century national water policy. A book now in preparation will look at these issues in more detail (Christian-Smith and Gleick, in press).

Background

More than four decades ago, the U.S. Congress recognized the need for a more rational, comprehensive approach to water resource planning and management, passing the National Water Commission Act (P.L. 90-515). The Act called for the creation of a

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_7,

National Water Commission to "review present and anticipated national water resource problems, making such projections of water requirements as may be necessary and identifying alternative ways of meeting these requirements—giving consideration, among other things, to conservation and more efficient use of existing supplies, increased usability by reduction of pollution, innovations to encourage the highest economic use of water, interbasin transfers, and technological advances." The commission's work culminated in a nearly 600-page report to Congress, concluding, among other things, that collaboration among agencies must be improved, that better water data must be collected, and that the beneficiary-pays principle should be applied more rigorously to water supply and infrastructure projects (NWC 1973).

Since the 1970s, the nation has seen some important strides in water management, including significant improvements in wastewater treatment and point source pollution associated with the implementation of the Clean Water Act, as well as an overall reduction in per-capita water use associated with increased water conservation and efficiency and changes in the economic structure of the country. However, the nation's fragmented approach to water has continued even as new cross-cutting challenges surface, such as emerging contaminants in public drinking water supplies, increased competition among water users, and climate change.

Persistent and emerging water challenges are apparent worldwide and have recently served as the basis for some governments to reassess their approach to water management. In the past few decades, South Africa, Australia, the European Union, and Russia have all passed innovative water policies, signaling a growing commitment to more comprehensive, integrated water management shaped by a variety of political, economic, environmental, and social factors. Because of the differing characteristics of water resources and political frameworks, governing mechanisms vary considerably across these countries. Yet, despite these variations, all four reform efforts include several similar components, including:

- Recognition of declining ecosystems and persistent water-quality problems;
- Better water data collection;
- Decentralized water decision making;
- Increased stakeholder participation;
- Clarification of institutional roles and responsibilities, such as through formal legislation and changes in water rights; and
- Application of more modern economic approaches, including principles of "user pays" and "polluter pays" and "full-cost pricing."

In this chapter, we discuss each of these water reform efforts in more detail and then consider the principles that are relevant for U.S. water policy makers and managers.

International Water Reform Efforts

More and more countries are facing and addressing water challenges, and there is growing experience with different approaches and solutions. Although the individual experiences described here for South Africa, Australia, the European Union, and Russia are not likely to be widely replicated because of economic, political, and cultural differences, they do offer lessons and insights that may prove to be informative and widely useful.

South Africa

South Africa has been at the vanguard of water reform efforts—it was one of the first to engage in significant water reform, including writing human and ecosystem water rights into the new constitution and then passing a comprehensive new National Water Act in 1998, four years after the end of apartheid. The Act was lauded as a progressive piece of policy, with the redress of past injustices as one of its overarching aims (Movik 2009). In addition, the constitution and the Act embodied the recognition that "nature" must have a "water right" if the natural environment was to continue to support and sustain human endeavors. The new reforms defined the "reserve," which refers to both an ecological reserve that requires a minimum level of instream flow to ensure ecosystem sustainability, and a human reserve, which requires quantities of water necessary to meet basic human needs. This reserve must be met before water is to be allocated to other uses and demands.

The Act also created compulsory national water-quality and supply standards, standard water tariffs, and regulations for water services providers to follow in order to provide a framework for local government to provide efficient, affordable, economical, and sustainable access to water services. The rules support the principles contained in both the constitution and the Act and help to give meaning to the right of access of all people to a basic level of clean water provision.

In terms of management, the country was partitioned into 19 water management areas based on drainage regions, to be governed by Catchment Management Agencies. The purpose of the agencies was first and foremost described as coordinating and promoting public participation in water management (Anderson 2005), though it was envisaged that these responsibilities could be expanded to include setting and collecting water-use charges and issuing water-use licenses (Schreiner and Van Koppen 2002).

In the past decade, significant progress has been made in providing basic water and sanitation for millions of people who had previously been denied these services. By some estimates, about 15 million people lacked safe water supply and more than 20 million lacked adequate sanitation services in 1990. According to the World Health Organization and the United Nations Children's Fund, access to improved water supply in rural areas, where most of the unserved or underserved live, increased from 66 percent in 1990 to 78 percent in 2008, implying that more than 10 million people had gained access (WHO/UNICEF 2010). Far less progress has been made in sanitation, however, and water-quality improvements are also lagging. Data from 2004, for example, also showed that fewer than 50 percent of water-service providers had programs in place to monitor drinking water quality (WHO/UNICEF 2010).

In 2005, the Drinking Water Quality Regulation Program was established, requiring microbial and chemical water-quality testing and setting compliance standards. The government also developed the "Blue Drop" status, which is awarded to water service providers who are at or above 95 percent compliance with water-quality standards. In

2010, 100 percent of the municipal authorities had water-quality monitoring programs in place, though only 26 municipalities had been awarded Blue Drop status, out of over 150 municipalities (Republic of South Africa 2011), and far less progress has been made outside the main cities, where rural populations still face serious water-quality challenges. In addition, Movik (2011) reports that there has been little progress to date in terms of redistributing water use rights.

Australia

Australia has been presented with a remarkable series of water challenges in recent years. Like many other regions, growing populations and economic demands have led to rising water diversions for agricultural and urban use. In turn, increased human use of water has been accompanied by emerging environmental problems, including decreased water quality, loss of wetlands, toxic cyanobacterial blooms, and increases in soil salinity. Over the past decade, these issues have been exacerbated by severe and prolonged drought and extreme flooding, considered by Australian scientists and others to be the explicit indications of impacts from human-induced climate change (see Chapter 5). Between 1997 and 2006, runoff to the country's main agricultural region, the Murray-Darling Basin, was 21 percent lower than the historical average (CSIRO 2008). And, 2006 marked the lowest annual runoff on record in the Murray River system (Figure 7.1).

Although recurrent drought conditions are common in the Murray-Darling basin, there is growing scientific evidence that climate change is influencing these extremes (see Chapter 5). Australia's Bureau of Meteorology predicts that within two to three decades, drought will occur twice as frequently and be twice as severe (Schneider 2009). In 2007, Australia launched a reform of its water-management system to try to address this new, water-scarce reality, passing the Commonwealth Water Act. The Act and accompanying intergovernmental agreements have seen constitutional rights over water resources in the Murray-Darling Basin assigned by the states to the Commonwealth and investment of approximately $13 billion Australian dollars (about US$10.5 billion) in water-reform measures, including:

- Federalizing water data collection;
- Requiring greater regulatory reporting (e.g., water balances and a National Water Account);
- Moving to full-cost recovery for all water infrastructure and services;
- Creating a market for water trading (based on tradable property rights and in combination with a review of existing caps on water extractions);
- Increasing on-farm efficiencies (e.g., canal lining, drip irrigation, shifting to more water-efficient crops); and
- Purchasing water entitlements from willing sellers to restore aquatic ecosystems.

Australia's water reform has been closely tied to increasing the efficiency of water use, largely through a water rights market. The water market alone has been credited with halving water consumption, particularly in drought-prone regions like the Murray-Darling Basin. The Act also created a new federal repository of water monitoring and

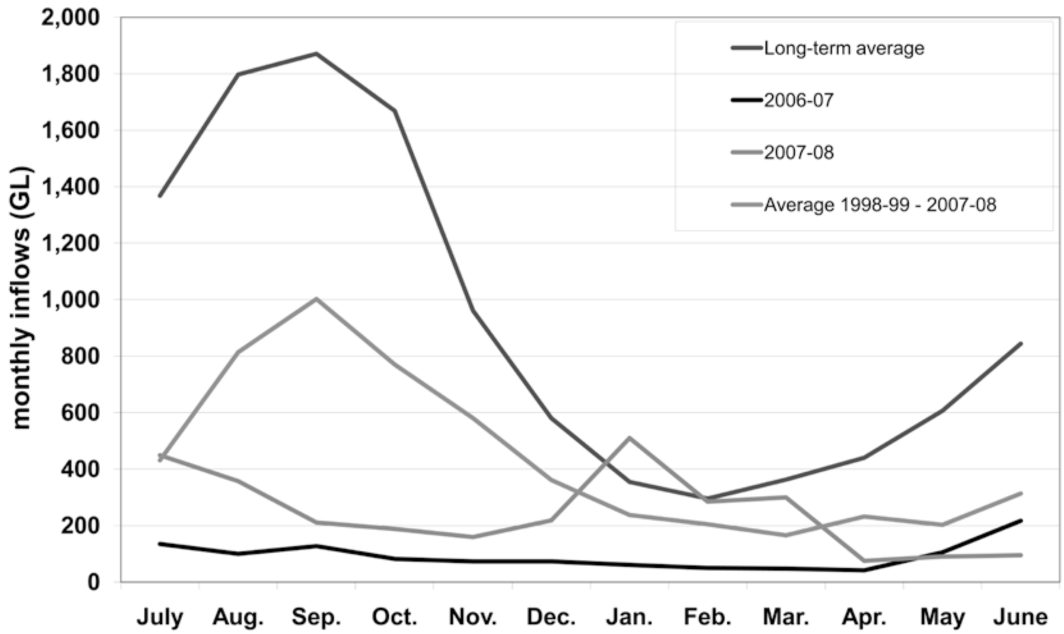

Figure 7.1 Monthly Inflows into the Murray River System.
Source: Craik and Cleaver, 2008.

measurement information. These data are considered critical for adequate water-quality and water-quantity protection. For more information about the impact of Australia's water reforms, see Chapter 5.

European Union

The European Union Water Framework Directive was passed in 2000 (Directive 2000/60/EC). The directive rewrote and centralized water policy for member states into one piece of legislation that encompasses three main issue areas that had previous been addressed only separately, and incompletely. The "three pillars" of the legislation are as follows:

- Ecology—all water bodies must reach "good" ecological status by 2015;
- Governance—new water management authorities were created at the river basin scale and were charged with more participatory decision making; and
- Economy—water suppliers should aim for full-cost recovery and begin economic analyses to charge the "true cost" of water by 2010.

Each pillar has its own series of measures to be enacted within a specific timeframe (Table 7.1). Beginning with the ecology pillar, the directive set the target of "good" ecological status and established a decision-making process to determine whether surface-water and groundwater bodies are in bad, poor, moderate, or good status. In order to attain "good" status, the physical, chemical, hydro-morphological, and biological elements must show very slight to no alterations from reference conditions (reference areas are chosen to reflect a lack of human disturbance). After characterizing all of the water bodies within a river basin district, river basin authorities are responsible for setting up monitoring programs, establishing a series of objectives and measures to achieve "good" status, and inscribing these in a river basin management plan (Bouleau 2008).

Article 3 of the directive requires member states to designate "Competent Water Authorities" for implementing river basin characterization and management plans. Competent authorities must ensure coordination among all stakeholders and bodies concerned with water management in order to draft these plans. In addition, Article 14 insists on the active involvement of all interested parties in the production, review, and iterative updates of the river basin management plans. This primarily involves consultation rather than active participation, as the directive states that member states shall "publish and make available for comments to the public a timetable and a work program . . . an interim overview of the significant water management issues . . . draft copies of the management plan." For each step, the public has at least six months to comment in writing on those documents and to provide access to background documents and information upon request.

In contrast with the narrow ecological definitions of the legislation, the very broad definitions of governance procedures may lead to widely different interpretations and implementation in member states. Depending on institutional and political contexts, competent authorities may be national bodies (e.g., the Environment Agency in England and the National Institute of Water in Portugal) or more local ones (e.g., river basin water agencies in France). In many ways, the directive leaves the governance

Table 7.1 Timeline for the Implementation of the European Union Water Framework Directive

Year	Issue	Policy Reference
2000	Directive entered into force.	Article 25
2003	Transposition into national legislation. Identification of river basin districts and authorities.	Article 23 and Article 3
2004	Characterize river basins through pressures, impacts, and economic analysis.	Article 5
2006	Establish monitoring network. Start of public consultation (at the latest).	Article 8 and Article 14
2008	Present draft river basin management plan.	Article 13
2009	Finalize river basin management plan, including program of measures.	Article 13 and Article 11
2010	Introduce pricing policies.	Article 9
2012	Implement program of measures.	Article 11
2015	Meet environmental objectives. First management cycle ends. Create second river basin management plan and first flood risk management plan.	Article 4
2021	Second management cycle ends.	Article 4 and Article 13
2027	Third management cycle ends; final deadline for meeting objectives.	Article 4 and Article 13

Source: Adapted from the European Commission, http://ec.europa.eu/environment/water/water-framework/info/timetable_en.htm.

issues flexible in order for member states with very different sociopolitical contexts to determine how they will organize implementation to achieve the goals (Grantham et al. 2008).

The directive also calls for an economic analysis of water uses in each river basin district. This economic analysis is necessary to make the relevant calculations necessary for taking into account the principle of cost recovery, using estimates of volume, prices, and costs of water services; estimates of present and forecasts of future investments; and estimates of the social, environmental, and economic effects of recovery. The analysis should also consider long-term forecasts of supply and demand for water in the river basin district in order to make judgments about the most cost-effective combination of measures to inform the Program of Measure (Article 11) and River Basin Management Plan (Article 13) (Bouleau 2008). Economic analysis is currently lagging behind the implementation of most other aspects of the Directive. And, some member states (e.g., Greece and Malta) have not yet reported on their surface water monitoring programs as required by the Directive (Commission of the European Communities 2009).

Russia

In 2006, Russia rewrote its water code (Russian Federation Water Code No. 174-ФЗ) to focus on integrated regional water management. The code's founding principles are that protection of water bodies (both surface and ground) takes priority over use, that usage shall not harm the environment, and that utilization be prioritized toward drinking and other domestic purposes (Simpson 2007). Some of the code's innovations include its river basin approach, the introduction of integrated water basin management schemes, and, in theory, improved involvement of civil society in decision making.

The new code sets new water-quality standards with maximum allowable concentrations for a range of chemicals, nuclear substances, microorganisms, and other contaminants. These norms are developed by responsible federal executive authorities for each water basin. For water bodies that are used for drinking water supply, special pollution prevention zones are established. A system of regulations and bans now apply to sewage discharges, along with new regulations constraining dumping and discharges of harmful substances.

Finally, Russia's new law establishes a monitoring system at the water basin level to provide regular observations on water quality and quantity, regimes of water use, data processing, and updating of a state water register. The state water register, to which there is free access (Article 31), is a compilation of data on water bodies and water basins, water quality and quantity, water use, water-related facilities, and water protection zones. It also provides access to legal agreements and decisions on water use. The new water code is only just beginning to be implemented broadly, so its impact on water management and use is still relatively unclear.

Common Themes and "Soft-Path" Solutions

While these varied international initiatives have different cultural dimensions and political imperatives, they share a commitment to many "soft-path" water solutions addressed in previous volumes of *The World's Water* (see, for example, Wolff and Gleick 2002). The "soft path" approach defines a new strategy for more sustainable water management and use that recognizes the limits to traditional approaches. It recognizes the importance of critical ecological services, such as nutrient cycling, flood protection, aquatic habitat, waste dilution and removal, and aesthetic values, while also satisfying human uses, such as the provision of clean drinking water, hydropower, agriculture, commercial fishing, and recreation. Soft-path solutions rely less on traditional hard infrastructure that transports water over large distances or centralized water supply and wastewater treatment. Rather, soft-path solutions encourage more local water-supply options, greater water conservation and efficiency (e.g., the use of low-flow devices in homes and businesses and the use of precision irrigation technologies on farms), using water more than once (e.g., graywater and recycled water), managing local surface and groundwater resources together, smarter use of economics (e.g., water pricing and innovative markets), and developing better urban and agricultural practices to retain water (e.g., low-impact development, rainwater harvesting, and conservation tillage).

Part of the impetus for the international water reforms described earlier include the perception that new approaches will be less expensive than traditional hard-supply options, that they will be less energy intensive and produce fewer greenhouse gas emissions, that they are more likely to be acceptable to local communities if public involvement is encouraged rather than ignored, and that they are likely to be more sustainable in the long term if the institutions created are adaptable, flexible, and able to manage for increased uncertainty in the future. This includes an explicit understanding that adaptation to climate changes will be inevitable, as in the Australian case, and that meeting basic needs for ecosystems and humans together is a top priority, as in the South African, Australian, and Russian cases. Many of these principles are relevant for the challenges now facing U.S. water policy makers and managers.

A 21st Century U.S. Water Policy

Conventional water management approaches in the U.S. have not been focused on comprehensive and integrated policies or soft-path solutions. Human systems and ecological systems have been managed separately or not at all. Economic tools are ineffective or absent, with few consistent water-pricing approaches and little effort to permit markets. And, management at the federal level involves segregation, disconnection, and isolated agencies and policies split into individual "silos" (Brooks et al. 2009). In response to the growing concerns around current and future water quality and supply, U.S. water policy must begin to address these obstacles and develop a more comprehensive approach to stewarding the nation's precious water resources. Below we offer several overarching conclusions of a new assessment of water management (Christian-Smith and Gleick, in press) and make specific recommendations for developing a 21st century national water policy.

Federal water-related agencies and programs are fragmented and require better coordination. More than 30 federal agencies, boards, and commissions in the United States have water-related programs and responsibilities. The complex legal and institutional framework of water management has evolved over two centuries and has never undergone comprehensive review or integration. The result is an incomplete and often inefficient approach to water management at the federal level that has been noted by numerous commissions, advisory boards, and councils over the years. Given the persistent and emerging challenges of the 21st century, the time is ripe for an integrated and comprehensive approach to national water policy (Neuman 2001, Leshy 2009). Although many water issues will remain local, to be resolved by community efforts, the national government can no longer ignore the more effective role it can play both in the U.S. and abroad by integrating some of the common principles of the water reform efforts discussed earlier. Following are key steps to a 21st century national water policy.

Clarify Institutional Roles and Responsibilities

Currently, more than 30 federal agencies and programs have water-related responsibilities. Few of these agencies' central missions are related to water and, therefore, none is ultimately responsible for the combination of land- and water-use impacts that have led to 42 percent of the nation's total stream length being classified as in poor condition (US EPA 2006).

The Office of Science, Technology, and Policy's Committee on Environment, Natural Resources, and Sustainability should be tasked with developing a national strategy for water protection. Such a strategy would define a protocol to assess existing pressures and potential threats to interstate surface and groundwater; recommend amendments, or new legislation, to bring interstate watersheds under existing regulatory authorities; develop a framework for systematic collection and dissemination of national water data; and serve as a focus for improved communication among federal agencies.

Decentralize Water Management and Increase Stakeholder Participation

The U.S. had a series of active river basin commissions first devised by the Hoover Commission on the Reorganization of the Executive Branch and supported in recommendations of the Cooke Commission, the Presidential Advisory Committee on Water Resources Policy, the National Water Commission, and the Western Water Policy Review Advisory Committee (Neuman 2010). In 1981, the majority of these commissions were eliminated by a single executive order (Executive Order 12319, President Ronald Reagan). As noted above, modern water management approaches such as those developed by the European Union, Russia, and South Africa recognize the importance of watersheds as a key to more effective and sustainable water management.

U.S. river basin commissions should be reconstituted, particularly in basins with ongoing disputes; commissions should be tasked with developing river basin management plans that become a gateway for federal funding. For example, grants for improved water management that are now dispersed through separate agencies and programs (e.g., the Farm Service Agency, the Environmental Protection Agency, and State Revolving Loans) could instead be integrated to prioritize projects developed through comprehensive river basin management plans.

A national water council composed of diverse, nonfederal experts, including leaders of the environmental justice movement, should be formed to develop guidelines and requirements to ensure that river basin management plans are scientifically rigorous and participatory, identify key threats to water resources, and recommend projects that address those threats. The council's responsibilities could also include reviewing all water-related budgets and making recommendations for key priorities. Broader participation and transparency is another hallmark of new international approaches to sustainable water management, as shown by the language in the Russian, South African, and European Union examples. The commission's first task should be to develop guidance documents for the river basin commissions in terms of creating scientifically rigorous, participatory river basin management plans. In addition, a national water commission could make recommendations for reducing the risks of international tensions over shared water resources, including how to resolve concerns with Mexico and Canada over shared water systems. These recommendations would be valuable in other international river basins where the United States' experience, international stature, and expertise can be effective.

Collect More Comprehensive Water Data

The nation lacks an adequate understanding of water supply, use, and flows. A consistent theme across all of the water reform efforts discussed earlier was improved water data collection and availability. In the U.S., Congress must prioritize funding for programs that provide critical information about the hydrology, quality, and use of the nation's water resources, including the U.S. Geological Survey's stream gage program, the national water census, and the Environmental Protection Agency's water-quality monitoring programs.

Apply Modern Economic Principles

Water pricing is often thought of as a local or state concern in the U.S. However, many modern water management strategies require integrating more sound economic principles into water pricing and applying pricing mechanisms where they are missing. In the U.S., the federal Bureau of Reclamation is the largest wholesaler of water in the West and therefore is directly involved in setting water rates for those customers. Instead of achieving full-cost recovery, the Bureau's water rates are heavily subsidized. In 1973, the National Water Commission recommended discontinuing the subsidization of new irrigation projects, writing: "Direct beneficiaries of Federal irrigation developments should pay in full the costs of new projects allocated to irrigation." Nearly four decades later, this recommendation has largely been ignored. The U.S. should reform pricing policies that subsidize the inefficient use of water. The Central Valley Project Improvement Act, passed by Congress in 1992, among other things required the Bureau of Reclamation to institute tiered water rates to encourage conservation. This requirement for conservation pricing should be extended to all Bureau projects and should be designed carefully so that tiered rates actually apply to current rates of water use and provide incentives for improving water-use practices.

In addition, we suggest creating new financing strategies to improve the administration of water-related laws. Rather than simply expanding federal investment, we recommend an approach that, first, requires increased local cost shares to reduce the amount spent on federal grants; encourages more local investment through continued federal capitalization of state revolving funds; encourages better local cost recovery through appropriate water-pricing policies; and raises fees on polluters to be re-invested in agencies that regulate water pollution. Again, these economic tools are increasingly being used worldwide to discourage unsustainable water practices.

Integrate Changing Climatic Conditions

The Government Accountability Office reports that although many federal resource managers understand that climate change impacts are important to the resources that they manage, they have not yet incorporated climate change projections, mitigation, or adaptation efforts into planning (GAO 2009). Although there has been increased collaboration on improving data collection and information dissemination in regard to the impacts of climate change on water supply, a coordinated national strategy is still lacking.

The passage of the Secure Water Act (2009) calls for the establishment of a Climate Change and Water Intra-governmental Panel, which primarily focuses on downscaling climate data and conducting individual basin studies (beginning with the Colorado, Yakima, and Milk/St. Mary river basins). This is critical in terms of enhancing our scientific understanding of climate change impacts, but such mitigation and adaptation efforts should be accelerated. The Council on Environmental Quality's recently formed Interagency Climate Change Adaptation Task Force finds that "there still are significant gaps in the U.S. government's approach to climate change adaptation and building resilience" (White House Council on Environmental Quality 2010). The Interagency Climate Change Adaptation Task Force should be tasked with developing national strategy for climate change adaptation.

In addition, the federal government should require states to develop adaptation planning documents (preparing contingency plans for both floods and droughts and identifying vulnerable communities). States should develop and submit these plans every five years to the Climate Change Adaptation Task Force for review. New financing available for climate change adaptation will be predicated on the approval of plans by the Climate Change Adaptation Task Force.

Transition from a Focus on Increasing Water Supply to Reducing Water Demand

The traditional approach to meeting water needs has been to increase water supply, building massive, capital-intensive infrastructure such as large dams and reservoirs, centralized water and wastewater treatment plants, and extensive pipelines and aqueducts. This approach has brought many benefits, permitting the nation to feed an ever-growing global population, reducing the incidence of water-related diseases, mitigating the threat of both floods and droughts, and supporting continued economic growth. But it has also come at great social, economic, and environmental costs, many of which were either ignored, undervalued, or unknown at the time. For example, many dams—including Kenzua Dam in Pennsylvania, Shasta Dam in California, the Tennessee Valley Authority dams in the Southeast, and American Falls Dam in Idaho—flooded communities and forced residents to relocate. Nearly 40 percent of North American freshwater and diadromous fish species are imperiled because of physical modifications to rivers and lakes (Jelks et al. 2008). Dams have been constructed on the most appropriate sites; the remaining sites provide fewer benefits at higher and higher costs.

As a result of these constraints, water managers are beginning to look seriously at new ways to enhance water supplies and are rethinking approaches to managing demand to ensure that sufficient water resources are available to meet anticipated needs. New emphasis should be placed on improving the overall productivity of water use rather than seeking endless sources of new supply; matching water quality to the users' needs (e.g., making better use of water waste streams, including stormwater, graywater, and recycled water); meeting basic human and ecosystem water needs as a top priority; and integrating decision making across sectors (e.g., water demand, flood management, and land-use planning, to promote projects or facilities that produce multiple services).

Conclusions

The 21st century brings with it both persistent and new water challenges, including growing human populations and demands for water, unacceptable water quality in many areas, weak or inadequate water data collection and regulation, and growing threats to the timing and reliability of water supply due to climate change. Several countries have reformed their water policies to better address these challenges. The political and cultural contexts of these reforms have varied, but these international water reforms reflect a greater focus on soft-path water solutions to address declining ecosystems and inequitable water policies, including water conservation and efficiency, smarter water pricing, polluter-pays, and more participatory water management.

The United States has not followed suit and continues to rely on a fragmented and outdated approach to water policy based on a patchwork of old laws, competing institutions, and aging infrastructure. In this chapter, we have laid out a path toward a more integrated national water policy for the U.S. Our recommendations draw on the unique characteristics of the United States' water system together with insights drawn from recent international water reforms, in an effort to help identify a more effective and sustainable approach to federal water management.

References

Anderson, A.J. 2005. Engaging Disadvantaged Communities: Lessons from the Inkomati CMA Process. Paper presented at the international workshop on African Water Laws: Plural Legislative Frameworks for Rural Water Management in Africa, January 26–28, 2005, Johannesburg, South Africa.

Bouleau, G. 2008. The WFD dreams: Between ecology and economics. *Water and Environment Journal* 22(4): 235–240.

Brooks, D., Brandes, O.M., and Gurman, S., eds. 2009. *Making the Most of the Water We Have: The Soft Path Approach to Water Management.* London: Earthscan.

Christian-Smith, J., and Gleick, P.H., eds. In press. *A 21st Century U.S. Water Policy.* London: Oxford University Press.

Commission of the European Communities. 2009. Report from the Commission to the European Parliament and the Council in Accordance with Article 18.3 of the Water Framework Directive

2000/60/EC on Programmes for Monitoring of Water Status. http://ec.europa.eu/environment/water/water-framework/implrep2007/pdf/com_209_156_en.pdf (accessed February 28, 2011).

Commonwealth Scientific and Industrial Research Organization (CSIRO). 2008. Water Availability in the Murray-Darling Basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. from www.csiro.au/mdbsy (accessed February 28, 2011).

Craik, W., and Cleaver, J. 2008. Modern agriculture under stress—Lessons from the Murray-Darling. The Murray-Darling Basin Commission. MDBC Publicaton 46/08. Canberra, Australia.

Government Accountability Office (GAO). (2009). Climate Change Adaptation: Strategic Federal Planning Could Help Government Officials Make More Informed Decisions. GAO-10-113. http://www.gao.gov/products/GAO-10-113 (accessed February 28, 2011).

Grantham, T., Christian-Smith, J., Kondolf, G.M., and Scheuer, S. 2008. *A Fresh Perspective for Managing Water in California: Insights from Applying the European Water Framework Directive to the Russian River.* Water Resources Center Report 208. Berkeley, California: Water Resources Center.

Jelks, H.L., Walsh, S.J., Burkhead, N.M., Contreras-Balderas, S., Díaz-Pardo, E., Hendrickson, D.A., Lyons, J., Mandrak, N.E., McCormick, F., Nelson, J.S., Platania, S.P., Porter, B.A., Renaud, C.B., Schmitter-Soto, J.J., Taylor, E.B., and Warren Jr., M.L. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. *Fisheries* 33(8): 372–406.

Leshy, J. 2009. Notes on a progressive national water policy. *Harvard Law and Policy Review* 3: 133–159.

Movik, S. 2009. *The Dynamics and Discourses of Water Allocation Reform in South Africa.* STEPS Working Paper 21. Brighton, United Kingdom: STEPS Centre.

Movik, S. 2011. Allocation discourses: South African water rights reform. *Water Policy* 13(2): 161–177.

National Water Commission (NWC). 1973. *Water Policies for the Future: Final Report to the President and to the Congress of the United States by the National Water Commission.* Washington, D.C.: U.S. Government Printing Office.

Neuman, J.C. 2001. Federal water policy: An idea whose time will (finally) come. *Virginia Environmental Law Journal* 20: 107–118.

Neuman, J.C. 2010. Are we there yet? Weary travelers on the long road to water policy reform. *Natural Resources Journal* 50: 139–166.

Republic of South Africa, Department of Water Affairs. 2011. Blue Drop System. http://www.dwa.gov.za/dir_ws/DWQR/default.asp (accessed February 21, 2011).

Schneider, K. 2009. Australia's food bowl, like The world's, is drying up. *Circle of Blue Water News*, March 9, 2009. http://www.circleofblue.org/waternews/2009/world/australia-drought-water-warning/ (accessed February 9, 2010).

Schreiner, B., and Van Koppen, B. 2002. Catchment management agencies for poverty eradication in South Africa. *Physics and Chemistry of the Earth* 27(11): 969–976.

Simpson, J. 2007. Safeguarding the World's Water. Cabri-Volga Brief, 3/4.

U.S. Environmental Protection Agency (US EPA). 2006. Wadeable streams assessment: A collaborative survey of the nation's streams. EPA 841-B-06–002. Washington, D.C.: Office of Research and Development and Office of Water, US Environmental Protection Agency.

White House Council on Environmental Quality. (2010). Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. http://www.whitehouse.gov/sites/default/files/microsites/ceq/Interagency-Climate-Change-Adaptation-Progress-Report.pdf

Wolff, G., and Gleick, P.H. 2002. The soft path for water. In: *The World's Water 2002–2003*. P.H. Gleick, editor. Covelo, California: Island Press.

World Health Organization and United Nations Children's Fund (WHO/UNICEF). 2010. Estimates for the Use of Improved Drinking Water Sources: South Africa. Joint Monitoring Programme for Water Supply and Sanitation. March 10, 2010. http://www.wssinfo.org/fileadmin/user_upload/resources/ZAF_wat.pdf (accessed February 19, 2011).

Bottled Water and Energy

Peter H. Gleick and Heather Cooley

The consumption of "bottled water"—fresh water sold in individual, consumer-sized containers—is growing rapidly. More than 200 billion liters of bottled water were sold in 2008 (the last year for which reliable, public data are available), mostly in North America and Europe, but with rapidly expanding sales in many developing countries as well.[1]

During that same year, the Beverage Marketing Corporation, which tracks beverage sales, estimated that consumers in the United States purchased around 33 billion liters of bottled water, or an average of more than 110 liters (nearly 30 gallons) per person. Bottled water sales have increased by 70 percent since 2001 in the United States, though they declined slightly in 2008 from the previous year. They now far surpass the sales of milk and beer (Table WB 1.1). The only beverage category with larger sales is carbonated soft drinks.

Bottled water is purchased by consumers for a wide variety of reasons, ranging from convenience to worry over the availability and quality of potable water from municipal systems. But new efforts are under way to cut the use of bottled water and to address its major environmental and social consequences. Among the issues of growing public concern are the impacts of water extractions on local watersheds, equity issues associated with commercializing a public resource, the environmental consequences of producing and disposing of plastic bottles, and the energy (and resulting greenhouse gas emissions) required to bottle water (Gleick 2010). We address the issue of energy here (and in detail in Gleick and Cooley 2009).

Energy to Produce Bottled Water

Energy is required in all segments of the bottled water supply chain, from production to packaging, transportation, chilling, use, and recycling. The total amount of energy needed is complicated by many factors, including the location and type of the water source, the distance from the bottler to the consumer, the types of material and packaging used, the method of transportation, and much more. Gleick and Cooley (2009) compute the energy required to bring the water to the consumer, including specifically the energy to make the plastic materials used in bottles, fabricate that plastic into the actual bottles, process the water prior to bottling, fill and seal the bottle, transport the

1. This Water Brief is modified and updated from Gleick and Cooley (2009).

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_8,

Table WB 1.1 Sales of Major Beverages in the United States, 2006

Beverage	Million Liters
Carbonated Soft Drinks (regular and diet)	57,169
Bottled Water (95% still and 5% sparkling)	31,238
Beer	24,489
Milk	21,476

Sales of bottled water in 2008 increased from 2006 to approximately 33 million liters.
Source: ERS 2007.

product to the end user, and chill it for use. Rather than compute a single energy factor for bottled water, we offer three examples to explore the range of bottled water energy requirements from production to point of sale.

Energy Required to Manufacture Plastic Bottles

Bottled water is sold in containers ranging from small eight-ounce or half-liter containers popular in school lunches to the multi-gallon bottles used in home and office water coolers. Most single-use plastic water bottles are made out of polyethylene terephthalate (PET). PET is a thermoplastic polymer resin used for a wide variety of purposes, ranging from the production of polyester fibers and clothing to food and beverage containers. In the United States, PET is easily recognized by the recycling code "1" (Figure WB 1.1), which is imprinted on the bottle to help consumers identify and recycle different forms of plastics. Some larger containers, such as those used in office coolers, are made from polycarbonate, which has greater rigidity at large sizes and requires approximately 40 percent more energy to produce than bottle-grade PET (Bousted 2005).

Energy is embodied in PET material itself, and additional energy is required to turn PET into bottles. This energy is typically supplied by natural gas and petroleum, along with electricity from the local electricity grid. Two comprehensive life-cycle assessments for producing PET and PET bottles have been completed; these indicate that the energy required to produce PET resin is approximately 70 to 83 megajoules (MJ) (thermal) per kilogram of PET resin (Bousted 2005, Franklin Associates 2007).[2] Producing preforms and turning them into bottles requires an additional 20 MJ per kilogram of finished bottle. The total energy used in producing PET bottles, including some transportation energy to move the resin to the point where bottles are produced and then filled, is thus about 100 MJ per kilogram, or 100,000 MJ per ton of PET.

The mass of PET required per bottle depends on the style, thickness, and size of the bottle. Research from the Pacific Institute indicates that an average 1-liter bottle weighs approximately 38 grams, excluding the cap, which typically weighs an additional 2 grams (Gleick and Cooley 2009). Some manufacturers have launched new efforts to reduce the amount of PET required to make a water bottle. In 2007, Logoplaste Group in Portugal announced a new line of lightweight preforms with a 0.33-liter bottle weighing 11.5 grams (35 g/l) (Pittman 2006). Nestlé produces a lightweight half-liter bottle weighing 12.2 grams (or around 24.4 g/l) and is experimenting with the production of a 1.5-liter PET bottle weighing between 28 and 33 g (or between 18 and 22 g/l). The Coca-Cola

2. All energy units here are thermal, unless otherwise specified as electrical—e.g., $kWh_{(e)}$. All conversions of thermal to electrical assume an efficiency of 0.33—i.e., three kWhr (thermal) equal one kWhr (electrical).

Figure WB 1.1 Recycling Code for Polyethylene Terephthalate (PET). These codes, introduced in 1988 by the plastics trade association (the Society of the Plastics Industry, Inc.), help consumers identify and recycle different forms of plastics.

Company recently introduced a new 20-ounce bottle weighing 18.6 grams (or around 31.5 g/l).

Combining the estimate of the energy required to make PET and form it into bottles with the average weight-to-volume data results in a manufacturing energy cost of around 4.0 MJ per a typical one-liter PET bottle weighing 38 grams. This estimate includes the energy required to convert raw materials into PET resin, the energy required to turn resin into bottles ready for filling, and the energy to transport PET or bottles to the filling plant.

If all bottled water required an average of 38 grams of PET per liter, approximately 3.8 million tons of PET were required to produce the 100 billion liters of bottled water containers sold worldwide in 2008. If all bottled water producers shifted toward the lightest bottles, PET production could be reduced by around 30 percent. These estimates exclude any PET waste generated during bottle production or used for the packaging (such as the label, carton, or plastic wrapping) of the final retail product. Using these data, we estimate that approximately one million tons of PET were produced to make the plastic bottles consumed in the United States in 2008, and three million tons were produced globally. Producing the PET bottles to satisfy global bottled water demand thus required approximately 300 billion MJ of energy, or the energy equivalent of approximately 50 million barrels of oil per year.[3] The use of recycled materials could lead to additional energy savings, but almost all plastic bottles for water are currently made from virgin PET.

Energy to Process Bottled Water

Energy is also required to prepare water for bottling. Bottled water usually comes from two primary sources: municipal water systems (often called "processed" or "purified" or "municipal" water) and surface-water and groundwater systems (often called "spring" water). Both sources typically undergo some kinds of additional filtering or purification, even municipal waters that are already treated to meet drinking water purity standards (Figure WB 1.2).

Treatment processes can include micro- or ultrafiltration, ozonation, ultraviolet radiation, and reverse osmosis. As shown in Table WB 1.2, energy (typically electricity) requirements vary considerably among the various water-treatment techniques. Disinfecting water with ultraviolet radiation, for example, requires as little as 10 $\text{kWh}_{(e)}$ per million liters (SBW Consulting, Inc. 2006). Energy requirements for reverse osmosis, however, can be as high as 1,600 $\text{kWh}_{(e)}$ per million liters for source water with a total

3. Not all the energy used to make these bottles is oil, or even fossil fuels; thus, we use the common comparison of "energy equivalent."

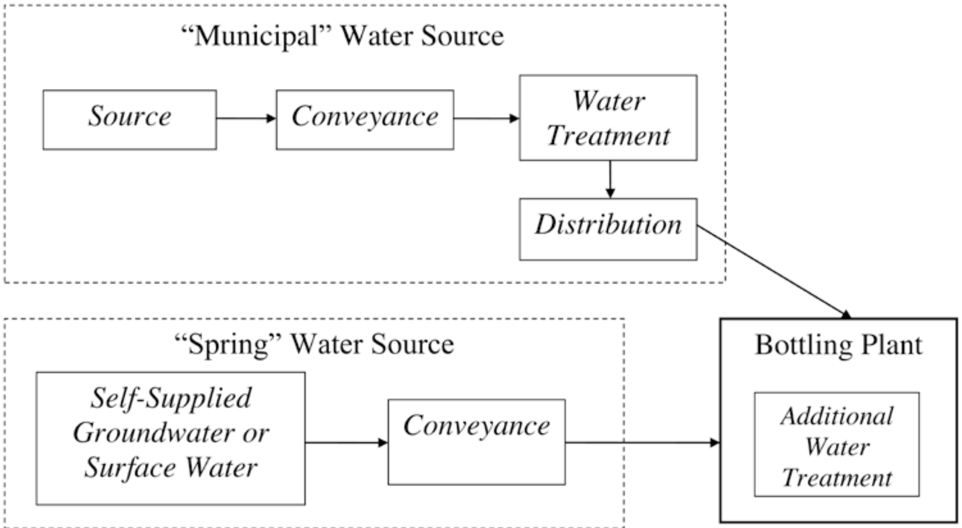

FIGURE WB 1.2 TYPICAL PROCESS DIAGRAM FOR BOTTLING WATER FROM A MUNICIPAL OR SPRING WATER SOURCE.
Source: Gleick and Cooley 2009

dissolved solids concentration of 4,000 parts per million (AWWA 1999) and even higher for desalinating seawater. Several companies worldwide are selling bottled water desalinated from seawater.

No public data are available on the number of bottling plants that employ the various treatment methods. Thus, the energy requirements for treating most municipal or spring waters at the bottling plant range from 10 $kWh_{(e)}$ per million liters for simple ultraviolet radiation alone to as high as 1,800 $kWh_{(e)}$ per million liters for treatment involving UV, filtration, ozone, and reverse osmosis. Even with this wide range, however, the typical energy requirements for processing water, even extensive processing, are small relative to the energy associated with the plastic bottle and its production. Extensive treatment requires only between 0.0001 and 0.02 $MJ_{(th)}$ per liter, a small fraction of the energy embedded in the PET bottle itself.

Energy to Clean, Fill, Seal, and Label Bottles

Following the production of the bottles and the treatment of the water, additional machines rinse, fill, cap, and label PET bottles. A review of energy specifications from nine major manufacturers shows that typical machines use between 0.002 and 0.01 MJ per bottle for machines that handle between 3,000 and 39,000 bottles per hour (Gleick and Cooley 2009). The average machine can clean, fill, and seal around 15,000 bottles per hour and requires 0.006 MJ per bottle.[4] High-volume labeling and packaging machines, such as those produced by Sacmi Industries, can label 36,000 to 42,000 bottles per hour using 27 $kWh_{(e)}$ per hour,[5] or around 0.008 MJ per bottle. Thus, the total energy required

4. We assume here an average ratio of 3 kW (thermal) per kW (electrical), and all energy use totals are presented as thermal equivalents.

5. Reported power requirements for a Sacmi beverage bottle labeler. Personal communication, Sacmi Industries, 2009.

TABLE WB 1.2 Energy Requirements for Water Treatment Methods

Treatment Technique	Energy Use ($kWh_{(e)}$/million liters)	Data Sources
Ozone		
Pre-oxidation (pre-treatment)	30	SBW Consulting 2006
Disinfection	100	SBW Consulting 2006
Ultraviolet Radiation (medium pressure)		
Bacteria	10	SBW Consulting 2006
Viruses	10–50	SBW Consulting 2006
Microfiltration/Ultrafiltration	70–100	SBW Consulting 2006
Nanofiltration (Source TDS = 500–1,000 ppm)	660	AWWA 1999
Reverse Osmosis		
Source TDS = 500 ppm	660	AWWA 1999
Source TDS = 1,000 ppm	790	AWWA 1999
Source TDS = 2,000 ppm	1,060	AWWA 1999
Source TDS = 4,000 ppm	1,590	AWWA 1999
Seawater Desalination (reverse osmosis)	2,500–7,000	NRC 2008

to clean, fill, seal, label, and package bottled water is around 0.014 MJ per bottle, or only about a third of a percent (0.34 percent) of the energy embodied in the bottle itself.

Energy to Transport Bottled Water

After the production of bottled water, more energy is required to move the finished product to markets. Because water is heavy—weighing one metric ton per cubic meter—energy associated with transporting bottled water can be significant. The total transportation energy requirements depend on two major factors: the distance from the bottling plant to the market and the mode of transportation.

Numerous government energy and transportation ministries, including the U.S. Department of Energy, the U.S. Department of Transportation, the European Union, and Natural Resources Canada, have compiled and analyzed data on the energy costs of different modes of freight transportation. Table WB 1.3 summarizes typical transportation energy-intensity values for major modes of freight transportation in megajoules per metric ton of cargo per kilometer transported. Air cargo is by far the most energy-intensive mode of transportation; truck transportation is more energy intensive than transportation by rail or bulk ocean shipping.

The distance from the bottling plant to the final point of consumption varies significantly with the type of bottled water. From a practical point of view, "purified water" is usually produced by treating and packaging municipal water in major demand centers close to markets. These products are bottled at local bottling plants spread across the country near major urban areas, with deliveries to local markets. The Coca-Cola Company, PepsiCo, and other major bottlers produce treated municipal waters in many major cities for local distribution, often at the same plants producing soft drinks and other beverages.

In contrast, "spring" waters are usually packaged at specific, single sources and transported, sometimes significant distances, to points of demand. Nestlé, for example, bottles water under the Arrowhead label at plants in Southern California for distribution

Table WB 1.3 Transportation Energy Costs

Cargo Ship/Ocean (MJ/t-km)	Air Cargo (MJ/t-km)	Rail (MJ/t-km)	Heavy Truck (MJ/t-km)	Medium Truck (MJ/t-km)
0.37	15.9	0.23	3.5	6.8

All values in units of megajoules per ton cargo per kilometer (MJ/t-km) traveled. Heavy trucks are typically used for long-distance and inter-city freight transport. Medium trucks are typically used for intra-city freight delivery.

Source: US DOE (2007); Natural Resources Canada (2007).

throughout their western markets, and bottles water under the Poland Spring label in Maine for distribution in eastern markets. More extreme examples include Fiji Spring Water, which is packaged at the source in the South Pacific, or Evian water, which is packaged at the source in France and then shipped to markets around the world.

Energy requirements for transportation can be evaluated using data in Table WB 1.3 and assumptions about the distance traveled. Gleick and Cooley (2009) evaluated three different transportation scenarios for products shipped to the major Los Angeles, California, market: (1) processed municipal water that is distributed locally by truck; (2) spring water produced in the south Pacific (such as Fiji Spring Water), transported by ship to Los Angeles, and distributed locally by truck; and (3) spring water packaged in France (such as Evian), shipped to the eastern United States, transported by freight railcars to Los Angeles, and distributed locally by truck.

The transportation energy cost varies significantly among these scenarios (Table WB 1.4) and will vary with different assumptions about distance and transport mode. The scenarios summarized in Table WB 1.4, however, represent the approximate minimum and maximum energy costs, unless bottled water is shipped any distance by air. Locally packaged and marketed purified bottled water delivered within 200 kilometers of a bottling plant by truck has a total transportation energy cost of around 1.4 MJ per liter. Spring water transported across the Pacific from Fiji to Los Angeles and then delivered locally within 100 kilometers has a total transportation energy cost of 4.0 MJ/liter. French spring water shipped by truck from the source to French ports, by ship across the Atlantic, by train from the East Coast of the U.S. to Los Angeles, and then locally by truck has a transportation energy cost of around 5.8 MJ per liter.

Energy to Cool Bottled Water Prior to Use

Energy is also required to cool the bottled water prior to sale or consumption, including the energy to cool the water from room temperature to the temperature of the refrigerator or commercial display cooler, and the energy to maintain the cold water until it is sold. For the first component, Gleick and Cooley (2009) estimate that bottled water is cooled from a room temperature of around 20.0°C to a typical refrigerator or cooler temperature of around 3.3°C. Given that the specific energy of water is around 4.2 KJ per kilogram per degree K, we estimate that cooling one liter of water 17°C requires 220 KJ, or 0.2 MJ per liter.

The second component depends on the length of time the bottled water is kept cool before consumption and the energy performance of the refrigerator. As of October 2008, more than 1,000 refrigerators met the U.S. Energy Star standards for efficiency. These refrigerators had an average volume of 17 cubic feet and used 450 $kWh_{(e)}$ per year, or

TABLE WB 1.4 Transportation Scenario Assumptions for Bottled Water Consumed in Los Angeles Metropolitan Region with Distances by Mode of Transport

Scenario	Medium Truck (km)	Heavy Truck (km)	Rail (km)	Cargo Ship (km)	Total Energy Cost (MJ/l)
Local production	200 (local delivery)	0	0	0	1.4
Spring water from Fiji	100 (local delivery)	0	0	8,900 (Fiji to Long Beach)	4.0
Spring water from France	100 (local delivery)	600 (Evian to Le Havre)	3,950 (New York to Los Angeles)	5,670 (Le Havre to New York)	5.8

Note: Distances in kilometers (km); Total energy in megajoules per liter (MJ/l).

around 8.65 $kWh_{(e)}$ per week. No data are available on the time the average consumer chills bottled water before consuming, but if we assume that a consumer keeps a liter of bottled water cold for a week before consuming it, then the energy required to maintain the cool bottle is another 0.2 MJ per liter.

Summary of Energy Uses

Table WB 1.5 summarizes the total energy requirements for capturing, conveying, and treating bottled water, producing the plastic bottles, and cooling the water prior to sale, given the assumptions described above. Based on these assumptions, the total energy required for bottled water will typically range from 5.8 MJ to 10.2 MJ per liter. In comparison, producing tap water typically requires about 0.005 MJ per liter for treatment and distribution (Burton 1996), making bottled water 1,000 to 2,000 times more energy intensive depending on the distance bottled water has to move from production to market.

Conclusions

This Water Brief summarizes research (done at the Pacific Institute and published in a peer-reviewed journal) on the energy footprint required for various phases of bottled water production, transportation, and use. For water transported short distances, the energy requirements of bottled water are dominated by the energy to produce the plastic bottles. Long-distance transport, however, can lead to energy costs comparable to or even larger than the energy to produce the bottle. Far less energy is needed for processing and treating the water, and for cooling bottles for retail sale. We did not evaluate waste disposal or recycling here. Transportation costs are highly variable, ranging from 1.4 MJ for water produced within 200 kilometers of the consumer market to 5.8 MJ for water produced in France and sold in Los Angeles. Combining all of the energy input totals, we estimate that producing bottled water requires between 5.6 and 10.2 MJ per liter—as much as 2,000 times the energy cost of producing tap water. Given an annual consumption of 33 billion liters of bottled water in the U.S., we estimate that the annual

Table WB 1.5 Total Energy Requirements for Producing Bottled Water

	Energy Intensity ($MJ_{(th)}/l$)
Manufacture Plastic Bottle	4.0
Treatment at Bottling Plant	0.0001 to 0.02
Fill, Label, and Seal Bottle	0.01
Transportation: range from three scenarios	1.4 to 5.8
Cooling	0.2 to 0.4
Total	**5.6 to 10.2**

We assume here an average ratio of 3.0 kWh(thermal) per kWh(electrical) and 3.6 MJ/kWh.

consumption of bottled water in the U.S. in 2007 required an energy input equivalent to between 32 and 54 million barrels of oil, or a third of a percent of total U.S. primary energy consumption—around 17 million barrels of oil equivalent to make the plastic bottles and the rest for other parts of the supply chain. Roughly three times this amount was required to satisfy global bottled water demand.

References

American Water Works Association (AWWA). 1999. *Reverse Osmosis and Nanofiltration.* AWWA Manual M46. Denver, Colorado: American Water Works Association.

Bousted, I. 2005. Eco-profiles of the European plastics industry: Polycarbonate. Plastics Europe. March 2005. http://lca.plasticseurope.org/pc7.htm (accessed May 2007).

Burton, F.L. 1996. *Water and Wastewater Industries: Characteristics and Energy Management Opportunities.* Palo Alto, California: Electric Power Research Institute (EPRI).

Economic Research Service (ERS). 2007. *Food Availability Data Sets.* Washington, D.C.: U.S. Department of Agriculture. http://www.ers.usda.gov/Data/FoodConsumption/FoodAvailSpreadsheets.htm#beverage (accessed May 2007).

Franklin Associates. 2007. Cradle-to-Gate Life Cycle Inventory of Nine Plastic Resins and Two Polyurethane Precursors. The Plastics Division of the American Chemistry Council. http://www.nrel.gov/lci/database/default.asp (accessed June 14, 2008).

Gleick, P.H. 2010. *Bottled and Sold: The Story Behind Our Obsession with Bottled Water*. Washington, D.C.: Island Press.

Gleick, P.H., and Cooley, H.S. 2009. Energy implications of bottled water. *Environmental Research Letters* 4. doi:10.1088/1748-9326/4/1/014009. http://iopscience.iop.org/1748-9326/4/1/014009/pdf/erl9_1_014009.pdf

Hemphill, G. 2007. Beverage Marketing Corporation. Personal communication, October 11, 2007.

National Research Council (NRC). 2008. *Desalination: A National Perspective*. Washington, D.C.: National Academies Press.

Natural Resources Canada. 2007. Canadian Freight Transportation Secondary Energy Use by Energy Source and Transportation Mode. http://www.oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tableshandbook2/tran_00_8_e_1.cfm?attr=0 (accessed November 14, 2008).

Pittman, S. 2006. Logoplaste launches Europe's lightest PET bottle. *Packwire.com*. http://www.foodproductiondaily.com/Packaging/Logoplaste-launches-Europe-s-lightest-PET-bottle (accessed May 19, 2011).

SBW Consulting, Inc. 2006. Municipal Water Treatment Plant Energy Baseline Study. Prepared for the Pacific Gas and Electric Company, Bellevue, Washington.

U.S. Department of Energy (US DOE). 2007. Transportation Energy Indicators. http://intensityindicators.pnl.gov/trend_data.stm (accessed November 14, 2008).

WATER BRIEF 2

The Great Lakes Water Agreements

Peter Schulte

The Great Lakes comprise the largest surface freshwater system on Earth, containing roughly 84 percent of the freshwater in North America and about 21 percent of the world's total freshwater supply (see Figure WB 2.1). The Great Lakes Basin is home to more than 30 million people in the United States and Canada and accounts for 7 percent of American farm production and 25 percent of Canadian farm production (US EPA 2008). Freshwater is among the region's most valuable and important resources—economically, ecologically, and culturally. In the last century, however, these resources have been subjected to heavy pollution and increased withdrawals and diversions often leading to adverse ecological and community impacts. In response, many have called for more effective and coordinated management of the Basin's freshwater resources. The Great Lakes–St. Lawrence River Basin Water Resources Compact (not to be confused with the Great Lakes Basin Compact of 1968) is the most recent and comprehensive in a long series of legislative actions to strengthen and coordinate basin water management while protecting it from use by interests outside the region.

History of Shared Water Resource Management

Water management concerns in the Great Lakes Basin have for decades been largely centered on concerns about pollution and diversion of the water resources and how best to protect those resources from out-of-basin interests. Given the location of the basin at the border of the U.S. and Canada, many of these problems—and the policies designed to address them—are transboundary in nature.

Since the early 20th century, many compacts, treaties, and agreements have sought to coordinate management of the basin's water resources (Table WB 2.1). These agreements have evolved from an emphasis on data collection to more comprehensive water management policies and procedures. The latest round of adjustments was initiated in 1998, when the Province of Ontario approved a permit for a private interest to extract 160 million gallons of Lake Superior water per year to be sold in Asia.[1] This led to a public outcry both in Ontario and neighboring U.S. states that rely on Lake Superior water. In response, the Great Lakes governors and the premiers of Ontario and Quebec negotiated

1. As a Canadian province, Ontario was not subject to out-of-basin diversion restrictions established in the Water Resources Development Act of 1986.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_9,

FIGURE WB 2.1 THE GREAT LAKES BASIN: HISTORY OF SHARED WATER RESOURCE MANAGEMENT.
Source: Pacific Institute 2011.

and then, in 2001, signed "Annex 1" to the 1985 Great Lakes Charter, which committed the parties to develop a collaborative water management system for the basin (CGLG 2010).

After significant further efforts, eight U.S. states and two Canadian provinces[2] signed the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement in 2005. This agreement provided a framework within which these states and provinces can collaboratively protect and manage their shared freshwater resources (CGLG 2005a). The United States then developed the Great Lakes–St. Lawrence River Basin Water Resources Compact to set forth the policies and practices by which the U.S. states adhere to their commitments under the Agreement. In 2008, it was ratified by all eight states, approved by the U.S. Congress, and signed by President George W. Bush (US EPA 2009; GLWI 2009). The Compact becomes fully binding in 2013 when states are required to formally establish their own water withdrawal regulation and management programs (SOP DEP 2011).

2. Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Wisconsin, Quebec, and Ontario are the 10 states and provinces that signed the Agreement.

Table WB 2.1 Compacts, Agreements, and Legislation Governing the Management of Great Lakes Basin Freshwater Resources

Name	Year	Stipulations / Function
Boundary Waters Treaty	1909	Established the International Joint Commission to examine and resolve disputes between the U.S. and Canada over use of the Great Lakes freshwater resources (GLWI 2009)
Great Lakes Basin Compact	1968	Established the Great Lakes Commission, whose authority was largely limited to collecting data, publishing reports, and making nonbinding technical and policy recommendations related to water management in the basin
The Great Lakes Water Quality Agreement	1972, 1978 (renewed)	Reaffirmed the rights and obligations of both countries under the Boundary Waters Treaty and outlined a series of commitments to ensure protection of basin ecosystems
The Great Lakes Charter	1985	Established a prior notice and consultation process for large water withdrawals, a cooperative resource-management program, and a Water Resource Management Committee to identify data needs, among other things (voluntary, not legally binding) (CGLG 2001)
The Water Resources Development Act	1986	Required approval from all eight states for any diversions taking water out of the basin (GLWI 2009)
Annex 1 to the Great Lakes Charter	2001	Committed basin states and provinces to develop a collaborative water-management system for the basin (Squillace 2007)
Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement	2005	Outlines framework for management system committed to in 2001 Annex (CGLG 2005a)
Great Lakes–St. Lawrence River Basin Water Resources Compact	2008	Establishes procedures and policies that constitute American adherence to the 2005 Agreement (CGLG 2005b)

Function and Governance of the Agreement and Compact

The goals of the 2005 Agreement are to maintain and strengthen cooperative and sustainable management, ecosystem protection, and data collection established in previous agreements. It also seeks to move beyond the previous agreements by adapting management models to changing climate conditions (which is quite uncommon for transboundary water agreements [Cooley et al. 2009]), emphasizing public participation in Basin management, and incorporating elements of the precautionary principle into the decision-making processes (CGLG 2005a, Squillace 2007). The Agreement is notable in that it provides a framework for jointly managing both surface and ground waters within the basin (CGLG 2005a).

The 2008 Compact also has a number of important features. Unlike the Great Lakes Basin Compact of 1968, which was consultative in nature, the 2008 Compact is legally binding and calls for state-level management plans that define a process by which to manage new withdrawals and diversions (GLC 2003, CGLC 2005b). The major stipulations agreed to in the Compact include (1) a requirement that each state create a program to manage and regulate all new or increased withdrawals in their jurisdiction; (2) stringent restrictions on new or increased diversions outside the basin; and (3) an inventory, registration, and reporting requirement for all withdrawals in excess of 100,000 gallons per day, among other provisions (CGLC 2005b). The Compact exempts removal of water in small containers (i.e., commercial bottled water) or water included in other products (e.g., beverages, paint) from its out-of-basin diversion restrictions (CGLC 2005b). It does not specify a threshold volume for regulation of withdrawals or a process by which to do so but, rather, leaves this to the individual states (Squillace 2007).

The Compact explicitly calls for the creation of the Great Lakes–St. Lawrence River Basin Water Resources Council to act as its main governing body. The Council consists of the governors of the eight U.S. member states, who are tasked with conducting research, collecting data, and overseeing disputes related to the water management of the basin (CGLC 2005b, Squillace 2007). Each member of the Council is given one vote, and decisions brought before the Council are decided by simple majority (CGLC 2005b). Each governor has veto power over any out-of-basin diversions (even when water is diverted out of basin but within member states) in excess of five million gallons per day (Squillace 2007). The Council of Great Lakes Governors (CGLG)—established in 1983 to promote regional cooperation on a wide range of issues—acts as the secretariat to the Great Lakes–St. Lawrence River Basin Water Resources Council (CGLC 2011). While technically a separate entity from the CGLC, the 2008 Council consists of the same membership and could be seen as an expansion of the CGLG's authority.

Support for and Criticisms of the Compact

The Compact has been widely supported and lauded for pioneering the way for sustainable and collaborative whole-basin management schemes across state and national boundaries. Many contend that whole-basin management that cuts across political borders provides a better opportunity to address concerns of sustainability and ecosystem health, and to generally manage and regulate the natural resource more coherently and effectively (Ericson 2007, Forster and Marley 2008, PEC 2008, Office of Betty Sutton 2008).

However, the Compact has also faced numerous criticisms, typically regarding ideological views on the appropriate ownership of water resources. Some, such as Ohio state senator Tim Grendell, believe that the Compact puts all water resources in the public trust, threatening property owners' rights to groundwater (Henry 2007, Oosting 2008). Others, such as U.S. representative Bart Stupak, assert that bottled water's exemption from the Compact's diversion ban may allow private interests to bypass the Compact and take Great Lakes water out of the public trust (Egan 2008).

In addition to these debates, some have questioned the effectiveness of the Compact's stipulations in meeting its stated objective of ensuring sustainable use of freshwater resources and ecological integrity in the Basin. For instance, one critique laments the Compact's and Agreement's marginalization of the International Joint Commission, calling the Compact a move away from true bilateral dispute resolution (as enacted by the Boundary Waters Treaty of 1909) to a largely subnational approach (Parrish 2006). Another contends that the Compact is inconsistent with respect to definitions for "diversions" and "products," potentially opening the door for weaker state control over water exports. This same critique argues that, despite apparent commitments to public participation and addressing climate change, the Compact in fact has few provisions that implement these commitments in meaningful ways (Olson 2006).

Professor Mark Squillace of the University of Colorado Law School has provided one of the most pointed critiques (see Squillace 2007). He contends that the Compact's focus on new withdrawals as opposed to existing withdrawals and consumptive uses severely limits its ability to address adverse impacts on freshwater ecosystems. He further argues that the Compact inappropriately restricts state power to divert water to areas within their state lines but outside the basin. Further, the Compact's ban on out-of-basin diversions may place greater strain on nearby watersheds that have less water to begin with, effectively transferring environmental impacts out of the basin rather than minimizing them. While prohibiting out-of-basin diversions, the Compact does not provide any stipulations on the diversion of water from watershed to watershed within the basin. Because of this, it may not adequately protect from significant ecological impacts in certain areas within the basin, particularly vulnerable upper watersheds (Squillace 2007).

Conclusion

Several decades of negotiations and legislation have led to the creation of the Great Lakes Compact—a unique transboundary, whole-basin approach to water management in the Great Lakes Basin. The Compact highlights a commitment to collaborative management of shared freshwater resources with the aim of preventing the disjointed and ineffective water management seen in many parts of the world. That said, given the highly sensitive nature of water—ecologically, politically, and culturally—the Compact has inevitably led to a wide range of concerns regarding its impacts on the environment, property rights, and states' rights, as well as debates as to whether it is structured in a way that best enables sustainable water use and ecosystem protection. Answers to these questions remain to be seen but will become clearer after the full provisions of the Compact come into effect and are implemented.

References

Cooley, H., Christian-Smith, J., Gleick, P.H., Allen, L., and Cohen, M. 2009. Understanding and Reducing the Risks of Climate Change for Transboundary Waters. Pacific Institute. http://www.pacinst.org/reports/transboundary_waters/transboundary_water_and_climate_report.pdf (accessed February 20, 2011).

Council of Great Lakes Governors (CGLG). 2001. The Great Lakes Charter: Principles for the Management of the Great Lakes Water Resources. http://www.cglg.org/projects/water/docs/GreatLakesCharter.pdf (accessed February 20, 2011).

Council of Great Lakes Governors (CGLG). 2005a. Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement. http://www.cglg.org/projects/water/docs/12-13-05/Great_Lakes-St_Lawrence_River_Basin_Sustainable_Water_Resources_Agreement.pdf (accessed February 20, 2011).

Council of Great Lakes Governors (CGLG). 2005b. Great Lakes–St. Lawrence River Basin Water Resources Compact. http://www.cglg.org/projects/water/docs/12-13-05/Great_Lakes-St_Lawrence_River_Basin_Water_Resources_Compact.pdf (accessed February 20, 2011).

Council of Great Lakes Governors (CGLG). 2010. Project Background, Organization and Road to Development. http://www.cglg.org/projects/water/CompactEducation/Project_Background_Organization_and_Road_to_Development.pdf (accessed February 20, 2011).

Council of Great Lakes Governors (CGLC). 2011. Great Lakes Water Management. http://www.cglg.org/projects/water/index.asp (accessed February 20, 2011).

Egan, D. 2008. Congressman raises concerns over Great Lakes Compact. *Milwaukee Journal-Sentinel: JSOnline*, August 1, 2008. http://www.jsonline.com/news/wisconsin/29397949.html (accessed February 20, 2011).

Ericson, M. 2007. Understanding the Great Lakes Compact. National Wildlife Federation. http://www.theoec.org/PDFs/water/GLC_NWFShortVer.pdf (accessed February 20, 2011).

Forster, S., and Marley, P. 2008. Great Lakes compact passes. *Milwaukee Journal-Sentinel*, May 14, 2008. http://www.midwestadvocates.org/media/coverage/2008/5-14-08%20MJS%20Great%20Lakes%20Comact%20Passes.htm (accessed February 20, 2011).

Great Lakes Commission (GLC). 2003. The Great Lakes Basin Compact. http://www.glc.org/about/glbc.html (accessed February 20, 2011).

Great Lakes Water Institute (GLWI). 2009. Our Waters: The Great Lakes Compact. University of Wisconsin-Milwaukee School of Freshwater Sciences. http://www.glwi.uwm.edu/ourwaters/documents/GreatLakesCompact.pdf (accessed February 20, 2011).

Henry, T. 2007. Great Lakes water-compact backers, foes stand ground on water diversion limits. *Toledo Blade*, November 19, 2007.

Office of United States Representative Betty Sutton of Ohio's 13th District. 2008. Sutton Praises Signing of Great Lakes Compact. http://sutton.house.gov/news/story.cfm?id=157 (accessed February 20, 2011).

Olson, J. 2006. Navigating the Great Lakes Compact: Water, public trust, and international trade agreements. *Michigan State Law Review* 2006: 5. http://www.commonslearningalliance.org/sites/default/files/Olson.pdf (accessed May 19, 2011).

Oosting, J. 2008. Ohio lawmaker fighting to change Great Lakes Compact. *Mlive.com*, April 2, 2008. http://www.mlive.com/environment/index.ssf/2008/04/ohio_lawmaker_fighting_to_chan.html (accessed February 20, 2011).

Parrish, A. 2006. Mixed blessings: The Great Lakes Compact and Agreement, the IJC, and international dispute resolution. *Michigan State Law Review* 2006: 5. http://www.msulawreview.org/PDFS/2006/5/Parrish.pdf (accessed February 20, 2011).

Pennsylvania Environmental Council (PEC). 2008. PEC Praises House Passage of Great Lakes Compact. http://www.pecpa.org/node/301 (accessed February 20, 2011).

Squillace, M.S. 2007. Rethinking the Great Lakes Compact. *Michigan State Law Review.* University of Colorado Law School Legal Studies Working Paper No. 07-01. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=960574 (accessed February 20, 2011).

State of Pennsylvania Department of Environmental Protection (SOP DEP). 2011. Great Lakes Withdrawal, Consumptive Use, and Diversion Baseline. http://www.dep.state.pa.us/river/news/baseline.htm (accessed February 20, 2011).

United States Environmental Protection Agency (US EPA). 2008. Great Lakes: Basic Information. http://www.epa.gov/glnpo/basicinfo.html (accessed February 20, 2011).

United States Environmental Protection Agency (US EPA). 2009. The Great Lakes Water Quality Agreement. http://www.epa.gov/glnpo/glwqa/1978/index.html (accessed February 20, 2011).

Water in the Movies

Peter H. Gleick

Water is a theme that runs through all forms of popular culture, from books to myths to Hollywood and international films, with a growing number of shorter video pieces posted online at YouTube and similar sites. A surprising number of popular movies, going back almost to the first days of movie-making, have incorporated the issue of water disputes and conflicts over water rights and allocation as a central theme. Below is a list of some of these classic (good and bad) films. I've also included a few links to online shorter videos related to water. Huge numbers of these are available; here are just a few of my favorites. Feel free to send suggestions of others to info@pacinst.org.

Popular Movies/Films

Three Word Brand (1921): Paul and Brand (twins separated at birth, played by William S. Hart) become, respectively, governor of Utah and a partner in a ranch where neighboring ranchers are trying to get control of local water rights.

Riders of Destiny (1933): Government agent Saunders (John Wayne) fights a local rancher who controls the local water supply and is trying to force other ranchers into contracts for water at exorbitant rates.

King of the Pecos (1936): John Wayne stars in a classic battle over western water rights and land in the Pecos River country.

Law of the Ranger (1937): Another western with a monopolistic rancher claiming local water rights. Bill Nash (John Merton), owner of the local water company and town boss, tries to control the valley's water rights by building a reservoir, but he must get control of the key property and murders the rightful owner to do so.

Oklahoma Frontier (1939): A land rush leads to an attempt to control the water rights in the Cherokee Strip (with Johnny Mack Brown).

Treasure of the Sierra Madre (1948): Humphrey Bogart and Walter Huston seek their fortune in gold in Mexico. Around the 28-minute mark, Huston says, "Water is more precious than gold." Winner of three Academy Awards: Best Supporting Actor (Walter Huston), Best Directing (John Huston), Best Screenplay.

Stampede (1949): Brothers Mike and Tim McCall (Rod Cameron and Don Castle) own a large ranch in Arizona. Stanley Cox (John Eldredge) and LeRoy Stanton (Donald Curtis) sell land to settlers, who arrive to find that the McCalls control all of the water. Fights ensue.

The Big Country (1958): Retired, wealthy sea captain Jame McKay, played by Gregory Peck, arrives in the west to marry fiancée Pat Terrill. Pat's father, Major Henry Terrill (Charles Bickford), is involved in a ruthless civil war over watering rights for cattle.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_10,

Dr. Strangelove or How I Learned to Stop Worrying and Love the Bomb (1964): U.S. Air Force general Jack Ripper (Sterling Hayden) goes off the deep end and sends bombers to destroy the U.S.S.R because he suspects that the Communists are conspiring to pollute the water supply and the "precious bodily fluids" of the American people. Also starring, of course, George C. Scott and Peter Sellers, Peter Sellers, and Peter Sellers. Nominated for four Oscars, including Best Picture, Best Actor (Peter Sellers), and Best Director (Stanley Kubrick).

El Dorado (1966): John Wayne plays Cole Thornton, a gunfighter for hire who joins forces with an old friend, Sheriff J.P. Hara, played by Robert Mitchum, to help a rancher and his family fight a rival rancher trying to steal their water.

Chinatown (1974): This is perhaps the classic water movie: a murder mystery centered around the political manipulations of water and land in turn-of-the-20th-century Los Angeles, with Jack Nicholson, Faye Dunaway, and John Huston, directed by Roman Polanski. Nominated for ten Oscars. Won for Best Original Screenplay.

The Man Who Fell to Earth (1976): David Bowie and Rip Torn in a brilliant sci-fi story of a humanoid alien who comes to Earth to get water for his dying planet. The alien's story is complicated by love and the ruthlessness of the business world.

The Crazies (1978): George A. Romero's low-budget film of a town affected by the accidental dumping of bio-weapons in their water supply, leading to murder, crazy psychoses, and a military crackdown.

Dune (1984): Frank Herbert's classic sci-fi story of the desert planet Arrakis and the fight for control of the drug melange. Has a strong underlying ecological story about the control of water and other resources.

Pale Rider (1985): Directed by and starring Clint Eastwood as a mysterious preacher who comes to a gold-mining camp near a small town in the mountains. The miners are facing a ruthless landowner who cuts off the water to drive them from their land and their gold claims. Eastwood kicks their butts, of course.

Water (1985): A tiny poor Caribbean island (the island's governor is played by Michael Caine) is completely forgotten by its British colonial masters, until an oil well strikes mineral water. Suddenly, the British, French, Americans, Cubans, and an incompetent local rebel are struggling for control.

Solarbabies (1986): Another in a series of apocalyptic sci-fi stories with a water theme. In the future, a nuclear war has left the Earth a desert wasteland where the oceans have dried up. Most of the water supplies are controlled by the elite corporation E-Protectorate, which takes children away from their families.

Jean de Florette and its sequel, *Manon of the Spring* (1986): Movies from Marcel Pagnol's famous novel *L'eau des Collines* (or, *The Water from the Hills*, 1963). In a rural French village, an old man and his only remaining relative try to steal the waters of a spring from a neighbor. They block up the spring and watch as their neighbor struggles to water his crops. Starring Gerard Depardieu.

Steel Dawn (1987): A post-apocalyptic world where a group of settlers are threatened by a murderous gang that wants the water they control. Featuring Patrick Swayze as the warrior who helps them. Swayze kicks their butts, of course.

Milagro Beanfield War (1988): Milagro, a small town in the American Southwest, experiences conflict between developers and local Hispanic farmers over land and water.

When one farmer diverts water to irrigate his beanfield, trouble arises. Directed by Robert Redford, with Rubén Blades, Richard Bradford, and Sonia Braga. Won an Oscar for Best Music, Original Score.

Xian dai hao xia zhuan (1993): Another post-apocalyptic story, set after a city has been devastated by nuclear attack. An evil villain controls the city's scarce water supply, and three heroes fight to prevent a military takeover and to find clean water for the people of the city.

Tank Girl (1995): Based on a British cult comic, a tank-riding anti-heroine (Lori Petty) fights a mega-corporation called Water and Power, which controls the world's water supply. With early performances by Ice-T and Naomi Watts.

Waterworld (1995): Kevin Costner in, yes, another post-apocalyptic world, where the land has disappeared and control of freshwater is a key plot element. Check out the opening scene where Costner (on a boat in an endless ocean) pees into a little distiller, filters the water, and drinks the output. You'll get the idea.

Christie Malry's Own Double Entry (2000): Johnson and Bent's film about a disaffected man who starts to revenge himself against society for perceived slights, escalating to environmental terrorism and poisoning London's water supplies.

Sabaku no kaizoku! Captain Kuppa (2001): Japanese anime. Sometime in the future, the world is completely dried up and water has become the most valuable commodity. Whoever controls water will control the world.

The Tuxedo (2002): Jackie Chan costars with an animated tuxedo. People who watch this movie forget that the bad guy is a power-hungry bottled-water mogul trying to destroy the world's natural water supply to force everyone to drink his bottled water.

Lord of the Rings: The Two Towers (2002): Part of an epic trilogy directed by Peter Jackson. In this, the second film, water is used as a weapon by the Ents, who destroy a dam in order to destroy and symbolically cleanse the stronghold of Isengard. Nominated for four Academy Awards (including Best Picture); winner of Best Sound Editing and Best Visual Effects.

Batman Begins (2005): Christian Bale, Michael Caine, and Ken Watanabe in one of the better Batman movies. Terrorists try to destroy Gotham by introducing a vapor-borne hallucinogen into the water system.

Waterborne (2005): Ben Rekhi's remarkable independent film, which follows the fictional aftermath of a bio-terrorist attack on the water supply of Los Angeles.

V for Vendetta (2006): Hugo Weaving, Natalie Portman, and Rupert Graves in a dark story about corrupt government leaders contaminating London's water supply in order to kill people, spread fear, and consolidate power.

Quantum of Solace (2008): James Bond fights terrorists working to gain control over Bolivia's water resources. With Daniel Craig as James Bond; directed by Marc Forster.

Well Done Abba (2009): A satirical look out of India at corruption rampant in Indian government departments, with a focus on water. The film tells the story of Armaan Ali, who takes a leave from work to build a well in his backyard to make life easier for his daughter and relatives, only to get trapped in a world of government corruption, bribes, and scandal.

The Book of Eli (2010): Denzel Washington and Gary Oldman star in another post-apocalyptic world where the control of water is a plot element.

Water Documentaries

Cadillac Desert (1997): Directed by Jon Else and Linda Harrar.

Thirst (2004): Directed by Alan Snitow.

Running Dry (2005): Directed by Jim Thebaut. Also, *Running Dry Southwest*.

Flow: For Love of Water (2008): Directed by Irena Salina.

Grand Canyon Adventure: River at Risk (3D/Imax) (2008): Directed by Greg MacGillivray.

Poisoned Waters (2009): PBS documentary on how America's waterways are threatened by pollution; features interviews with some of the nation's environmental experts.

Blue Gold: Water Wars (2009): Focuses on privatization of the world's water.

The Story of Bottled Water (2010): Annie Leonard's nine-minute short take on the bottled water industry.

Last Call at the Oasis (2011): Participant Media's new major water documentary from Jessica Yu and Elise Pearlstein.

Short Water Videos and Films

Penn and Teller, "The Truth About Bottled Water," season 1, episode 7, including the famous "water sommelier" segment
http://www.youtube.com/watch?v=XfPAjUvvnIc

Southern Nevada Water Authority, "Mrs. Nuttington"
http://www.youtube.com/watch?v=Lhpevdl2Sng

"Water wasting cat" http://www.youtube.com/watch?v=ahjojDl-rAc

"Bottle vs. Tap Water"
http://www.youtube.com/watch?v=3XNRu0GHBY4&feature=related

"Bottle vs. Tap Water 2" http://www.youtube.com/watch?v=q0K5h3VBnXc

"That's not Tang! NASA Tests Water from Urine Converter"
http://pierceshow.blogspot.com/2009/06/thats-not-tang-nasa-tests-water-from.html

"No Reason" (from Circle of Blue)
http://www.youtube.com/watch?v=Q4er1Bc8ETQ

"Drunk Flowers"
http://www.youtube.com/watch?v=ULSZzNit_IY&feature=player_embedded

"Running Toilets Waste Water"
http://www.youtube.com/watch?v=A-Fg0ykuQyw&feature=player_embedded

"Shower"
http://www.youtube.com/watch?v=ebhBDmOwrfw&feature=player_embedded

"Fish Out of Water" http://www.youtube.com/watch?v=jvtBuKBr7-0

Jim Gaffigan, "Bottled Water"
http://comedians.comedycentral.com/jim-gaffigan/videos/jim-gaffigan-bottled-water

W A T E R   B R I E F   4

Water Conflict Chronology

Peter H. Gleick and Matthew Heberger

I'm delighted to note two important changes to the Water Conflict Chronology since it last appeared in print in *The World's Water 2008–2009*. First, a completely revamped electronic version now appears at http://www.worldwater.org, with integrated Google Maps; time, location, and subject filters; and a separate searchable bibliography. This is the first substantive redesign in more than a decade, facilitated by Matthew Heberger at the Pacific Institute. The second change is a substantive set of additions, with a major contribution from some readers, especially Pavlo Anakhov from Kiev, Ukraine.

The Water Conflict Chronology has appeared in every volume of *The World's Water* since 1998. It continues to be one of the most popular and regular features of *The World's Water* reports, and new additions are sent by readers and researchers around the world. The chronology is used regularly by the media and by academics interested in understanding more about both the history and character of disputes over water resources.

As noted in previous volumes, the history of violence over freshwater is long and distressing, but unfortunately it continues. The Pacific Institute has been evaluating and analyzing these connections for more than two decades, since our founding in 1987. A series of papers on these questions has been published; the papers range from historical reviews to regional case studies to theoretical analyses. We have organized workshops on lessons from regional conflicts in the Middle East, Central Asia, and Latin America to the connections between traditional and nontraditional arms control tools, and we have even helped coordinate a workshop on the role of science and religion in reducing the risks of water-related violence, which was held at the Pontifical Academy of Sciences of the Vatican.

In 2004, we added a series of myths, legends, and history of water conflicts in the Middle East beginning 5,000 years before the present. The 2006 version added new connections between water and terrorism, as did the first chapter in that volume (Gleick 2006). World events continue to expand the modern list, with examples in southern Asia, northern Africa, the Middle East, and elsewhere. Of particular note is the continuing trend toward disputes over economic development, water allocations, and water equity. More and more of the entries in the chronology are related to subnational players and actors, and fewer are related to transnational conflicts. This supports the thesis identified a decade ago in the first volume of *The World's Water*: "Traditional political and ideological questions that have long dominated international discourse are now becoming more tightly woven with other variables that loomed less large in the past,

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_11,

including population growth, transnational pollution, resource scarcity and inequitable access to resources and their use" (Gleick 1998).

The current categories or types of conflicts include the following:

Military Tool (state actors): where water resources, or water systems themselves, are used by a nation or state as a weapon during a military action.

Military Target (state actors): where water resources or water systems are targets of military actions by nations or states.

Terrorism, including cyberterrorism (non-state actors): where water resources, or water systems, are the targets or tools of violence or coercion by non-state actors. A distinction is drawn between environmental terrorism and eco-terrorism (see Gleick 2006, Chapter 1).

Development Disputes (state and non-state actors): where water resources or water systems are a major source of contention and dispute in the context of economic and social development.

Despite the changes in the nature of tensions over water in recent years, one factor remains constant: the importance of water to life means that providing for water needs and demands will never be free of politics. As social and political systems change and evolve, this chronology and the kinds of entries and categories will change and evolve. I look forward to the ongoing debate over water conflicts and to new contributions and comments from readers. Please email any contributions with full citations and supporting information to pgleick@pipeline.com.

Water Conflict Chronology
Updated February 23, 2011

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
3000 BC	Ea, Noah	Religious account	No: Threat	Ancient Sumerian legend recounts the deeds of the deity Ea, who punished humanity for its sins by inflicting the Earth with a six-day storm. The Sumerian myth parallels the Biblical account of Noah and the deluge, although some details differ.	Hatami and Gleick 1994
2500 BC	Lagash, Umma	Military tool	Yes	The dispute over the "Gu'edena" (edge of paradise) region begins. Urlama, King of Lagash from 2450 to 2400 BC, diverts water from this region to boundary canals, drying up boundary ditches to deprive Umma of water. His son Il cuts off the water supply to Girsu, a city in Umma.	Hatami and Gleick 1994
1790 BC	Hammurabi	Development dispute	No	The Code of Hammurabi for the State of Sumer lists several laws pertaining to irrigation that address negligence of irrigation systems and water theft.	Hatami and Gleick 1994
1720–1684 BC	Abi-Eshuh, Iluma-Ilum	Military tool	Yes	A grandson of Hammurabi, Abish or Abi-Eshuh, dams the Tigris to prevent the retreat of rebels led by Iluma-Ilum, who declared the independence of Babylon. This failed attempt marks the decline of the Sumerians who had reached their apex under Hammurabi.	Hatami and Gleick 1994
circa 1300 BC	Sisera, Barak, God	Religious account, Military tool	Yes	The Old Testament gives an account of the defeat of Sisera and his "nine hundred chariots of iron" by the unmounted army of Barak on the fabled Plains of Esdraelon. God sends heavy rainfall in the mountains, and the Kishon River overflows the plain and immobilizes or destroys Sisera's technologically superior forces ("…the earth trembled, and the heavens dropped, and the clouds also dropped water," Judges 5:4; "…The river of Kishon swept them away, that ancient river, the river Kishon," Judges 5:21).	Scofield 1967
1200 BC	Moses, Egypt	Military tool, Religious account	Yes	When Moses and the retreating Jews find themselves trapped between the Pharaoh's army and the Red Sea, Moses miraculously parts the waters of the Red Sea, allowing his followers to escape. The waters close behind them and cut off the Egyptians.	Hatami and Gleick 1994

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
720–705 BC	Assyria, Armenia	Military tool	Yes	After a successful campaign against the Halidians of Armenia, Sargon II of Assyria destroys their intricate irrigation network and floods their land.	Hatami and Gleick 1994
705–682 BC	Sennacherib, Babylon	Military tool, Military target	Yes	In quelling rebellious Assyrians in 695 BC, Sennacherib razes Babylon and diverts one of the principal irrigation canals so that its waters wash over the ruins.	Hatami and Gleick 1994
701 BC	Israel (Judah), Assyria	Military tool, Military maneuvers	Yes	When King Hezekiah of Judah sees that Sennacherib of Assyria is coming in war, he has the water from the springs and brook outside Jerusalem stopped to keep the water from the Assyrians. ("So there was gathered much people together, who stopped all the fountains, and the brook that ran through the midst of the land, saying, Why should the kings of Assyria come, and find much water?" 2 Chronicles 32:1–4).	Scofield 1967
681–699 BC	Assyria, Tyre	Military tool, Religious account	Yes	Esarhaddon, an Assyrian, refers to an earlier period when gods, angered by insolent mortals, created destructive floods. According to inscriptions recorded during his reign, Esarhaddon besieges Tyre, cutting off food and water.	Hatami and Gleick 1994
669–626 BC	Assyria, Arabia, Elam	Military tool, Military target	Yes	In campaigns against both Arabia and Elam in 645 BC, Assurbanipal, son of Esarhaddon, dries up wells to deprive Elamite troops. He also guards wells from Arabian fugitives in an earlier Arabian war. On his return from victorious battle against Elam, Assurbanipal floods the city of Sapibel, and ally of Elam. According to inscriptions, he dams the Ulai River with the bodies of dead Elamite soldiers and deprives dead Elamite kings of their food and water offerings.	Hatami and Gleick 1994
612 BC	Egypt, Persia, Babylon, Assyria	Military tool	Yes	A coalition of Egyptian, Median (Persian), and Babylonian forces attacks and destroys Ninevah, the capital of Assyria. Nebuchadnezzar's father, Nebopolassar, leads the Babylonians. The converging armies divert the Khosr River to create a flood, which allows them to elevate their siege engines on rafts.	Hatami and Gleick 1994

605–562 BC	Babylon	Military tool	No	Nebuchadnezzar builds immense walls around Babylon, using the Euphrates and canals as defensive moats surrounding the inner castle.	Hatami and Gleick 1994; Drower 1954
590–600 BC	Cirrha, Delphi	Military tool	Yes	Athenian legislator Solon reportedly has roots of helleborus thrown into a small river or aqueduct leading from the Pleistrus River to Cirrha during a siege of this city. The enemy forces became violently ill and are defeated as a result. Some accounts have Solon building a dam across the Plesitus River cutting off the city's water supply. Such practices were widespread.	Wikipedia (First Sacred War) undated-c
6th Century BC	Assyria	Military target, Military tool	Yes	Assyrians poison the wells of their enemies with rye ergot.	Eitzen and Takafuji 1997
558–528 BC	Babylon	Military tool	Yes	On his way from Sardis to defeat Nabonidus at Babylon, Cyrus faces a powerful tributary of the Tigris, probably the Diyalah. According to Herodotus' account, the river drowns his royal white horse and presents a formidable obstacle to his march. Cyrus, angered by the "insolence" of the river, halts his army and orders them to cut 360 canals to divert the river's flow. Other historians argue that Cyrus needed the water to maintain his troops on their southward journey, while another asserts that the construction was an attempt to win the confidence of the locals.	Hatami and Gleick 1994
539 BC	Babylon	Military tool	Yes	According to Herodotus, Cyrus invades Babylon by diverting the Euphrates above the city and marching troops along the dry riverbed. This popular account describes a midnight attack that coincided with a Babylonian feast.	Hatami and Gleick 1994
430 BC	Athens	Military tool	Yes	During the second year of the Peloponnesian War in 430 BC when plague breaks out in Athens, the Spartans are accused of poisoning the cisterns of the Piraeus, the source of most of Athens' water.	Strategy Page 2006
355–323 BC	Babylon	Military tool	Yes	Returning from the razing of Persepolis, Alexander proceeds to India. After the Indian campaigns, he heads back to Babylon via the Persian Gulf and the Tigris, where he tears down defensive weirs that the Persians had constructed along the river. Arrian describes Alexander's disdain for the Persians' attempt to block navigation, which he saw as "unbecoming to men who are victorious in battle."	Hatami and Gleick 1994

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
210–209 BC	Rome and Carthage	Military tool	Yes	Scipio crosses the Ebro to attack New Carthage. During a short siege, Scipio led a breaching column through a supposedly impregnable lagoon located on the landward side of the city; a strong northerly wind combined with the natural ebb of the tide left the lagoon shallow enough for the Roman infantry to wade through. New Carthage was soon taken.	Fonner 1996
September 52 BC	Rome, Gaul	Military tool	Yes	Caesar constructs water-filled ditches as blockade during Siege of Alesia in Gaul, site of modern-day Alise-Sainte-Reine in Côte d'Or near Dijon, France.	Wikipedia ("Battle of Alesia") undated-a
51 BC	Rome, Gaul	Military target	Yes	Caesar attacks water supplies during siege of Uxellodunum by undermining one of the local springs and placing attackers near the other. Shortage of water leads to the surrender of the Gauls.	History of War Online undated
49 BC	France, Rome	Military tool	Yes	At the siege of Marseille, the city's defenders counter attempts by the Romans to tunnel under their walls by digging a large basin inside the walls and filling it with water. When the mines approached the basin, the water flowed out, flooding them and causing them to collapse.	Illustrated History of the Roman Empire undated
30 AD	Roman Empire (Pontius Pilate), Jews	Development dispute	Yes	Roman Procurator Pontius Pilate uses sacred money to divert a stream to Jerusalem. The Jews are angered at the diversion, and tens of thousands gather to protest. Pilate's soldiers mingle among the crowd with daggers hidden in their garments and attack the protesters. "A great number" are slain and wounded and the sedition ends.	Josephus 90 A.D.
537	Goths and Rome	Military tool, Military target	Yes	In the 6th century AD, as the Roman Empire begins to decline, the Goths besiege Rome and cut almost all of the aqueducts leading into the city. In 537 AD, this siege was successful. The only aqueduct that continues to function is that of the Aqua Virgo, which runs entirely underground.	Rome Guide 2004; InfoRoma 2004

1187	Saladin and the Crusaders	Military tool	Yes	Saladin was able to defeat the Crusaders at the Horns of Hattin in 1187 by denying them access to water. In some reports, Saladin had sanded up all the wells along the way and had destroyed the villages of the Maronite Christians, who would have supplied the Christian army with water.	Lockwood 2006; Delli Priscoli 1998
1503	Florence and Pisa warring states	Military tool	No: Plan only	Leonardo da Vinci and Machiavelli plan to divert the Arno River away from Pisa during a conflict between Pisa and Florence.	Honan 1996
1573–1574	Holland and Spain	Military tool	Yes	In 1573, at the beginning of the Eighty Year War against Spain, the Dutch flood the land to break the siege of Spanish troops on the town Alkmaar. The same defense is used again to protect Leiden in 1574. This strategy became known as the Dutch Water Line and is used frequently for defense in later years.	Dutch Water Line 2002
1626–1629	Spain, Dutch Republic	Development dispute, Military tool	No	The Spanish Habsburgs attempt to prevent ship traffic on the River Rhine from reaching the Dutch Republic in order to damage the Dutch economy. Plans were also made to divert water from the Rhine to lands under Spanish control to dry up downstream cities in Holland. The first stage was a canal between the Rhine and Meuse, between the cities of Rheinberg and Venlo. Plans for a later stage called for a connection between the Meuse and the Scheldt to circumvent the Scheldt Estuary, controlled by the Dutch. Although some 60 km was constructed, the plan failed due to changed military conditions and lack of funding. Parts of the canal are still visible in present-day Germany.	Israel 1997; Bachiene 1791
1642	China, Ming Dynasty	Military tool	Yes	Near the end of the Ming dynasty (1368–1644), General Gao Mingheng breaches the dikes of the Huang He (Yellow River) near Kaifeng in a campaign to suppress peasant uprisings.	Hillel 1991
1672	French, Dutch	Military tool	Yes	Louis XIV starts the third of the Dutch Wars in 1672, in which the French overran the Netherlands. In defense, the Dutch open their dikes and flood the country, creating a watery barrier that is virtually impenetrable.	Columbia Encyclopedia 2000b
1748	United States	Development dispute, Terrorism	Yes	A ferry house on the Brooklyn shore of the East River burns down. New Yorkers accuse Brooklynites of setting the fire as revenge for unfair East River water rights.	MCNY undated

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1777	United States	Military tool	Yes	British and Hessians attack the water system of New York during the War for Independence.	Thatcher 1827
1804	France, Holland	Development dispute, Military tool	No	Napoleon orders the construction of a canal between Neuss and Venlo, to connect the Rhine and Meuse rivers, to divert trade from the Batavia Republic to the Southern Netherlands, then under French control. Three-quarters of the canal were completed, but work stopped because of lack of funds.	Israel 1997
1841	Canada	Development dispute, Terrorism	Yes	A reservoir in Ops Township, Upper Canada (now Ontario), is destroyed by neighbors who consider it a hazard to health.	Forkey 1998
1844	United States	Development dispute, Terrorism	Yes	A reservoir in Mercer County, Ohio, is destroyed by a mob who consider it a hazard to health.	Scheiber 1969
1850s	United States	Development dispute, Terrorism	Yes	Attack on a New Hampshire dam that impounded water for factories downstream by local residents unhappy over its effect on water levels.	Steinberg 1990
1853–1861	United States	Development dispute, Terrorism	Yes	Repeated destruction of the banks and reservoirs of the Wabash and Erie Canal in southern Indiana by mobs regarding it as a health hazard.	Fatout 1972; Fickle 1983
1860–1865	United States	Military tool, Military target	Yes	General William T. Sherman's memoirs contain an account of Confederate soldiers poisoning ponds by dumping the carcasses of dead animals into them. Other accounts suggest this tactic was used by both sides.	Eitzen and Takafuji 1997
1862	United States Union and Confederate Armies	Military tool	Yes	During the U.S. Civil War, near Yorktown, Confederate forces use dams on the Warwick River to cut off Union troops. "The enemy is pushed behind a … branch of the Warwick river in which they control the depths of water by dams. McClellan did not intend to pass that stream at that time, or at that point where the skirmish took place. But the troops, finding the stream fordable went over (under whose immediate orders does not appear) and the water was then deepened so that they were measurably cut off."	Hitchcock 1862

1863	United States	Military tool	Yes	General Ulysses S. Grant, during the U.S. Civil War campaign against Confederates in Vicksburg, cuts levees along the Mississippi River.	Grant 1885, Barry 1997
1870s	China	Development dispute	No	Government authorities twice remove an unauthorized dam constructed by locals in Hubei Province.	Rowe 1988
1870s to 1881	United States	Development dispute	Yes	Recurrent friction and eventual violent conflict over water rights in the vicinity of Tularosa, New Mexico, involving villagers, ranchers, and farmers.	Rasch 1968
1887	United States	Development dispute, Terrorism	Yes	Dynamiting of a canal reservoir in Paulding County, Ohio by a mob regarding it as a health hazard. The state militia is called out to restore order.	Walters 1948
1890	Canada	Development dispute, Terrorism	Yes	Partly successful attempt to destroy a lock on the Welland Canal in Ontario, Canada, either by Fenians protesting English Policy in Ireland or by agents of Buffalo, New York grain handlers unhappy at the diversion of trade through the canal.	Styran and Taylor 2001
1898	Egypt, France, Britain	Military tool, Political tool	Military maneuvers	Military conflict nearly ensues between Britain and France in 1898 when a French expedition attempts to gain control of the headwaters of the White Nile. While the parties ultimately negotiate a settlement of the dispute, the incident is characterized as having "dramatized Egypt's vulnerable dependence on the Nile, and fixed the attitude of Egyptian policy-makers ever since."	Moorehead 1960
1907–1913	Owens Valley, Los Angeles, California	Terrorism, Development dispute	Yes	The Los Angeles Valley aqueduct/pipeline suffers repeated bombings in an effort to prevent diversions of water from the Owens Valley to Los Angeles.	Reisner 1993
1908–1909	United States	Development dispute	Yes	Violence, including a murder, is directed against agents of a land company that claimed title to Reelfoot Lake in northwestern Tennessee after it attempts to levy charges for fish and threatens to drain the lake for agriculture.	Vanderwood 1969
1915	German Southwest Africa	Military tool	Yes	Union of South Africa troops capture Windhoek, capital of German Southwest Africa, in May 1915. Retreating German troops poison wells—"a violation of the Hague convention."	Daniel 1995
1935	California, Arizona	Development dispute	Military maneuvers	Arizona calls out the National Guard and militia units to the border with California to protest the construction of Parker Dam and diversions from the Colorado River; the dispute is ultimately settled in court.	Reisner 1993

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1937	Republican Government of Spain, Spanish Nationalists	Military target	Yes	During the Spanish Civil War, the Nationalist army attacks two concrete gravity dams at Burguillo and Ordunte by placing a 2.5-ton charge in an inspection gallery at Ordunte. The attacks do limited damage, which is repaired in 1938–1939.	Pagan 2005
1938	China and Japan	Military tool, Military target	Yes	Chiang Kai-shek orders the destruction of flood-control dikes of the Huayuankou section of the Huang He (Yellow) River to flood areas threatened by the Japanese army. West of Kaifeng, dikes are destroyed with dynamite, spilling water across the flat plain. The flood destroyed part of the invading army, and its heavy equipment was mired in thick mud, though Wuhan, the headquarters of the Nationalist government, was taken in October. The waters flooded an area variously estimated as between 3,000 and 50,000 square kilometers, and killed Chinese estimated in numbers between "tens of thousands" and "one million."	Hillel 1991, Yang Lang 1989/1994
1939–1940	Netherlands, Germany	Military tool	Yes	During the mobilization of the Dutch at the beginning of World War II, the Dutch attempt to flood the Gelderse Vallei with the New Dutch Water Defence Line, which had been completed in 1885. During the German invasion in May 1940, large areas were inundated.	IDG 1996
1939–1942	Japan, China	Military target, Military tool	Yes	Japanese chemical and biological weapons activities reportedly include tests by "Unit 731" against military and civilian targets by lacing water wells and reservoirs with typhoid and other pathogens.	Harris 1994
1940	Finland, Soviet Union	Military tool	Yes	Manipulation of the waters of the Saimaan Canal (Finland) by partisan Finns in order to flood surrounding land and hinder Soviet troop movements during the Soviet-Finnish conflict.	Malik 2005
1940–1945	Multiple parties	Military target	Yes	Hydroelectric dams are routinely bombed as strategic targets during World War II.	Gleick 1993

1941	Germany, Soviet Union	Military tool	Yes	In November 1941, the Soviets flood lands to the south of the Istra Reservoir near Moscow in an effort to slow the German advance. Just a few weeks later, German troops use the same tactic to create a water barrier to halt advances by the Soviet 16th Army.	Malik 2005
1941	Ukraine, Soviet Union, Germany	Military target	Yes	The strategically important Dnieper hydropower plant in the Ukraine is targeted throughout World War II by both Soviet and German troops. On August 18, 1941, the dam and power plant were dynamited by Soviet troops retreating in front of advancing German forces. The facility was then bombed in 1943 by retreating German troops.	Pagan 2005; NYT 1941, Makarov 2005, Axis History Forum 2004
1941–1943	Germany, USSR	Military target	Yes	World War II inflicts enormous harm to hydroelectricity systems in the Soviet Union. Over two-thirds of the hydroelectric power stations were lost.	Malik 2005
1943	Britain, Germany	Military target	Yes	The British Royal Air Force bombs dams on the Möhne, Sorpe, and Eder rivers, Germany (May 16 and 17). The Möhne Dam breech kills 1,200 and destroys all downstream dams for 50 km. The flood that occurred after breaking the Eder dam reached a peak discharge of 8,500 m^3/s, which is nine times higher than the highest flood observed. Many houses and bridges were destroyed, and 68 people were killed.	Kirschner 1949, Semann 1950
1944	Germany, Italy, Britain, United States	Military target	Yes	German forces use waters from the Isoletta Dam (Liri River) in January and February to destroy British assault forces crossing the Garigliano River (downstream of Liri River). The German Army then dams the Rapido River, flooding a valley occupied by the American Army.	Corps of Engineers 1953
1944	Germany, Italy, Britain, United States	Military tool	Yes	The German Army floods the Pontine Marches by destroying drainage pumps to contain the Anzio beachhead established by the Allied landings in 1944. Over 40 square miles of land were flooded; a 30-mile stretch of landing beaches was rendered unusable for amphibious support forces.	Corps of Engineers 1953
1944	Germany, Allied forces	Military tool	Yes	Germans flood the Ay River, France, in July 1944, creating a lake two meters deep and several kilometers wide, slowing an advance on Saint Lo, a German communications center in Normandy.	Corps of Engineers 1953
1944	Germany, Allied forces	Military tool	Yes	Germans flood the Ill River Valley during the Battle of the Bulge (winter 1944–1945) creating a lake 16 kilometers long, 3–6 kilometers wide, and 1–2 meters deep, greatly delaying the American Army's advance toward the Rhine.	Corps of Engineers 1953
1944	United States, Japan	Military target	Yes	The U.S. bombardment of the Japanese-occupied island of Saipan in June 1944 targets water supply points, causing severe shortages.	Stewart undated

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1944	Finland, USSR	Military target	Yes	In June, the Soviet air force attacks the Svir River Dam near Leningrad, then under the control of the Finnish military.	Orlenko 1981, Axis History Forum 2004
1945	Romania, Germany	Military tool	Yes	The only known German tactical use of biological warfare was the pollution of a large reservoir in northwestern Bohemia with sewage in May 1945.	SIPRI 1971
1947–1960s	India, Pakistan	Development Dispute	Yes	Partition leaves the Indus basin divided between India and Pakistan; disputes over irrigation water ensue, during which India stems flow of water into irrigation canals in Pakistan. The Indus Waters Agreement is reached in 1960 after 12 years of World Bank–led negotiations.	Bingham, Wolf, and Wohlegenant 1994
1947 onwards	Bangladesh, India	Development dispute	No	Partition divides the Ganges River between Bangladesh and India; construction of the Farakka barrage by India, beginning in 1962, increases tension; short-term agreements settle dispute in 1977–1982, 1982–1984, and 1985–1988, and thirty-year treaty is signed in 1996.	Butts 1997, Samson and Charrier 1997
1948	Arabs, Israel	Military tool	Yes	Water and food supplies are cut off during the Arab siege of Jerusalem from December 1, 1947, to July 10, 1948. Arab forces block the road to Jerusalem in an attempt to defeat Jewish Jerusalem. Shortages cause Israelis to begin rationing water on May 12, limiting each person to 2 gallons per day (8 L), of which 4 pints (2 L) were for drinking.	Collins and LaPierre 1972, Joseph 1960, Wikipedia undated-b2011b
1950s	Korea, United States, others	Military target	Yes	Centralized dams on the Yalu (Amnok) River serving North Korea and China are attacked during Korean War.	Gleick 1993
1951	Korea, United Nations	Military tool, Military target	Yes	North Korea releases flood waves from the Hwacheon Dam, damaging floating bridges operated by UN troops in the Pukhan Valley. U.S. Navy planes are then sent to destroy spillway crest gates.	Calcagno 2004; Corps of Engineers 1953
1951	Israel, Jordan, Syria	Military tool, Development dispute	Yes	Jordan makes public its plans to irrigate the Jordan Valley by tapping the Yarmouk River; Israel responds by commencing drainage of the Huleh swamps located in the demilitarized zone between Israel and Syria; border skirmishes ensue between Israel and Syria.	Wolf 1997, Samson and Charrier 1997

1953	Israel, Jordan, Syria	Development dispute, Military target	Yes	Israel begins construction of its National Water Carrier to transfer water from the north of the Sea of Galilee out of the Jordan basin to the Negev Desert for irrigation. Syrian military actions along the border and international disapproval lead Israel to move its intake to the Sea of Galilee.	Naff and Matson 1984, Samson and Charrier 1997
1958	Egypt, Sudan	Military tool, Development dispute	Yes	Egypt sends an unsuccessful military expedition into disputed territory amidst pending negotiations over the Nile waters, Sudanese general elections, and an Egyptian vote on Sudan-Egypt unification. The Nile Water Treaty is signed when pro-Egyptian government elected in Sudan.	Wolf 1997
1960s	North Vietnam, United States	Military target	Yes	Irrigation water supply systems in North Vietnam are bombed during the Vietnam War by the U.S. An estimated 661 sections of dikes are damaged or destroyed.	ICRC 1977, Gleick 1993, Zemmali 1995
1962	Israel, Syria	Development dispute, Military target	Yes	Israel destroys irrigation ditches in the lower Tarfiq in the demilitarized zone. Syria complains.	Naff and Matson 1984
1962 to 1967	Brazil, Paraguay	Military tool, Development dispute	Military maneuvers	Negotiations between Brazil and Paraguay over the development of the Paraná River are interrupted by a unilateral show of military force by Brazil in 1962, which invades the area and claims control over the Guaíra Falls site. Military forces are withdrawn in 1967 following an agreement for a joint commission to examine development in the region.	Murphy and Sabadell 1986
1963–1964	Ethiopia, Somalia	Development dispute, Military tool	Yes	The creation of boundaries in 1948 leaves Somali nomads under Ethiopian rule; border skirmishes occur over disputed territory in the Ogaden desert where critical water and oil resources are located. A cease-fire is negotiated only after several hundred are killed.	Wolf 1997
1964	Cuba, United States	Military tool	No	On February 6, 1964, the Cuban government orders the water supply to the U.S. Naval Base at Guantanamo Bay cut off.	Guantanamo Bay Gazette 1964
1964	Israel, Syria	Military target	Yes	Headwaters of the Dan River on the Jordan River are bombed at TellEl-Qadi in a dispute about sovereignty over the source of the Dan.	Naff and Matson 1984
1965	Zambia, Rhodesia, Great Britain	Military target	No	Zambian President Kenneth Kaunda calls on the British government to send troops to Kariba Dam to protect it from possible saboteurs from the breakaway colony of Rhodesia, which had declared its independence earlier that year.	Chenje 2001
1965	Israel, Palestinians	Terrorism	Yes	The first attack launched by the Palestinian National Liberation Movement Al-Fatah is on the diversion pumps for the Israeli National Water Carrier. The attack fails.	Naff and Matson 1984, Dolatyar 1995

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1965–1966	Israel, Syria	Military tool, Development dispute	Yes	Fire is exchanged over the “all-Arab” plan to divert the Jordan River headwaters on the Hasbani and Banias Rivers in Syria. The plan would presumably have preempted Israel’s National Water Carrier, a plan to transfer water from the Sea of Galilee at the Jordan’s terminus to population centers in its arid south. Syria halts construction of its diversion in July 1966.	Wolf 1995, Wolf 1997
1966–1972	Vietnam, United States	Military tool	Yes	U.S. tries cloud-seeding in Indochina to stop flow of materiel along Ho Chi Minh trail.	Plant 1995
1967	Israel, Syria	Military target, Military tool	Yes	Israel destroys the Arab diversion works on the Jordan River headwaters. During the Arab-Israeli War, Israel occupies the Golan Heights, where the Jordan’s largest tributary, the Banias River, flows into it.	Gleick 1993, Wolf 1995, Wolf 1997, Wallenstein and Swain 1997
1969	Israel, Jordan	Military target, Military tool	Yes	Israel, suspicious that Jordan is over-diverting the Yarmouk River, leads two raids to destroy the newly built East Ghor Canal. Secret negotiations, mediated by the U.S., lead to an agreement in 1970.	Samson and Charrier 1997
1970	United States	Terrorism	No: Threat	The Weathermen, a group opposed to American imperialism and the Vietnam war, allegedly attempts to obtain biological agents to contaminate the water supply systems of U.S. urban centers.	Kupperman and Trent 1979, Eitzen and Takafuji 1997, Purver 1995
1970s	Chinese Citizens	Development dispute	Yes	Conflicts over excessive water withdrawals and subsequent water shortages from China’s Zhang River have been worsening for over three decades between villages in Shenxian and Linzhou counties. In the 1970s, militias from competing villages fought over withdrawals. (See also entries for 1976, 1991, 1992, and 1999.)	China Water Resources Daily 2002
1970s	Argentina, Brazil, Paraguay	Development dispute	No	Brazil and Paraguay announce plans to construct a dam at Itaipu on the Paraná River, making Argentina concerned about downstream environmental harm and its effect on the dam project it is planning downstream. Argentina demands to be consulted during the planning of Itaipu but Brazil refuses. An agreement is reached in 1979 that provides for the construction of both Brazil and Paraguay’s dam at Itaipu and Argentina’s Yacyreta dam.	Wallenstein and Swain 1997

1972	North Vietnam	Military target	Yes	The United States bombs dikes in the Red River delta, rivers, and canals during a massive bombing campaign.	Columbia Encyclopedia 2000a
1972	United States	Terrorism	No: Threat	Two members of the right-wing "Order of the Rising Sun" are arrested in Chicago with 30–40 kg of typhoid cultures that are allegedly to be used to poison the water supply in Chicago, St. Louis, and other cities. It was felt that the plan would have been unlikely to cause serious health problems due to chlorination of the water supplies.	Eitzen and Takafuji 1997
1972	United States	Terrorism	No: Threat	Reported threat to contaminate water supply of New York City with nerve gas.	Purver 1995
1973	Germany	Terrorism	No: Threat	A German biologist threatens to contaminate water supplies with bacilli of anthrax and botulinum toxin unless he is paid $8.5 million.	Jenkins and Rubin 1978, Kupperman and Trent 1979
1974	Iraq, Syria	Military target, Military tool, Development dispute	Military maneuvers	Iraq threatens to bomb the al-Thawra (Tabaqah) dam in Syria and masses troops along the border, alleging that the dam has reduced the flow of Euphrates River water into Iraq.	Gleick 1994
1975	Angola, South Africa	Military goal, Military target	Yes	South African troops move into Angola to occupy and defend the Ruacana hydropower complex, including the Gové Dam on the Kunene River. Their goal is to take possession of and defend the water resources of southwestern Africa and Namibia.	Meissner 2000
1975	Iraq, Syria	Development dispute, Military tool	Military maneuvers	As upstream dams are filled during a low-flow year on the Euphrates, Iraq claims that flow reaching its territory is "intolerable" and asks the Arab League to intervene. Syrians claim they are receiving less than half the river's normal flow and pull out of an Arab League technical committee formed to mediate the conflict. In May, Syria closes its airspace to Iraqi flights, and both Syria and Iraq reportedly transfer troops to their mutual border. Saudi Arabia successfully mediates the conflict.	Gleick 1993, Gleick 1994, Wolf 1997
1976	Chinese citizens and government	Development dispute	Yes	In 1976, a local militia chief is shot to death in a clash over the damming of Zhang River. Conflicts over excessive water withdrawals and subsequent water shortages from China's Zhang River have been worsening for over three decades. (See also entries for 1970, 1991, 1992, and 1999.)	China Water Resources Daily 2002
1977	United States	Terrorism	Yes	Contamination of a North Carolina reservoir with unknown materials. According to Clark: "Safety caps and valves were removed, and poison chemicals were sent into the reservoir… Water had to be brought in."	Clark 1980, Purver 1995

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1978–1984	Sudan	Development dispute, Military target, Terrorism	Yes	Demonstrations in Juba, Sudan, in 1978 opposing the construction of the Jonglei Canal led to the deaths of two students. Construction of the Jonglei Canal in the Sudan is forcibly suspended in 1984 following a series of attacks on the construction site.	Suliman 1998, Keluel-Jang 1997
1978 onwards	Egypt, Ethiopia	Development dispute, Political tool	No	Long-standing tensions over the Nile, especially the Blue Nile, originating in Ethiopia. Ethiopia's proposed construction of dams on the headwaters of the Blue Nile leads Egypt to repeatedly declare the vital importance of water. "The only matter that could take Egypt to war again is water" (Anwar Sadat, 1979). "The next war in our region will be over the waters of the Nile, not politics" (Boutros Boutrous-Ghali, 1988).	Gleick 1991, Gleick 1994
1980–1988	Iran, Iraq	Military tool	Yes	Iran diverts water to flood Iraqi defense positions.	Plant 1995
1980s	Mozambique, Rhodesia/ Zimbabwe, South Africa	Military target, Terrorism	Yes	Regular destruction of power lines from Cahora Bassa Dam during fight for independence in the region. The dam is targeted by RENAMO (the Mozambican National Resistance).	Chenje 2001
1981	Iran, Iraq	Military target, Military tool	Yes	Iran claims to have bombed a hydroelectric facility in Kurdistan, thereby blacking out large portions of Iraq, during the Iran-Iraq War.	Gleick 1993
1981–1982	Angola, Namibia	Military target, Military tool	Yes	Water infrastructure, including dams and the major Cunene-Cuvelai pipeline, is targeted during the conflicts in Namibia and Angola in the 1980s.	Turton 2005
1982	Guatemala	Development dispute	Yes	The Guatemalan government forcibly relocates residents, most of them minority Maya Achi people, from the fertile Río Negro valley to sparse uplands to make way for the Chixoy Hydroelectric Dam. Hundreds of Maya Achi who refused to relocate are kidnapped, raped, or killed by the military and paramilitary organizations in what has become known as the Río Negro Massacres.	Levy 2000
1982	Israel, Lebanon, Syria	Military tool	Yes	Israel cuts off water supplies during the Siege of Beirut in the summer of 1982.	Wolf 1997

1982	United States	Terrorism	No: Threat	Los Angeles police and the FBI arrest a man who was preparing to poison the city's water supply with a biological agent.	Livingston 1982, Eitzen and Takafuji 1997
1983	Lebanon	Terrorism	Yes	An explosives-laden truck disguised as a water delivery vehicle destroys a barracks in a U.S. military compound, killing more than 300 people. The attack was blamed on Hezbollah with support from the Iranian government.	BBC 2007
1983	Israel	Terrorism	No	The Israeli government reports that it had uncovered a plot by Israeli Arabs to poison the water in Galilee with "an unidentified powder."	Douglass and Livingstone 1987
1984	United States	Terrorism	Yes	Members of the Rajneeshee religious cult contaminate a city water supply tank in The Dalles, Oregon, using Salmonella. A community outbreak of over 750 cases occurred in a county that normally reports fewer than five cases per year.	Clark and Deininger 2000
1985	United States	Terrorism	No	Authorities learn of plans by a survivalist group in the Ozark Mountains of Arkansas known as the Covenant, the Sword, and the Arm of the Lord (CSA) to poison water supplies of major U.S. cities in the belief it would speed the return of the Messiah. The group's 30 gallons of potassium cyanide was insufficient to contaminate the water supply of even one city.	Tucker 2000, NTI 2005
1986	North Korea, South Korea	Military tool	No	North Korea's announcement of its plans to build the Kumgansan hydroelectric dam on a tributary of the Han River upstream of Seoul raises concerns in South Korea that the dam could be used as a tool for ecological destruction or war.	Gleick 1993
1986	Lesotho, South Africa	Development dispute, Military goal	Yes	A bloodless coup by Lesotho's defense forces with support from South Africa leads to an immediate agreement with South Africa for water from the Highlands of Lesotho, after 30 previous years of unsuccessful negotiations. There is disagreement over the degree to which water was a motivating factor for either party.	Mohamed 2001, American University 2000b
1988	Angola, South Africa, Cuba	Military goal, Military target	Yes	Cuban and Angolan forces launch an attack on Calueque Dam in South Africa-occupied Namibia via land and then air. The attack kills 12 South African soldiers and inflicts considerable damage to the dam. A water pipeline to Owamboland in northern Namibia is also cut and destroyed.	Meissner 2000
1990	South Africa	Development dispute	No	Pro-apartheid council cuts off water to the Wesselton township of 50,000 blacks following protests over miserable sanitation and living conditions.	Gleick 1993

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1990	Iraq, Syria, Turkey	Development dispute, Military tool	No	The flow of the Euphrates is interrupted for a month as Turkey finishes construction of the Ataturk Dam, part of the Grand Anatolia Project. Syria and Iraq protest that Turkey now has a weapon of war. In mid-1990, Turkish president Turgut Ozal threatens to restrict water flow to Syria to force it to withdraw support for Kurdish rebels operating in southern Turkey.	Gleick 1993, Gleick 1995
1991	Chinese villages of Huanglongkou and Qianyu	Development dispute	Yes	In December 1991, the villages of Huanglongkou and Qianyu exchange mortar fire over the construction of new water diversion facilities. Conflicts over excessive water withdrawals and subsequent water shortages from China's Zhang River have been worsening for over three decades. (See also entries for 1970, 1976, 1992, and 1999.)	China Water Resources Daily 2002
1991	Iraq, Kuwait, United States	Military target	Yes	During the Gulf War, Iraq destroys much of Kuwait's desalination capacity during retreat.	Gleick 1993
1991	Iraq, Turkey, United Nations	Military tool	Yes	Discussions are held at the United Nations about using the Ataturk Dam in Turkey to cut off flows of the Euphrates to Iraq.	Gleick 1993
1991	Canada	Terrorism	No: Threat	A threat is made via an anonymous letter to contaminate the water supply of the city of Kelowna, British Columbia, with "biological contaminates." The motive was apparently "associated with the Gulf War." The security of the water supply was increased in response, and no group was identified as the perpetrator.	Purver 1995
1991	Iraq, Kuwait, United States	Military target	Yes	Baghdad's modern water supply and sanitation systems are intentionally and unintentionally damaged by Allied coalition. "Four of seven major pumping stations were destroyed, as were 31 municipal water and sewerage facilities—20 in Baghdad—resulting in sewage pouring into the Tigris. Water purification plants were incapacitated throughout Iraq" (Arbuthnot 2000). In the first eight months of 1991, after Iraq's water infrastructure was damaged by the Persian Gulf War, the New England Journal of Medicine reported that nearly 47,000 more children than normal died in Iraq and the country's infant mortality rate doubled to 92.7 per 1,000 live births.	Gleick 1993, Arbuthnot 2000, Barrett 2003

1991–2001	United States, Iraq	Military target, Military tool	No	The United States deliberately pursues policy of destroying Iraq's water systems through sanctions and withholding contracts.	Nagy 2001
1991–present	Karnataka, India	Development dispute	Yes	Violence erupts when Karnataka rejects an Interim Order handed down by the Cauvery Waters Tribunal, set up by the Indian Supreme Court. The Tribunal was established in 1990 to settle two decades of dispute between Karnataka and Tamil Nadu over irrigation rights to the Cauvery River.	Gleick 1993, Butts 1997, American University 2000a
1992	Turkey	Terrorism	Yes	Lethal concentrations of potassium cyanide are reportedly discovered in the water tanks of a Turkish Air Force compound in Istanbul. The Kurdish Workers' Party (PKK) claims credit.	Chelyshev 1992
1992	Chinese villages	Development dispute	Yes	In August 1992, bombs are set off along a Zhang River distribution canal, collapsing part of the canal and causing flooding and economic losses. Violence continues in the late 1990s with confrontations, mortar attacks, and bombings. Conflicts over excessive water withdrawals and subsequent water shortages from China's Zhang River have been worsening for over three decades. (See also entries for 1970, 1976, 1991, and 1999.)	China Water Resources Daily 2002
1992	Czechoslovakia, Hungary	Political tool, Development dispute	Military maneuvers	Hungary abrogates a 1977 treaty with Czechoslovakia concerning construction of the Gabĉíkovo/Nagymaros project based on environmental concerns. Slovakia continues construction unilaterally, completes the dam, and diverts the Danube into a canal inside the Slovakian republic. Massive public protest and movement of military to the border ensue; issue taken to the International Court of Justice.	Gleick 1993
1992	Moldova, Russia	Military target	Yes	In June, hostilities between Moldova and Russia in a short but intense conflict included a rocket-artillery attack on the hydroelectric turbines at the Dubossary power station on the Nistru (or Dniester) River.	Malik 2005, Belitser et al. 2009
1992	Bosnia, Bosnian Serbs	Military tool	Yes	The Serbian siege of Sarajevo, Bosnia and Herzegovina includes a cutoff of all electrical power and the water feeding the city from the surrounding mountains. The lack of power cuts the two main pumping stations inside the city despite pledges from Serbian nationalist leaders to United Nations officials that they would not use their control of Sarajevo's utilities as a weapon. Bosnian Serbs take control of water valves regulating flow from wells that provide more than 80 percent of water to Sarajevo; reduced water flow to city is used to "smoke out" Bosnians.	Burns 1992, Husarska 1995

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1993	Iran	Military target, Military tool	Yes	A report suggests that proposals were made at a meeting of fundamentalist groups in Tehran, under the auspices of the Iranian Foreign Ministry, to poison water supplies of major cities in the West "as a possible response to Western offensives against Islamic organizations and states."	Gleick 1993, Rathfelder 2007
1993	Yugoslavia	Terrorism	No	The 65-meter high Peruća Dam on the Cetina River was Yugoslavia's second-largest hydroelectric facility before the country's breakup with the Croation War beginning in 1991. On January 28, 1993, Serbian/Yugoslav army forces detonated explosives at the dam in an attempt to wipe out Croatian villages and the port city of Omiš. A successful Croatian counterattack allowed military engineers to reach the dam and release water on time to prevent it from bursting, saving an estimated 20,000 to 30,000 civilians. Credit for preventing a dam burst is also given to British Marine Captain Mark Gray, a UN Observer, for opening gates to reduce water levels prior to the attack.	Haeri 1993
1993–present	Iraq	Military tool	No	To quell opposition to his government, Saddam Hussein reportedly poisons and drains the water supplies of southern Shiite Muslims, the Ma'dan. The marshes of southern Iraq are intentionally targeted. The European Parliament and UN Human Rights Commission deplore use of water as a weapon in the region.	Gleick 1993, American University 2000c, National Geographic News 2001
1994	Moldova, Russia	Terrorism	No: Threat	Reported threat by Moldavian General Nikolay Matveyev to contaminate the water supply of the Russian 14th Army in Tiraspol, Moldova, with mercury.	Purver 1995
1998/1994	United States	Cyber-terrorism	No	The *Washington Post* reports a 12-year old computer hacker broke into the computer system that runs Arizona's Roosevelt Dam, giving him complete control of the dam's massive floodgates. The cities of Mesa, Tempe, and Phoenix, Arizona, are downstream of this dam. No damage was done. This report turns out to be incorrect. A hacker did break into the computers of an Arizona water facility, the Salt River Project, in the Phoenix area. But he was 27, not 12, and the incident occurred in 1994, not 1998. And while clearly trespassing in critical areas, the hacker never could have had control of any dams, leading investigators to conclude that no lives or property were ever threatened.	Gellman 2002, Lemos 2002

1995	Ecuador, Peru	Military tool, Political tool	Yes	Armed skirmishes arise in part because of disagreement over the control of the headwaters of Cenepa River. Wolf argues that this is primarily a border dispute simply coinciding with the location of a water resource.	Samson and Charrier 1997, Wolf 1997
1997	Singapore, Malaysia	Political tool	No	Malaysia, which supplies about half of Singapore's water, threatens to cut off that supply in retribution for criticism of its policies.	Zachary 1997
1998	Angola	Military tool, Political tool	Yes	In September 1998, fierce fighting breaks out at the Gové Dam on the Kunene River, as UNITA and Angolan government forces battle for control of the installation.	Meissner 2001
1998	Tajikistan	Terrorism, Political tool	No: Threat	On November 6, a guerrilla commander threatens to blow up a dam on the Kairakkhum channel if political demands were not met. Col. Makhmud Khudoberdyev made the threat, reported by the ITAR-Tass News Agency.	WRR 1998
1998	Democratic Republic of Congo	Military target, Terrorism	Yes	Attacks on Inga Dam during efforts to topple President Kabila. Disruption of electricity supplies from Inga Dam and water supplies to Kinshasa.	Chenje 2001, Human Rights Watch 1998
1998–1999	Kosovo	Terrorism, Political tool	Yes	Contamination of water supplies/wells by Serbs disposing of bodies of Kosovar Albanians in local wells. Other reports of Yugoslav federal forces poisoning wells with carcasses and hazardous materials.	CNN 1999, Hickman 1999
1998–2000	Eritrea and Ethiopia	Military target	Yes	Water pumping plants and pipelines in the border town of Adi Quala are destroyed during the civil war between Eritrea and Ethiopia.	ICRC 2003
1999	Bangladesh	Development dispute, Political tool	Yes	Fifty are hurt during strikes called to protest power and water shortages, led by former Prime Minister Begum Khaleda Zia.	Ahmed 1999
1999	Yemen	Development dispute	Yes	Yemen sends 700 soldiers to quell fighting that claimed six lives and injured 60 others in clashes that erupted between two villages fighting over a local spring near Ta'iz. The village of Al-Marzuh believed it was entitled to exclusive rights from a spring because it was located on their land; the neighboring village of Quradah believed their rights to the water were affirmed in a 50-year-old court verdict. The dispute erupted in violence. President Ali Abdullah Saleh intervened by summoning the sheikhs of the two villages to the capital, and sorted out the problem by dividing the water into halves.	Al-Qadhi 2003
1999	East Timor	Military tool, Terrorism	Yes	Militia opposing East Timor independence kills pro-independence supporters and throws bodies in water well.	BBC 1999

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
1999	China	Development dispute, Terrorism	Yes	Around the Lunar New Year, farmers from Hebei and Henan Provinces fight over limited water resources. Heavy weapons, including mortars and bombs, were used and nearly 100 villagers were injured. Houses and facilities were damaged and the total loss reached one million US dollars.	China Water Resources Daily 2002
1999	Lusaka, Zambia	Terrorism, Political tool	Yes	A bomb blast destroys Lusaka's main water pipeline, cutting off water for Zambia's capital of three million.	FTGWR 1999
1999	Angola	Terrorism, Political tool	Yes	One hundred bodies are found in four drinking water wells in central Angola.	International Herald Tribune 1999
1999	Puerto Rico, U.S.	Political tool	No	Protesters block water intake to Roosevelt Roads Navy Base in opposition to U.S. military presence and Navy's use of the Blanco River, following chronic water shortages in neighboring towns.	NYT 1999
1999	South Africa	Terrorism	Yes	A homemade bomb is discovered at a water reservoir at Wallmansthal near Pretoria. It was thought to have been meant to sabotage water supplies to farmers.	IOL 1999
1999	Yugoslavia	Military target	Yes	Belgrade reports that NATO planes had targeted a hydroelectric plant during the Kosovo campaign.	Reuters 1999a
1999	Yugoslavia	Military target	Yes	NATO targets utilities and shuts down water supplies in Belgrade. It also bombs bridges on Danube, disrupting navigation.	Reuters 1999b
1999	Kosovo	Political tool	Yes	Serbian engineers shut down water system in Pristina prior to occupation by NATO.	Reuters 1999c
1999	Yugoslavia	Political tool	Yes	Yugoslavia refuses to clear downed bridges on the Danube River caused by its civil war unless financial aid for reconstruction is provided. European countries on Danube fear that flooding due to winter ice dams will result and condemn the refusal as "environmental blackmail."	Simons 1999
2000	France, Belgium, Netherlands	Terrorism	Yes	In July, workers at the Cellatex chemical plant in northern France dump 5,000 liters of sulfuric acid into a tributary of the Meuse River when they are denied workers' benefits. A French analyst points out that this was the first time "the environment and public health were made hostage in order to exert pressure, an unheard-of situation until now."	Christian Science Monitor 2000

2000	Hazarajat, Afghanistan	Development dispute	Yes	Violent conflicts break out over water resources in the villages Burna Legan and Taina Legan, and in other parts of the region, as drought depletes local resources.	Cooperation Center for Afghanistan 2000
2000	India: Gujarat	Development dispute	Yes	Water riots are reported in some areas of Gujarat amidsts protests against authorities' failure to arrange adequate supplies of tanker water. Police are reported to have shot into a crowd at Falla village near Jamnagar, resulting in the death of three and injuries to 20 following protests against the diversion of water from the Kankavati dam to Jamnagar town.	FTGWR 2000
2000	United States	Terrorism	No	A drill simulating a terrorist attack on the Nacimiento Dam in Monterey County, California gets out of hand when two radio stations report it as a real attack.	Gaura 2000
2000	Australia	Cyber-terrorism	Yes	In Queensland, Australia, police arrest a man for using a computer and radio transmitter to take control of the Maroochy Shire wastewater system and release sewage into parks, rivers, and property.	Gellman 2002
2000	Central Asia: Kyrgyzstan, Kazakhstan, Uzbekistan	Development dispute	No	Kyrgyzstan cuts off water to Kazakhstan until coal is delivered; Uzbekistan cuts off water to Kazakhstan for non-payment of debt.	Pannier 2000
2000	China	Development dispute	Yes	Civil unrest erupts over use and allocation of water from Baiyangdian Lake—the largest natural lake in northern China. Several people died in riots by villagers in July 2000 in Shandong after officials cut off water supplies. In August 2000, six died when officials in the southern province of Guangdong blew up a water channel to prevent a neighboring county from diverting water.	Pottinger 2000
2000	Ethiopia	Development dispute	Yes	A man is stabbed to death during a fight over clean water during a famine in Ethiopia.	Sandrasagra 2000
2000	Bolivia	Development dispute	Yes	Massive protests, riots, and violence result from efforts to privatize the water system of Cochabamba, Bolivia.	Shultz and Draper 2009
2000	Kenya	Development dispute	Yes	A clash between villagers and thirsty monkeys leaves eight apes dead and 10 villagers wounded. The duel started after water tankers brought water to a drought-stricken area and monkeys desperate for water attacked the villagers.	BBC 2000, Okoko 2000

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
2001	China	Development dispute	Yes	In a protest over destruction of fisheries from uncontrolled water pollution, fishermen in northern Jiaxing City, Zhejiang Province, dam the canal that carries 90 million tons of industrial wastewater per year for 23 days. Discharges into the neighboring Shengze Town, Jiangsu Province, kill fish and threaten residents' health.	China Ministry of Water Resources 2001
2001	Philippines	Terrorism	No	The Philippine Islamic militant group Abu Sayyaf is accused of poisoning the water supply to six villages near the Christian town of Isabela on Basilan Island. After residents complain of a gasoline smell from their taps, authorities shut off water supplies, bring in water trucks, and send soldiers and police to patrol the reservoir.	World Environment News 2001
2001	Israel, Palestine	Terrorism, Military target	Yes	Palestinians destroy water supply pipelines to West Bank settlement of Yitzhar and to Kibbutz Kisufim. After Palestinians looted and damaged local water pumps, Israel cuts off the water supply to Agbat Jabar refugee camp near Jericho. Palestinians accuse Israel of destroying a water cistern, blocking water tanker deliveries, and attacking materials for a wastewater treatment project.	Israel Line 2001a, Israel Line 2001b, ENS 2001a
2001	Macedonia	Terrorism, Military target	Yes	Water flow to Kumanovo (population 100,000) is cut off for 12 days in the conflict between ethnic Albanians and Macedonian forces. Valves at dams on the Glaznja and Lipkovo Lakes are damaged.	AFP 2001, BBC 2001b
2001	Afghanistan	Military target	Yes	U.S. forces bomb the hydroelectric facility at Kajaki Dam in Helmand province of Afghanistan, cutting off electricity for the city of Kandahar. The dam itself is apparently not targeted.	BBC 2001a, Parry 2001
2001	Pakistan	Development dispute, Terrorism	Yes	Long-term drought and water shortages lead to civil unrest in Pakistan. Protests begin in March and continue into summer, leading to riots, four bombings, 12 injuries, and 30 arrests. Ethnic conflicts erupt as some groups "accuse the government of favoring the populous Punjab province [over Sindh province] in water distribution."	Nadeem 2001, Soloman 2001
2002	Rome, Italy	Terrorism	No: Threat	Italian police arrest four Moroccans allegedly planning to contaminate the water supply system in Rome with a cyanide-based chemical, targeting buildings that included the United States embassy. Ties to al-Qaida are suggested.	BBC 2002

2002	Kashmir, India	Development dispute	Yes	Two people are killed and 25 others injured in Kashmir when police fire at a group of clashing villagers. The incident takes place in Garend village in a dispute over sharing water from an irrigation stream.	Japan Times 2002
2002	Colombia	Terrorism	Yes	Colombian rebels damage the dam that supplies most of Bogota's drinking water. The Revolutionary Armed Forces of Colombia (FARC), detonate an explosive device planted on a German-made gate valve inside a tunnel in the Chingaza Dam.	Waterweek 2002
2002	Botswana, Bushmen	Development dispute	Yes	Botswana's president Festus Mogae sends troops to the Kalahari Desert to destroy wells and empty water sources of indigenous Khoisan (also known as Bushmen), ostensibly in an effort to remove them from their ancestral lands and assimilate them into modern society. Critics blame the government of taking away water rights in favor of mining interests and label the government's actions a "siege"; Botswana is condemned by international observers. Against expectations, a band of Bushmen retreat into the desert and survive for years with little outside assistance.	Workman 2009
2002	United States	Terrorism	No: Threat	Earth Liberation Front threatens the water supply for the town of Winter Park. Previously, this group claimed responsibility for the destruction of a ski lodge in Vail, Colorado that threatened lynx habitat.	Crecente 2002, AP 2002
2002	Nepal	Terrorism, Political Tool	Yes	The Khumbuwan Liberation Front (KLF) blows up a hydroelectric powerhouse in Bhojpur District on January 26, cutting off power to Bhojpur and surrounding areas. By June 2002, Maoist rebels had destroyed more than seven micro-hydro projects as well as an intake of a drinking water project and pipelines supplying water to Khalanga in western Nepal.	Kathmandu Post 2002, FTGWR 2002
2002	United States	Terrorism	No: Threat	Papers are seized during the arrest of a Lebanese national in the U.S. The man, an imam at a mosque in Seattle, possessed papers with "instructions on poisoning water sources" from a London-based al-Qaida recruiter. The FBI issues a bulletin to computer security experts indicating that al-Qaida may have been studying American dams and water-supply systems in preparation for new attacks.	McDonnell and Meyer 2002, MSNBC 2002
2002	Karnataka, Tamil Nadu, India	Development dispute	Yes	Violence continues over the allocation of the Cauvery (Kaveri) River between Karnataka and Tamil Nadu, including riots, arrests, property destruction, and more than 30 injuries.	The Hindu 2002a, The Hindu 2002b, Times of India 2002a

continues

Water Conflict Chronology *continued*

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
2003	United States	Terrorism	Yes	Four incendiary devices are found in the pumping station of a Michigan water-bottling plant. The Earth Liberation Front (ELF) claims responsibility, accusing Ice Mountain Water Company of "stealing" water for profit. Ice Mountain is a subsidiary of Nestle Waters.	AP 2003ab
2003	Jordan	Terrorism	No: Threat	Jordanian authorities arrest Iraqi agents in connection with a botched plot to poison the water supply that serves American troops in the eastern Jordanian desert near the border with Iraq. The scheme involved poisoning a water tank that supplies American soldiers at a military base in Khao, which lies in an arid region of the eastern frontier near the industrial town of Zarqa.	MJS 2003
2003	Colombia	Terrorism, Development dispute	Yes	A bomb blast at the Cali Drinking Water Treatment Plant kills three workers on May 8. The workers were members of a trade union involved in intense negotiations over privatization of the water system.	PSI 2003
2003	Iraq	Terrorism	Yes	Terrorists bomb a main water pipeline in Baghdad. According to city engineers, it is the first time insurgents have targeted water supply infrastructure in the city.	Tierney and Worth 2003
2003	Iraq, United States, Others	Military target	Yes	During the U.S.-led invasion of Iraq, water systems were reportedly damaged or destroyed by different parties, and major dams were military objectives of the U.S. forces. Damage directly attributable to the war includes vast segments of the water distribution system and the Baghdad water system, damaged by a missile.	UNICEF 2003, Booth 2003
2003	United States	Terrorism	No: Threat	Al-Qaida threatens U.S. water systems via a phone call to a Saudi Arabian magazine. Al-Qaida does not "rule out … the poisoning of drinking water in American and Western cities."	AP 2003ba, Waterman 2003, NewsMax 2003, US Water News 2003
2003–2007	Sudan, Darfur	Military tool, Military target, Terrorism	Yes	Water sources are attacked during the ongoing civil war in Sudan. In 2003, villagers from around Tina said that bombings had destroyed water wells. In Khasan Basao they alleged that water wells were poisoned. In 2004, wells in Darfur were intentionally contaminated as part of a strategy to harass refugees.	Amnesty International 2004, Reuters Foundation 2004

2004	Gaza Strip	Terrorism, Development dispute	Yes	The United States halts two water development projects as punishment to the Palestinian Authority for their failure to find those responsible for a deadly attack on a U.S. diplomatic convoy in October 2003.	AP 2004
2004	South Africa	Development dispute	Yes	The poor delivery of water and sanitation services in Phumelela Township leads to several months of protests, including some severe injuries and property damage. No one was killed during the protests, but a few people were seriously injured, and municipal property was damaged.	CDE 2007
2004	Mexico	Development dispute	Yes	Two Mexican farmers had argued for years over water rights to a small spring used to irrigate a small corn plot near the town of Pihuamo. In March, these farmers shot each other dead in a duel.	Guardian 2004
2004	India	Development dispute	Yes	Four people are killed in October and more than 30 are injured in November in ongoing protests by farmers over allocations of water from the Indira Gandhi Irrigation Canal in Sriganganagar district, which borders Pakistan. Authorities impose curfews on the towns of Gharsana, Raola, and Anoopgarh.	Indo-Asian News Service 2004
2004	Pakistan	Terrorism	Yes	In military action aimed at Islamic terrorists, including al-Qaida and the Islamic Movement of Uzbekistan, homes, schools, and water wells are damaged and destroyed.	Reuters 2004a
2004	India, Kashmir	Terrorism	Yes	Twelve Indian soldiers are killed by an explosive planted in an underground water pipe during “counter-insurgency operation in Khanabal area in Anantnag district.”	TNN 2004
2004	China, Taiwan United States	Military target	No	A 2004 Pentagon report on China’s military capacity raises the concept of Taiwan adopting military technology to deter Chinese military coercion by “presenting credible threats to China’s urban population or high-value targets, such as the Three Gorges Dam.” China promptly denounces “a U.S. suggestion” that Taipei target the Three Gorges dam, leading to a U.S. denial that it had so urged.	China Daily 2004, Pentagon 2004
2004	China	Development dispute	Yes	Tens of thousands of farmers stage a sit-in against the construction of the Pubugou dam on the Dadu River in Sichuan Province. Riot police are deployed to quell the unrest, and one policeman is killed. Witnesses also report the deaths of a number of residents. (See China 2006 for follow-up.)	BBC 2004b, VOA 2004
2004–2006	Ethiopia	Development dispute	Yes	At least 250 people are killed and many more injured in clashes over water wells and pastoral lands. Villagers call it the “War of the Well” and describe “well warlords, well widows, and well warriors.” A three-year drought has led to extensive violence over limited water resources, worsened by the lack of effective government.	BBC 2004a, AP 2005, Wax 2006

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
2005	Ukraine	Terrorism	Yes	On April 13, the Kiev Hydropower Station on the Dnieper River receives a threat that 40 rail cars filled with explosives have been placed on a portion of levees holding back the reservoir.	Levitsky 2005
2005	Kenya	Development dispute	Yes	Police are sent to the northwestern part of Kenya to control a major violent dispute between Kikuyu and Maasai groups over water. More than 20 people were killed in fighting in January. By July, the death toll exceeded 90, principally in the rural center of Turbi. The tensions arose over grazing and water. Maasai herdsmen accused a local Kikuyu politician of diverting a river to irrigate his farm, depriving downstream livestock. Fighting displaced more than 2,000 villagers and reflects tensions between nomadic and settled communities.	BBC 2005, Ryu 2005, Lane 2005
2006	Yemen	Development dispute	Yes	Local media report a struggle between Hajja and Amran tribes over a well located between the two governorates in Yemen. According to news reports, armed clashes between the two sides forced many families to leave their homes and migrate. News reports confirm that authorities arrested 20 people in an attempt to stop the fighting.	Al-Ariqi 2006
2006	Ethiopia	Development dispute	Yes	At least 12 people die and over 20 are wounded in clashes over competition for water and pasture in the Somali border region.	BBC 2006a
2006	Sudan	Development dispute		Militia of the Merowe Dam Militia Implementation Unit in the Sudan attack a gathering of villagers concerned about the community impacts of the dam at a school in Amri village, killing three farmers and injuring more than 50 others.	Bosshard 2009
2006	Ethiopia and Kenya	Development dispute	Yes	At least 40 people die in Kenya and Ethiopia in continuing clashes over water, livestock, and grazing land. Fighting occurrs in southern Ethiopia in the region of Oromo and the northern Kenya Marsabit district.	Reuters 2006
2006	Israel, Lebanon	Military target, Terrorism	Yes	During the 2006 Lebanon War, Hezbollah rockets damage a wastewater treatment plant in Israel. The Lebanese government estimates that Israeli attacks damaged water systems throughout southern Lebanon, including tanks, pipes, pumping stations, and facilities along the Litani River.	Science 2006, Amnesty International 2006, Murphy 2006

2006	Sri Lanka	Military tool, Military target, Terrorism	Yes	Tamil Tiger rebels cut the water supply to government-held villages in northeastern Sri Lanka. Sri Lankan government forces then launched attacks on the reservoir, declaring the Tamil actions to be terrorism. Conflict around the water blockade had claimed more than 425 lives as of August.	BBC 2006b, BBC 2006c, Gutierrez 2006
2006	China	Development dispute	Yes	Chinese authorities execute a man who took part in protests against the Pubugou dam in Sichuan province in 2004 (see China 2004 entry). Chen Tao had been convicted of killing a policeman but was executed before legal appeals had been completed.	BBC 2006d, Coonan 2006
2007	Sudan	Development dispute		Angry villagers in Sudan stage protests against the Kajbar Dam; four villagers are killed by government militias.	Bosshard 2009
2007	Afghanistan	Military target, Terrorism	Yes	The Kajaki Dam is the scene of major fighting between the Taliban and NATO forces, mainly British and Dutch. The Taliban attempts to prevent work on reconstruction of the dam and power lines.	Friel 2007
2007	Israel, Palestine	Development dispute	No	Israel's sanctions against Gaza cause water shortages and a growing public health risk. In particular, restrictions on fuel, spare parts, and maintenance equipment threaten the functioning of Gaza's already limited water and sanitation system.	Oxfam 2007
2007	India	Development dispute	Yes	Thousands of farmers breach security and storm the area around the Hirakud Dam in the east Indian state of Odisha (Orissa) to protest allocation of water to industry. Minor injuries are reported during the conflict between the farmers and police.	Statesman News Service 2007
2007	Canada	Terrorism	No	A Toronto man previously accused of attempted murder and illegal possession of explosives is charged with eight more counts of attempted murder after allegedly tampering with bottled water, which had been injected with an unspecified liquid.	Toronto Star 2007
2007	Burkina Faso, Ghana, and Côte d'Ivoire	Development dispute	Yes	Declining rainfall leads to growing fights between animal herders and farmers with competing needs. In August 2007, residents are forced to flee their homes by fighting in Zoundwéogo province in southern Burkina Faso.	UNOCHR 2007
2007	Sydney residents	Development dispute	Yes	A 36-year-old Australian is charged with murder, after allegedly killing a man during a fight over water restrictions in Sydney. A number of incidents have been reported following 10 years of drought and water restrictions, leading scholars to suggest a "link between persistent urban water restrictions and civil unrest."	ABC News 2007, Crase 2009
2008	Pakistan	Terrorism	Yes	In October, the Taliban threatens to blow up Warsak Dam, the main water supply for the city of Peshawar during a government offensive in the region.	Perlez and Shah 2008

continues

Date	Parties Involved	Basis of Conflict	Violent Conflict or in the Context of Violence?	Description	Sources
2008	Murulle and Garre clans, Kenya	Development dispute	Yes	Fighting over boreholes in arid northern Kenya kills at least four people as competition for resources grows in the drought-hit region between the Murulle and Garre clans in Elwak, Mandera District.	Reuters 2008
2008	China, Tibet	Military target, Development dispute	Yes	China launches a political crackdown in Tibet. Some observers have noted the importance of Tibet for the water resources of China, though the political complications between Tibet and China extend far beyond water. "Tibet is referred to in some circles as the 'world's water tower'; the Tibetan plateau is home to vast reserves of glaciated water, the sources of 10 of the largest rivers in Asia, including the Yellow, Yangtze, Mekong, Brahmaputra, Salween, Hindus and Sutlej among others. By some estimates, the Tibetan plateau is the source of fresh water for fully a quarter of the world's population."	Sharife 2008
2008	Nigeria	Development dispute	Yes	A protest over the price of water in the town of Nyanya just outside of Nigeria's capital Abuja results in violence, including the beating of water vendors.	Yakubu 2008
2009	Oromia and Somali regions, Ethiopia	Development dispute	Yes	Ethiopian Somalis attack a Borana community in the Oromia region over ownership of a new borehole being drilled on the disputed border between them. Three people from the Oromia village of Kafa are killed and seven injured, and the entire community driven from their homes. The drilling rig is destroyed as well.	BBC 2009
2009	Mumbai residents, Police	Development dispute	Yes	On December 3, police clash with hundreds of Mumbai residents protesting water cuts. One man is killed and a dozen others injured. Mumbai authorities are faced with rationing supplies after the worst monsoon season in decades.	Chandran 2009
2009	North Korea, South Korea	Political tool	Yes	Without previous warning, North Korea releases 40 million cubic meters of water from the Hwanggag dam, which caused a flash flood on the Imjin River. In South Korea, at least six fisherman and campers drowned. South Korea fears that North Korea could use the water of the dam as a weapon during a violent conflict. North Korea claims that the water had to be urgently released and promised to warn the South of future releases in advance.	Choe 2009

2009	Indian Citizens	Development dispute	Yes	A family in Madhya Pradesh state in India is killed by a small mob for illegally drawing water from a municipal pipe. Others ran to collect water for themselves before the pipe ran out. Drought and inequality in water distribution lead to more than 50 violent clashes in the region in the month of May, and media reports more than a dozen people killed and even more injured since January, mostly fighting over a bucket of water.	Singh 2009
2009	China and India	Development dispute, Military tool	No	China claims a part of historical Tibet that is now under Indian control as part of the state of Arunachal Pradesh. To influence this territorial dispute, China tries to block a $2.9 billion loan to India from the Asian Development Bank on the grounds that part of this loan was destined for water projects in the disputed area.	Wong 2009
2010	Pakistani tribes	Development dispute, Military tool	Yes	More than 100 are dead and scores injured following two weeks of tribal fighting in Parachinar in the Kurram region of Pakistan, near the Afghanistan border. The conflict over irrigation water began as the Shalozan Tangi tribe cut off supplies to the Shalozan tribe. Some report that the terrorist group al-Qaida may be involved; others claim sectarian violence is to blame as one group is Sunni Muslim and the other Shiite.	Express Tribune 2010, AP 2010
2010	Afghanistan	Terrorism	Yes	A remote-controlled bomb hidden in a water truck kills three people, including two children, in the eastern Afghan province of Khost, which borders Pakistan.	AP 2009
2010	Mangal and Tori tribes, Pakistan	Development dispute	Yes	A water dispute in Pakistan's tribal region leads to 116 deaths. In early September, the Mangal tribe stopped water irrigation on lands used by the Tori tribe, leading to fighting.	CNN 2010
2010	India	Development dispute	Yes	A protest about water shortages leads to violence. Erratic water supply, and eventually a complete cutoff of water in the Kondli area of Mayur Vihar in east Delhi, causes a violent protest and several injuries.	Gosh 2010

References

ABC News. 2007. Man charged with murder after lawn watering dispute. *Australian Broadcasting Company (ABC)*, November 1, 2007. http://www.abc.net.au/news/stories/2007/11/01/2078076.htm (accessed February 11, 2011).

Agence France Press (AFP). 2001. Macedonian troops fight for water supply as president moots amnesty. *AFP*, June 8, 2001. http://www.balkanpeace.org/index.php?index=article&articleid=10488, (accessed May 19, 2011).

Ahmed, A. 1999. Fifty hurt in Bangladesh strike violence. *Reuters News Service*, Dhaka, April 18, 1999.

Al-Ariqi, A. 2006. Water war in Yemen. *Yemen Times* 14(932), April 24, 2006. http://yementimes.com/article.shtml?i=932&p=health&a=1(accessed July 1, 2011).

Al-Qadhi, M. 2003. Thirst for water and development leads to conflict in Yemen. United Nations Development Programme, *Choices* 12(1): 13–14. See also: http://yementimes.com/article.shtml?i=642&p=health&a=1 (accessed July 1, 2011).

American University (Inventory of Conflict and the Environment, ICE). 2000a. Cauvery River Dispute. http://www1.american.edu/ted/ice/cauvery.htm (accessed July 1, 2011).

American University (Inventory of Conflict and the Environment, ICE). 2000b. Lesotho "Water Coup." http://www1.american.edu/projects/mandala/TED/ice/LESWATER.HTM (accessed July 1, 2011).

American University (Inventory of Conflict and the Environment, ICE). 2000c. Marsh Arabs and Iraq. http://www1.american.edu/projects/mandala/TED/MARSH.HTM (accessed July 1, 2011).

Amnesty International. 2004. Sudan: Darfur: "Too many people killed for no reason." February 3, 2004. http://www.amnesty.org/en/library/info/AFR54/008/2004 (accessed July 1, 2011).

Amnesty International. 2006. Israel/Lebanon. Deliberate Destruction or "Collateral Damage"? Israeli Attacks on Civilian Infrastructure. http://www.amnesty.org/en/library/info/MDE18/007/2006 (accessed May 19, 2011).

Associated Press (AP). 2002. Earth Liberation Front members threaten Colorado town's water. *AP*, October 15, 2002.

Associated Press (AP). 2003a. Incendiary devices placed at water plant. *AP*, September 25, 2003.

Associated Press (AP). 2003b. Water targeted, magazine reports. *AP*, May 29, 2003.

Associated Press (AP). 2004. US dumps water projects in Gaza over convoy bomb. *AP*, May 6, 2004.

Associated Press (AP). 2005. At least 16 killed in Somalia over water, pasture battles. *AP*, June 8, 2005.

Associated Press (AP). 2009. Bomb in water truck kills 3 in Afghanistan. *AP*, November 24, 2009. http://www.signonsandiego.com/news/2009/nov/23/bomb-in-water-truck-kills-3-in-afghanistan/ (accessed February 10, 2011).

Associated Press (AP). 2010. Fighting between tribes in Pakistan kills 102. *AP*, September 17, 2010.

Arbuthnot, F. 2000. Allies deliberately poisoned Iraq public water supply in Gulf War. *Sunday Herald* (Scotland), September 17, 2000.

Axis History Forum. 2004. Dnieper Dam Blown Up by Retreating Russians. http://forum.axishistory.com/viewtopic.php?f=55&t=52940 (accessed February 10, 2011).

Bachiene, W. 1791. *Vaderlandsche geographie of nieuwe tegenwoordige staat en hedendaagsche historie der Nederlanden*. Amsterdam, Netherlands: Nabu Press (republished 2010) .

Barrett, G. 2003. Iraq's bad water brings disease, alarms relief workers. *Olympian* (Olympia, Washington), June 29, 2003.

Barry, J.M. 1997. *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America*. New York: Simon and Schuster, p. 67.

Booth, M. 2003. Baghdad Hospitals Reopen but Health Care System Strained. American Red Cross. April 24, 2003.

British Broadcasting Corporation (BBC). 1999. World: Asia-Pacific Timor atrocities unearthed. *BBC News*, September 22, 1999. http://news.bbc.co.uk/hi/english/world/asia-pacific/newsid_455000/455030.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2000. Kenyan monkeys fight humans for water. *BBC News*, March 21, 2000. http://news.bbc.co.uk/1/hi/world/africa/685381.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2001a. US "bombed Afghan power plant." *BBC News*, November 1, 2001. http://news.bbc.co.uk/1/hi/world/south_asia/1632304.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2001b. "Macedonian army chief resigns." *BBC News*. June 12, 2001. http://news.bbc.co.uk/2/hi/europe/1385241.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2002. "Cyanide attack" foiled in Italy. *BBC News*, February 20, 2002. http://news.bbc.co.uk/hi/english/world/europe/newsid_1831000/1831511.stm

British Broadcasting Corporation (BBC). 2004a. "Dozens dead" in Somalia clashes. *BBC News World Edition online*, December 6, 2004. http://news.bbc.co.uk/2/hi/africa/4073063.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2004b. China tries to calm dam protests. *BBC News* (L. Lim), November 18, 2004. http://news.bbc.co.uk/go/pr/fr/-/2/hi/asia-pacific/4021901.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2005. Thousands flee Kenyan water clash. *BBC News*, January 24, 2005. http://news.bbc.co.uk/1/hi/world/africa/4201483.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2006a. Somalis clash over scarce water. *BBC News*, February 17, 2006. http://news.bbc.co.uk/go/pr/fr/-/1/hi/world/africa/4723008.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2006b. Sri Lanka forces attack reservoir. *BBC News*, August 7, 2006. http://news.bbc.co.uk/2/hi/south_asia/5249884.stm?ls (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2006c. Water and war in Sri Lanka. *BBC News*, August 3, 2006. http://news.bbc.co.uk/2/hi/south_asia/5239570.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2006d. China "executes dam protester." *BBC News*, December 7, 2006. http://www.bbc.co.uk/go/pr/fr/-/2/hi/asia-pacific/6217148.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2007. Iran faces $2.65 bn US bomb award. *BBC News*, September 7, 2007. http://news.bbc.co.uk/go/pr/fr/-/2/hi/middle_east/6984365.stm (accessed July 1, 2011).

British Broadcasting Corporation (BBC). 2009. Water pipe sparks Ethiopian conflict. *BBC News*, March 13, 2009. http://news.bbc.co.uk/2/hi/africa/7929104.stm (accessed July 1, 2011).

Belitser, N., Gerasymchuk, S., Grytsenko, O., Dovgopol, Y., Zhminko, Z., Matiychyk, Y., Sushko, O., and Chabala, O. 2009. *Transnistrian Problem: A View from Ukraine*. Kieve, Ukraine: Strategic and Security Studies Group (SSSG). http://www.irf.ua/files/eng/text_eng.pdf (accessed July 1, 2011).

Bingham, G., Wolf, A., and Wohlegenant, T. 1994. *Resolving Water Disputes: Conflict and Cooperation in the United States, the Near East, and Asia*. Washington, D.C.: U.S. Agency for International Development (USAID), Bureau for Asia and the Near East.

Bosshard, P. 2009. China dams the world. *World Policy Journal* (Winter 2009/10): 43–51.

Burns, J.F. 1992. Tactics of the Sarajevo siege: Cut off the power and water. *New York Times*, September 25, 1992, p. A1.

Butts, K., ed. 1997. *Environmental Change and Regional Security*. Carlisle, Pennsylvania: Asia-Pacific Center for Security Studies, Center for Strategic Leadership, U.S. Army War College.

Calcagno, F. 2004. Historical Overview—Licensee Assessments (Lessons Learned). Federal Energy Regulatory Commission, U.S. Department of Energy, San Francisco, California, January 27, 2004. http://www.ferc.gov/EventCalendar/Files/20040309095131-1%20Historical%20Overview.pdf

Centre for Development and Enterprise (CDE). 2007. Voices of Anger: Phumelela and Khutsong: Protest and Conflict in Two Municipalities. No. 10. April 2007. http://www.cde.org.za/article.php?a_id=246 (accessed July 1, 2011).

Chandran, R. 2009. One killed in Mumbai water shortage protests. *Reuters*, December 3, 2009. http://www.reuters.com/article/idUSBOM105009 (accessed July 1, 2011).

Chelyshev, A. 1992. Terrorists poison water in Turkish Army cantonment. *Telegraph Agency of the Soviet Union (TASS)*, March 29, 1992.

Chenje, M. 2001. Hydro-politics and the quest of the Zambezi River Basin Organization. In: *International Waters in Southern Africa*. M. Nakayama, editor. Tokyo, Japan: United Nations University.

China Daily. 2004. PLA General: Attempt to destroy dam doomed. *China Daily*, June 16, 2004. http://www.chinadaily.com.cn/english/doc/2004-06/16/content_339969.htm (accessed July 1, 2011).

China Ministry of Water Resources. 2001. Policy and Regulatory Department website. http://shuizheng.chinawater.com.cn/ssjf/20021021/200210160087.htm (accessed July 1, 2011).

China Water Resources Daily. 2002. Villagers fight over water resources. *China Water Resources Daily*, October 24, 2002. Citation provided by Ma Jun, personal communication.

Choe, Sang-Hun. 2009. South Korea demands apology from North over dam incident. *New York Times*, September 8, 2009. http://www.nytimes.com/2009/09/09/world/asia/09korea.html (accessed February 10, 2011).

Christian Science Monitor. 2000. Ecoterrorism as negotiating tactic. *Christian Science Monitor*, July 21, 2000, p. 8.

Clark, R.C. 1980. *Technological Terrorism*. Old Greenwich, Connecticut: Devin-Adair.

Clark, R.M., and R.A. Deininger. 2000. Protecting the nation's critical infrastructure: The vulnerability of U.S. water supply systems. *Journal of Contingencies and Crisis Management* 8(2): 73–80.

Cable News Network (CNN). 1999. U.S.: Serbs destroying bodies of Kosovo victims. *CNN*, May 5, 1999. www.cnn.com/WORLD/europe/9905/05/kosovo.bodies (accessed July 1, 2011).

Cable News Network (CCN). 2010. Water conflict in Pakistan's tribal region leaves dozens dead. *CNN International Edition*, September 19, 2010. http://articles.cnn.com/2010-09-19/world/pakistan.water.dispute_1_tribal-region-water-dispute-mumtaz-zareen?_s=PM:WORLD (accessed February 10, 2011).

Collins, L., and LaPierre, D. 1972. *O Jerusalem*. New York: Simon and Schuster.

Columbia Encyclopedia. 2000a. Vietnam: History. http://www.infoplease.com/ce6/world/A0861793.html (accessed July 1, 2011).

Columbia Encyclopedia. 2000b. Netherlands. 6th ed. http://www.bartleby.com/65/ne/Nethrlds.html (accessed July 1, 2011).

Coonan, C. 2006. China secretly executes anti-dam protester. *The Independent* (London), December 7, 2006. http://www.independent.co.uk/news/world/asia/china-secretly-executes-anti dam-protester-427401.html (accessed July 1, 2011).

Cooperation Center for Afghanistan. 2000. The Social Impact of Drought in Hazarajat. Mazar-e-Sharif, Afghanistan.

Corps of Engineers. 1953. *Applications of Hydrology in Military Planning and Operations and Subject Classification Index for Military Hydrology Data*. Washington, D.C.: Military Hydrology R&D Branch, Engineering Division, Corps of Engineers, Department of the Army.

Crase, L. 2009. Water policy in Australia: The impact of drought and uncertainty. In: *Policy and Strategic Behaviour in Water Resource Management*. A. Dinar and J. Albiac, editors. London: Earthscan, pp. 91–107.

Crecente, B.D. 2002. ELF targets water: Group threatens eco-terror attack on Winter Park tanks. *Rocky Mountain News*, October 15, 2002. http://www.rockymountainnews.com/drmn/state/article/0,1299,DRMN_21_1479883,00.html (accessed July 1, 2011).

Daniel, C., ed. 1995. *Chronicle of the 20th Century*. New York: Dorling Kindersley.

Delli Priscoli, J. 1998. Water and Civilization: Conflict, Cooperation and the Roots of a New Eco Realism. A keynote address for the 8th Stockholm World Water Symposium, August 10–13, 1998, Stockholm, Sweden. http://www.genevahumanitarianforum.org/docs/Priscoli.pdf (accessed July 1, 2011).

Dolatyar, M. 1995. Water diplomacy in the Middle East. In: *The Middle Eastern Environment*. E. Watson, editor. London: John Adamson Publishing.

Douglass, J.D., and Livingstone, N.C. 1987. *America the Vulnerable: The Threat of Chemical and Biological Warfare*. Lexington, Massachusetts: Lexington Books.

Drower, M.S. 1954. Water-supply, irrigation, and agriculture. In: *A History of Technology*. C. Singer, E.J. Holmyard, and A.R. Hall, editors. New York: Oxford University Press.

Dutch Water Line. 2002. Information on the Historical Use of Water in Defense of Holland. http://www.xs4all.nl/~pho/Dutchwaterline/dutchwaterl.htm (accessed July 1, 2011).

Eitzen, E.M., and Takafuji, E.T. 1997. Historical overview of biological warfare. In: *Textbook of Military Medicine, Medical Aspects of Chemical and Biological Warfare*. Washington, D.C.: Office of the Surgeon General, Department of the Army.

ENS: Environment News Service. 2001. Environment a weapon in the Israeli-Palestinian conflict. *ENS*, February 5, 2001. http://www.ens-newswire.com/ens/feb2001/2001-02-05-01.asp (accessed July 1, 2011).

Express Tribune. 2010. Kurram tribal clash leaves 13 more dead. *Express Tribune* (Lahore, Pakistan), September 19, 2010. http://tribune.com.pk/story/51998/kurram-tribal-clash-leaves-13-more-dead/

Fatout, P. 1972. *Indiana Canals*. West Lafayette, Indiana: Purdue University Studies, pp. 158–162.

Fickle, J.E. 1983. The "people" versus "progress": Local opposition to the construction of the Wabash and Erie Canal. *Old Northwest* 8(4): 309–328.
Fonner, D.K. 1996. Scipio Africanus. *Military History Magazine* (March 1996). http://history-world.org/scipio_africanus.htm (accessed May 19, 2011).
Forkey, N.S. 1998. Damning the dam: Ecology and community in Ops Township, Upper Canada. *Canadian Historical Review* 79(1): 68–99.
Friel, T. 2007. Taliban flee battle using children as shields: NATO. *Reuters*, February 14, 2007. http://www.reuters.com/article/2007/02/14/us-afghan-idUSISL29139620070214 (accessed July 1, 2011).
Financial Times Global Water Report (FTGWR). 1999. Zambia: Water cutoff. *FTGWR* 68 (March 19, 1999): 15.
Financial Times Global Water Report (FTGWR). 2000. Drought in India comes as no surprise. *FTGWR* 94 (April 28, 2000): 14.
Financial Times Global Water Report (FTGWR). 2002. Maoists destroy Nepal's infrastructure. *FTGWR* 146 (May 17, 2002): 4–5.
Gaura, M.A. 2000. Disaster simulation too realistic. *San Francisco Chronicle*, October 27, 2000, p. A1.
Gellman, B. 2002. Cyber-attacks by Al Qaeda feared. *Washington Post*, June 27, 2002, p. A1.
Gleick, P.H. 1991. Environment and security: The clear connections. *Bulletin of the Atomic Scientists* (April): 17–21.
Gleick, P.H. 1993. Water and conflict: Fresh water resources and international security. *International Security* 18(1): 79–112.
Gleick, P.H. 1994. Water, war, and peace in the Middle East. *Environment* 36(3): 6+.
Gleick, P.H. 1995. Water and Conflict: Critical Issues. Presentation to the 45th Pugwash Conference on Science and World Affairs, Hiroshima, Japan, July 23–29, 1995.
Gleick, P.H. 1998. Water and conflict. In: *The World's Water 1998–1999*. Washington, D.C.: Island Press.
Gleick, P.H. 1998. Conflict and cooperation over fresh water. In: *The World's Water 1998–1999: The Biennial Report on Freshwater Resources*. P.H. Gleick, editor. Washington, DC: Island Press, p. 105.
Gleick, P.H. 2006. Water and terrorism. In: *The World's Water 2006–2007: The Biennial Report on Freshwater Resources*. P.H. Gleick, editor. Washington, D.C.: Island Press, pp. 1–28.
Gosh, D. 2010. Protest against water shortage turns violent. *Times of India*, July 7, 2010. http://timesofindia.indiatimes.com/articleshow/6136544.cms (accessed July 1, 2011).
Grant, U.S. 1885. *Personal Memoirs of U.S. Grant*. New York: C.L. Webster.
Guantanamo Bay Gazette. 1964. *The History of Guantanamo Bay: An Online Edition*. Chapter 21, The 1964 water crisis. http://web.archive.org/web/20011121080500/www.nsgtmo.navy.mil/History/HISCHP21.HTM
Guardian. 2004. Water duel kills elderly cousins. *The Guardian* (London), March 11, 2004. http://www.guardian.co.uk/world/2004/mar/11/mexico
Gutierrez, J. 2006. Sri Lanka rejects Norway deal with Tigers, battle for water resumes. *Agence France Press*, August 6, 2006.
Haeri, S. 1993. Iran: Vehement reaction. *Middle East International*, March 19, 1993, p. 8.
Harris, S.H. 1994. *Factories of Death: Japanese Biological Warfare 1932–1945 and the American Cover-up*. New York: Routledge.
Hatami, H., and Gleick, P. 1994. Chronology of conflict over water in the legends, myths, and history of the ancient Middle East. In: Water, war, and peace in the Middle East. *Environment* 36(3): 6+.
Hickman, D.C. 1999. A Chemical and Biological Warfare Threat: USAF Water Systems at Risk. Counterproliferation Paper No. 3. USAF Counterproliferation Center, Air War College, Maxwell Air Force Base, Alabama.
Hillel, D. 1991. Lash of the dragon. *Natural History* (August): 28–37.
The Hindu. 2002a. Ryots on the rampage in Mandya. *The Hindu, India's National Newspaper*, October 31, 2002. http://www.hinduonnet.com/thehindu/2002/10/31/stories/2002103106680100.htm
The Hindu. 2002b. Farmers go berserk; MLA's house attacked. *The Hindu, India's National Newspaper*, October 30, 2002. http://www.hinduonnet.com/thehindu/2002/10/30/stories/2002103004870400.htm
History of War online. Undated. Siege of Uxellodunum, Spring-Summer 51 B.C. http://www.historyofwar.org/articles/siege_uxellodunum.html (accessed February 11, 2011).
Hitchcock, E.A. 1862. Signed Letter from Major General Ethan Allen Hitchcock to his niece Mary,

Washington City, April 20, 1862. (During this period, Hitchcock served as chairman of the War Board serving President Lincoln and Secretary of War Stanton.) http://www.liveauctioneers.com/item/7093913
Honan, W.H. 1996. Scholar sees Leonardo's influence on Machiavelli. *New York Times*, December 8, 1996, p. 18. http://www.nytimes.com/1996/12/08/us/scholar-sees-leonardo-s-influence-on-machiavelli.html
Human Rights Watch. 1998. Human Rights Watch Condemns Civilian Killings by Congo Rebels. http://www.unhcr.org/cgi-bin/texis/vtx/refworld/rwmain?page=search&docid=3ae6b6e14&skip=0&query=inga%20dam (accessed May 19, 2011).
Husarska, A. 1995. Running dry in Sarajevo: Water fight. *New Republic* (July 17 and 24).
Information and Documentation Center for the Geography of the Netherlands (IDG). 1996. Water In, Around and Under the Netherlands. *IDG-Bulletin* (1995/96).
Illustrated History of the Roman Empire. http://www.roman-empire.net/army/leg-siege.html (accessed February 11, 2011).
Indo-Asian News Service. 2004. Curfew imposed in three Rajasthan towns. *Hindustan Times*, December 4, 2004.
InfoRoma. 2004. Roman Aqueducts. http://www.inforoma.it/feature.php?lookup=aqueduct (accessed March 2005).
International Committee of the Red Cross (ICRD). 1977. Commentary on the additional protocols of 8 June 1977 to the Geneva Convention of 12 August 1949. By (Authors: Claude Pilloud, Yves Sandoz, Christophe Swinarski, Bruno Zimmermann, and others.)
International Committee of the Red Cross (ICRC). 2003. Eritrea: ICRC repairs war-damaged health centre and water system. *ICRC News* No. 03/158, December 15, 2003.
International Court of Justice (ICJ). 1999. International Court of Justice Press Communiqué 99/53, Kasikili Island/Sedudu Island (Botswana/Namibia). The Hague, Holland, December 13, 1999, p. 2.
International Herald Tribune. 1999. 100 bodies found in well. *International Herald Tribune*, August 14–15, 1999, p. 4.
IOL News. 1999. Bomb meant for sabotage, says Kasrils. July 20. http://www.iol.co.za/news/south-africa/bomb-meant-for-sabotage-says-kasrils-1.6355. (accessed May 19, 2011).
Israel, J. 1997. *Conflicts of Empires: Spain, the Low Countries and the Struggle for World Supremacy, 1585–1713*. London: Hambledon Press.
Israel Line. 2001a. Palestinians loot water pumping center, cutting off supply to refugee camp. *Israel Line*, January 5, 2001. http://www.mfa.gov.il/mfa/go.asp?MFAH0iy50 (accessed January 5, 2001).
Israel Line. 2001b. Palestinians vandalize Yitzhar water pipe. *Israel Line*, January 9, 2001. http://www.mfa.gov.il/mfa/go.asp?MFAH0izu0 (accessed July 1, 2011).
Japan Times. 2002. Kashmir water clash. *Japan Times*, May 27, 2002, p. 3.
Jenkins, B.M., and Rubin, A.P. 1978. New vulnerabilities and the acquisition of new weapons by nongovernment groups. In: *Legal Aspects of International Terrorism*. A.E. Evans and J.F. Murphy, editors. Lexington, Massachusetts: Lexington Books, pp. 221–276.
Joseph, D.B. 1960. *The Faithful City: The Siege of Jerusalem, 1948*. New York: Simon and Schuster.
Josephus. 90 A.D. *Antiquities of the Jews*. Book 18, Chapter 3, Section 2. http://www.fullbooks.com/The-Antiquities-of-the-Jews20.html
Kathmandu Post. 2002. KLF destroys micro hydro plant. *Kathmandu Post*, January 28, 2002.
Keluel-Jang, S.A. 1997. Alier and the Jonglei Canal. *Southern Sudan Bulletin* 2(3).
Kirschner, O. 1949. Destruction and Protection of Dams and Levees. Military Hydrology, Research and Development Branch, U.S. Corps of Engineers, Department of the Army, Washington District. From Schweizerische Bauzeitung, March 14, 1949. Translated by H.E. Schwarz, Washington, D.C.
Kupperman, R.H., and Trent, D.M. 1979. *Terrorism: Threat, Reality, Response*. Stanford, California: Hoover Institution Press.
Lane, M. 2005. Personal communication to P. Gleick regarding conflicts in Northern Kenya, with reference to *Sunday Nation* newspaper reports of July 17, 2005.
Lemos, R. 2002. Safety: Assessing the infrastructure risk. *CNET News.com*, August 26, 2002. http://news.cnet.com/2009-1001_3-954780.html
Levitsky, Y. 2005. Kiev hydropower station threatened. *Evening News,* no. 15, p. 123. In Russian only. Левицький Я. Київську ГЕС погрожували підірвати, Вечірні вісті.
Levy, K. 2000. Guatemalan dam massacre survivors seek reparations from financiers. *World Rivers Review* (International Rivers Network, Berkeley, California), December 2000, pp. 12–13.

Livingston, N.C. 1982. *The War Against Terrorism*. Lexington, Massachusetts, and Toronto, Canada: Lexington Books.
Lockwood, R.P. The Battle Over the Crusades. Reviewed April 2006. http://www.catholicleague.org/research/battle_over_the_crusades.htm
Makarov, P. 2005. To look in the shameless eyes of officials! In Russian only. Взглянуть в бесстыжие глаза чиновника! http://www.makarov.nikopol.net/doc/otnoshenie_vlasti.doc (accessed November 12, 2010).
Malik, L.K. 2005. *Factors of Risk of Hydro Technical Buildings Damage: Problems of Safety*. Moscow: Nauka. In Russian only. Факторы риска повреждения гидротехнических сооружений: Проблемы безопасности.
McDonnell, P.J., and Meyer, J. 2002. Links to terrorism probed in Northwest. *Los Angeles Times*, July 13, 2002.
Museum of the City of New York (MCNY). Undated. The Greater New York Consolidation Timeline. http://replay.web.archive.org/20050312091707/http://www.mcny.org/Exhibitions/GNY/timeline.htm (accessed May 19, 2011).
Meissner, R. 2000. Hydropolitical hotspots in Southern Africa: Will there be a water war? The case of the Kunene river. In: *Water Wars: Enduring Myth or Impending Reality?* H. Solomon and A. Turton, editors. Africa Dialogue Monograph Series No. 2. Umhlanga Rocks, South Africa: ACCORD.
Meissner, R. 2001. Interaction and existing constraints in international river basins: The case of the Kunene River Basin. In: *International Waters in Southern Africa*. M. Nakayama, editor. Tokyo, Japan: United Nations University.
Milwaukee Journal Sentinel (MJS). 2003. Jordan foils Iraqi plot to poison U.S. troops' water, officials say. *Milwaukee Sentinel*, April 1, 2003.
Mohamed, A.E. 2001. Joint development and cooperation in international water resources: The case of the Limpopo and Orange River Basins in Southern Africa." In *International Waters in Southern Africa*. M. Nakayama, editor. Tokyo, Japan: United Nations University.
Moorehead, A. 1960. *The White Nile*. London, United Kingdom: Penguin Books.
MSNBC. 2002. FBI says al-Qaida after water supply. *MSNBC*, January 31, 2002. http://www.ionizers.org/water-terrorism.html
Murphy, K. 2006. Old feud over Lebanese river takes new turn. Israel's airstrikes on canals renew enduring suspicions that it covets water from the Litani. *Los Angeles Times*, August 10, 2006. http://articles.latimes.com/2006/aug/10/world/fg-litani10
Murphy, I.L., and Sabadell, J.E. 1986. International river basins: A policy model for conflict resolution. *Resources Policy* 12(1): 133–144.
Nadeem, A. 2001. Bombs in Karachi kill one. *Associated Press*, June 13, 2001.
Naff, T., and Matson, R.C., eds. 1984. *Water in the Middle East: Conflict or Cooperation?* Boulder, Colorado: Westview Press.
Nagy, T.J. 2001. The secret behind the sanctions: How the U.S. intentionally destroyed Iraq's water supply. *The Progressive* 165(9): 22–26.
National Geographic News. 2001. Ancient Fertile Crescent almost gone, satellite images show. *National Geographic News*, May 18, 2001. http://news.nationalgeographic.com/news/2001/05/0518_crescent.html
NewsMax. 2003. Al-Qaida threat to U.S. water supply." *NewsMax Wires*, May 29, 2003. http://www.newsmax.com/archives/articles/2003/5/28/202658.shtml
Nuclear Threat Initiative (NTI). 2005. A Brief History of Chemical Warfare. http://www.nti.org/h_learnmore/cwtutorial/chapter02_02.html
New York Times (NYT). 1941. Act laid to Stalin: Razing of dam reported ordered to bar Nazis' path with flood. *New York Times*, August 21, 1941.
New York Times (NYT). 1999. Puerto Ricans protest Navy's use of water. *New York Times*, October 31, 1999, p. 30.
Okoko, T.O. 2000. Monkeys, humans fight over drinking water. *Panafrican News Agency*, March 21, 2000.
Orlenko, I.P. 1981. *We Are "Tallinim."* Tallinn, Estonia: Eesti raamat. In Russian only. Орленко И. Ф. Мы. 1981."Мы - 'Таллиннские'." Ээсти раамат, Таллин, Эстония. http://www.bellabs.ru/51/Book1/Book1-00.html
Oxfam. 2007. Gaza Siege Puts Public Health at Risk as Water and Sanitation Services Deteriorate Warns Oxfam. http://www.old-adalah.org/newsletter/eng/nov07/oxfam.pdf (accessed May 19, 2011).
Pagan, A. 2005. Catastrophic dam failures. *CE News.com*, December 2005. http://www.cenews.

com/magazine-article-cenews.com-december-2005-catastrophic_dam_failures-4617.html (accessed July 1, 2011).

Pannier, B. 2000. Central Asia: Water becomes a political issue. *Radio Free Europe*, http://reliefweb.int/node/67416 (accessed May 19, 2011).

Parry, R.L. 2001. UN fears "disaster" over strikes near huge dam. *The Independent* (London), November 8, 2001.

Pentagon. 2004. FY04 Report to Congress on PRC Military Power, Pursuant to the FY2000 National Defense Authorization Act. Annual Report on the Military Power of the People's Republic of China 2004. http://www.defenselink.mil/pubs/d20040528PRC.pdf (accessed July 1, 2011).

Perlez, J., and Shah, P.Z. 2008. Confronting the Taliban at home, Pakistan finds itself at war. *New York Times*, October 3, 2008, p. 1.

Plant, G. 1995. *Water as a Weapon in War.* Water and War, Symposium on Water in Armed Conflicts, November 21–23, 1994, Montreux, Switzerland. Geneva, Switzerland: International Committee of the Red Cross.

Pottinger, M. 2000. Major Chinese lake disappearing in water crisis. *Reuters Science News*, December 20, 2000. http://us.cnn.com/2000/NATURE/12/20/china.lake.reut/ (accessed July 1, 2011).

Public Services International (PSI). 2003. Urgent action: Bomb blast kills 3 workers at the Cali Water Treatment Plant. www.world-psi.org.

Purver, R. 1995. Chemical and Biological Terrorism: The Threat According to the Open Literature. Canadian Security Intelligence Service, Ottawa, Canada.

Rasch, P.J. 1968. The Tularosa ditch war. *New Mexico Historical Review* 43(3): 229–235.

Rathfelder, Erich. 1999. Dangerous forces: Dams, dikes, and nuclear stations. In Crimes of war: what the public should know, ed. Roy Gutman and David Rieff, 116-117. Singapore: W. W. Norton & Company.

Reisner, M. 1993. *Cadillac Desert: The American West and Its Disappearing Water*. New York: Penguin Books.

Reuters. 1999a. Serbs say NATO hit refugee convoys. *Reuters*, April 14, 1999.

Reuters. 1999b. NATO keeps up strikes but Belgrade quiet. *Reuters*, June 5, 1999.

Reuters. 1999c. NATO builds evidence of Kosovo atrocities. *Reuters*, June 17, 1999.

Reuters. 2004a. Al Qaeda spy chief killed in Pakistani raid. *Reuters*, March 29, 2004. http://www.washingtonpost.com/wp-dyn/articles/A32878-2004Mar29_2.html (accessed July 1, 2011).

Reuters. 2006. Clashes over water, pasture kill 40 in east Africa. *Reuters/Asia News*, June 7, 2006. http://asia.news.yahoo.com/060606/3/2lk9x.html (accessed July 23, 2006).

Reuters. 2008. Clashes over water kill 4 in drought-hit Kenya. *Reuters*, October 17, 2008. http://www.reuters.com/article/latestCrisis/idUSWAL762271 (accessed July 1, 2011).

Reuters Foundation. 2004. Darfur: "2.5 million people will require food aid in 2005." *Reuters Foundation* (R. Schofield), November 22, 2004. http://replay.web.archive.org/20070805183644/http://www.medair.org/en_portal/medair_news?news=258 (accessed May 19, 2011).

Rome Guide. 2004. Fontana di Trevi: History. http://web.tiscali.it/romaonlineguide/Pages/eng/rbarocca/sBMy5.htm (accessed March 2005).

Rowe, W.T. 1988. Water control and the Qing political process: The Fankou Dam controversy, 1876–1883. *Modern China* 14(4): 353–387.

Ryu, A. 2005. Water rights dispute sparks ethnic clashes in Kenya's Rift Valley. *Voice of America*, March 21, 2005. http://replay.web.archive.org/20090116030429/http://www.voanews.com/english/archive/2005-03/2005-03-21-voa28.cfm (accessed May 19, 2011).

Samson, P., and Charrier, B. 1997. International Freshwater Conflict: Issues and Prevention Strategies. Green Cross International. http://cours.ifage.ch/archives/webdev03/mikay/GreenCrossPrograms/waterres/gcwater/study.html (accessed May 19, 20110.

Sandrasagra, M.J. 2000. Development Ethiopia: Relief agencies warn of major food crisis. *Inter Press Service*, April 11, 2000.

Scheiber, H.N. 1969. *Ohio Canal Era*. Athens, Ohio: Ohio University Press, pp. 174–175.

Science. 2006. Tallying Mideast damage. *Science* 313(5793): 1549.

Scofield, C.I., ed. 1967. *New Scofield Reference Bible, Authorized King James Version*. Oxford, United Kingdom: Oxford University Press.

Semann, D. 1950. Die Kriegsbeschädigungen der Edertalsperrmauer, die Wiederherstellungsarbeiten und die angestellten Untersuchungen über die Standfestigkeit der Mauer. *Die Wasserwirtschaft*, 41. Jg., Nr. 1 u. 2.

Sharife, Khadija. 2008. "Shifting Climates on the Roof of the World." Guernica, May 18. http://www.guernicamag.com/blog/593/shifting_climates_on_the_roof/index.php (accessed July 1, 2011).

Shultz, J., and Draper, M.C., eds. 2009. *Dignity and Defiance: Stories from Bolivia's Challenge to Globalization*. Berkeley: University of California Press.

Simons, M. 1999. Serbs refuse to clear bomb-littered river. *New York Times*, October 24, 1999.

Singh, G. 2009. Water Wars strike ahead of predictions. *EcoWorldly.com*, May 16, 2009. http://ecolocalizer.com/2009/05/16/water-wars-strike-ahead-of-predictions/ (accessed July 1, 2011).

Stockholm International Peace Research Institute (SIPRI). 1971. *The Rise of CB Weapons: The Problem of Chemical and Biological Warfare*. New York: Humanities Press.

Soloman, A. 2001. Policeman dies as blasts rock strike-hit Karachi. *Reuters*, June 13, 2001. http://news.indian-network.de/partikel/karachi/bombse.htm (accessed May 19, 2011).

Statesman News Service. 2007. Clash takes place over water rights. *The Statesman*, Sambalpur, India.

Steinberg, T.S. 1990. Dam-breaking in the nineteenth-century Merrimack Valley. *Journal of Social History* 24(1): 25–45.

Stewart, W.H. Undated. An Analysis of the 1944 Japanese Defense of Saipan. http://saipanstewart.com/essays/Defense%20of%20Saipan.html (accessed February 11, 2011).

Strategy Page. 2006. Biotoxins in Warfare. http://www.strategypage.com/articles/biotoxin_files/BIOTOXINSINWARFARE.asp (accessed June 2006).

Styran, R.M., and Taylor, R.R. 2001. *"The Great Swivel Link": Canada's Welland Canal*. Toronto, Ontario: The Champlain Society.

Suliman, M. 1998. Resource Access: A Major Cause of Armed Conflict in the Sudan. The Case of the Nuba Mountains. Institute for African Alternatives, London, United Kingdom. http://srdis.ciesin.org/cases/Sudan-Paper.html (accessed July 1, 2011).

Thatcher, J. 1827. *A Military Journal During the American Revolutionary War, From 1775 to 1783. Second Edition, Revised and Corrected*. Boston, Massachusetts: Cottons and Barnard. http://www.fortklock.com/journal1777.htm (accessed July 1, 2011).

Tierney, J., and Worth, R.F. 2003. Attacks in Iraq may be signals of new tactics. *New York Times*, August 18, 2003, p. 1. http://www.nytimes.com/2003/08/18/international/worldspecial/18IRAQ.html (accessed July 1, 2011).

Times of India. 2002. Cauvery row: Farmers renew stir. *Times of India*, October 20, 2002. http://timesofindia.indiatimes.com/cms.dll/html/uncomp/articleshow?art_id=26586125 (accessed July 1, 2011).

Times News Network (TNN). 2004. IED was planted in underground pipe. *TNN*, December 5, 2004. http://timesofindia.indiatimes.com/articleshow/947432.cms (accessed July 1, 2011).

Toronto Star. 2007. Man faces attempted murder charge over water. *Toronto Star*, November 6, 2007. http://www.thestar.com/printArticle/274128 (accessed July 1, 2011).

Tucker, J.B., ed. 2000. *Toxic Terror: Assessing Terrorist Use of Chemical and Biological Weapons*. Cambridge, Massachusetts: MIT Press.

Turton, A.R. 2005. A Critical Assessment of the River Basins at Risk in the Southern African Hydropolitical Complex. Paper presented at the Workshop on the Management of International Rives and Lakes, hosted by the Third World Centre for Water Management and the Helsinki University of Technology, August 17–19, 2005, Helsinki, Finland. CSIR Report No. ENV-P-CONF 2005-001.

United Nations Children's Fund (UNICEF). 2003. Iraq: Cleaning up neglected, damaged water system, clearing away garbage. News Note Press Release, May 27, 2003. http://www.unicef.org/media/media_6998.html (accessed July 1, 2011).

UN Office for the Coordination of Humanitarian Affairs (OCHR). 2007. Burkina Faso: Innovation and Education Needed to Head Off Water War. http://www.irinnews.org/PrintReport.aspx?ReportId=74308 (accessed July 1, 2011).

US Water News. 2003. Report suggests al-Qaida could poison U.S. water. *US Water News Online*, June 2003. http://web.archive.org/web/20030813082618/http://www.uswaternews.com/archives/arcquality/3repsug6.html (accessed July 1, 2011).

Vanderwood, P.J. 1969. *Night Riders of Reelfoot Lake*. Memphis, Tennessee: Memphis State University Press.

Voice of America News (VOA). 2004. China's Sichuan Province tense in aftermath of violent anti-dam protests. *VOA* (L. Ramirez), November 24, 2004.

Wallenstein, P., and Swain, A. 1997. International freshwater resources—Conflict or cooperation? In: *Comprehensive Assessment of the Freshwater Resources of the World*. Stockholm, Sweden: Stockholm Environment Institute.

Walters, E. 1948. *Joseph Benson Foraker: Uncompromising Republican*. Columbus, Ohio: Ohio History Press, pp. 44–45.

Waterman, S. 2003. Al-Qaida threat to U.S. water supply. *United Press International (UPI)*, May 28, 2003.

Waterweek. 2002. Water facility attacked in Colombia. *Waterweek* (American Water Works Association), January 2002. http://replay.web.archive.org/20040628072007/http://www.awwa.org/advocacy/news/020602.cfm (accessed May 19, 2011).

Wax, E. 2006. Dying for water in Somalia's drought: Amid anarchy, warlords hold precious resource. *Washington Post*, April 14, 2006, p. A1. http://www.washingtonpost.com/wp-dyn/content/article/2006/04/13/AR2006041302116.html (accessed July 1, 2011).

Wikipedia. Undated-a. Battle of Alesia. http://en.wikipedia.org/wiki/Battle_of_Alesia (accessed February 10, 2011).

Wikipedia. Undated-b. Siege of Jerusalem (1948). http://en.wikipedia.org/wiki/Siege_of_Jerusalem_(1948) (accessed February 10, 2011).

Wikipedia, Undated-c. First Sacred War. http://en.wikipedia.org/wiki/First_Sacred_War (accessed July 1, 2011).

Wolf, A.T. 1995. *Hydropolitics Along the Jordan River: Scarce Water and Its Impact on the Arab-Israeli Conflict*. Tokyo, Japan: United Nations University Press.

Wolf, A.T. 1997. "Water Wars" and Water Reality: Conflict and Cooperation Along International Waterways. Presentation at NATO Advanced Research Workshop on Environmental Change, Adaptation, and Human Security, October 9–12, 1997, Budapest, Hungary.

Wong, E. 2009. Tibetan area a tinderbox for China-India tensions. *New York Times*, September 3, 2009. http://www.nytimes.com/2009/09/04/world/asia/04chinaindia.html (accessed July 1, 2011).

Workman, J.G. 2009. *Heart of Dryness: How the Last Bushmen Can Help Us Endure the Coming Age of Permanent Drought*. New York: Walker and Company.

World Environment News. 2001. Philippine rebels suspected of water "poisoning." *World Environment News*. http://replay.web.archive.org/20060928183138/http://www.planetark.org/avantgo/dailynewsstory.cfm?newsid=12807 (accessed May 19, 2011).

World Rivers Review (WRR). 1998. *Dangerous Dams: Tajikistan* 13 (6): 13. Berkeley, California: International Rivers Network.

Yakubu, A. 2008. Water vendors protest at Nyanya. *Daily Trust* (Abuja), AllAfrica.com, March 4, 2008. http://allafrica.com/stories/200803040513.html (accessed July 1, 2011).

Yang Lang. 1989/1994. High dam: The sword of Damocles. In: *Yangtze! Yangtze!* Dai Qing, editor. London, United Kingdom: Probe International, Earthscan Publications, pp. 229–240.

Zachary, G.P. 1997. Water pressure: Nations scramble to defuse fights over supplies. *Wall Street Journal*, December 4, p. A17.

Zemmali, H. 1995. *International Humanitarian Law and Protection of Water*. Water and War, Symposium on Water in Armed Conflicts, November 21–23, 1994, Montreux, Switzerland. Geneva, Switzerland: International Committee of the Red Cross.

DATA TABLE 1

Total Renewable Freshwater Supply, by Country

Description

Average annual renewable freshwater resources are listed by country, updating Table 1 in the previous versions of *The World's Water.* Data from UN FAO AQUASTAT was updated to reflect the most recent data in that database. However, because these data are typically produced by modeling or estimation, rather than measurement, we use data from other sources where possible (even if older than data in AQUASTAT).

Data in this table typically comprise both renewable surface-water and groundwater supplies, including surface inflows from neighboring countries. The UN FAO refers to this as total natural renewable water resources. Flows to other countries are not subtracted from these numbers. All quantities are in cubic kilometers per year (km^3/yr). These data represent average freshwater resources in a country—actual annual renewable supply will vary from year to year.

Limitations

These detailed country data should be viewed, and used, with caution. The data come from different sources and were estimated over different periods. Many countries do not directly measure or report internal water resources data, so some of these entries were produced using indirect methods.

Not all of the annual renewable water supply is available for use by the countries to which it is credited here; some flows are committed to downstream users. For example, under treaty requirements, the Sudan must pass significant flows downstream to Egypt. Other countries, such as Turkey, Syria, and France, to name only a few, also pass significant amounts of water to other users. The annual average figures hide large seasonal, interannual, and long-term variations.

SOURCES

Compiled by P. H. Gleick, H. Cooley, and L. Allen, Pacific Institute.

a. Total natural renewable surface and groundwater. Typically includes flows from other countries. (FAO: "Natural total renewable water resources.")
b. Estimates from Belyaev, Institute of Geography, USSR (1987).
c. Frenken, K., ed. Estimates from FAO (2005), *Irrigation in Africa in Figures— AQUASTAT Survey*

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_12,

2005. Rome, Italy: Food and Agriculture Organization.

d. Estimates from WRI (1994). See this source for original data source.
e. Estimates from Goscomstat, USSR (1989), as cited in Gleick 1993, Table A16.
f. Estimates from FAO (1997), *Water Resources of the Near East Region: A Review*. Rome, Italy: Food and Agriculture Organization, United Nations.
g. Estimates from FAO (1997), *Irrigation in the Countries of the Former Soviet Union in Figures*. Rome, Italy: Food and Agriculture Organization, United Nations.
h. UNFAO. 1999. *Irrigation in Asia in Figures*. Rome, Italy: Food and Agriculture Organization, United Nations.
i. Nix, H. 1995. *Water/Land/Life: The Eternal Triangle*. Canberra, Australia: Water Research Foundation of Australia.
j. UNFAO. 2000. *Irrigation in Latin America and the Caribbean*. Rome, Italy: Food and Agriculture Organization, United Nations.
k. AQUASTAT website as of January 2011.
l. Margat, J./OSS. 2001. Les ressources en eau des pays de l'OSS. Evaluation, utilisation et gestion. UNESCO/Observatoire du Sahara et du Sahel (updating of 1995).
m. Estimates from FAO (2003), *Review of World Water Resources by Country*. Rome, Italy: Food and Agriculture Organization, United Nations (see specific references in this document for more information).
n. United States Geological Survey revised: conterminous U.S. (2071); Alaska (980); Hawaii (18).
o. EUROSTAT, U. Wieland. 2003. Water resources in the EU and in the candidate countries. Statistics in Focus, Environment and Energy, European Communities.
p. Margat, J, and Vallée, D. 2000. Blue Plan—Mediterranean Vision on Water, Population and the Environment for the 21st Century. Sophia Antipolis, France.
q. Geres, D. 1998. Water Resources in Croatia. International Symposium on Water Management and Hydraulic Engineering. Dubrovnic, Croatia, September 14–19, 1998.
r. AQUASTAT website as of November 2005.
s. EUROSTAT. 2005.
t. Pearse, P.H., Bertrand, F., and MacLaren, J.W. 1985. *Currents of Change*. Final Report of Inquiry on Federal Water Policy. Ottawa, Canada: Environment Canada.
u. China Ministry of Water. Annual Report 2007–2008. *Ministry of Water Resources People's Republic of China, 2007–2008 Annual Report.* www.mwr.gov.cn/english/2007-2008.doc
v. EUROSTAT, accessed 2010.
w. Australian Government National Water Commission. 2005. Australian Water Resources 2005.
x. Frenken, K., ed. Estimates from FAO (2005). Irrigation in the Middle East Region in Figures. AQUASTAT Survey—2008.

Data Table 1 Total Renewable Freshwater Supply, by Country

Region	Country	Annual Renewable Water Resources (km^3/yr)	Year of Estimate	Source of Estimate
AFRICA	Algeria	11.6	2005	c
	Angola	184.0	1987	b
	Benin	25.8	2001	l
	Botswana	14.7	2001	l
	Burkina Faso	17.5	2001	l
	Burundi	3.6	1987	b
	Cameroon	285.5	2003	m
	Cape Verde	0.3	2005	c
	Central African Republic	144.4	2005	c
	Chad	43.0	1987	b
	Comoros	1.2	2005	c
	Congo	832.0	1987	b
	Congo, Democratic Republic (formerly Zaire)	1283	2001	l
	Cote D'Ivoire	81	2001	l
	Djibouti	0.3	2005	c
	Egypt	58.3	2005	c
	Equatorial Guinea	26	2001	l
	Eritrea	6.3	2001	l
	Ethiopia	110.0	1987	b
	Gabon	164.0	1987	b
	Gambia	8.0	2005	c
	Ghana	53.2	2001	l
	Guinea	226.0	1987	b
	Guinea-Bissau	31.0	2005	c
	Kenya	30.7	2005	c
	Lesotho	5.2	1987	b
	Liberia	232.0	1987	b
	Libya	0.6	2005	c
	Madagascar	337.0	2005	c
	Malawi	17.3	2001	l
	Mali	100.0	2005	c
	Mauritania	11.4	2005	c
	Mauritius	2.8	2005	c
	Morocco	29.0	2005	c
	Mozambique	217.1	2005	c
	Namibia	17.7	2005	c
	Niger	33.7	2005	c
	Nigeria	286.2	2005	c
	Reunion	5.0	1988	m
	Rwanda	9.5	2005	c
	Senegal	39.4	1987	b
	Sierra Leone	160.0	1987	b
	Somalia	14.2	2005	c
	South Africa	50.0	2005	c
	Sudan	64.5	2005	c
	Swaziland	4.5	1987	b
	Tanzania	91	2001	l

continues

Data Table 1 *continued*

Region	Country	Annual Renewable Water Resources (km^3/yr)	Year of Estimate	Source of Estimate
	Togo	14.7	2001	l
	Tunisia	4.6	2005	c
	Uganda	66.0	2005	c
	Zambia	105.2	2001	l
	Zimbabwe	20.0	1987	b
NORTH AND CENTRAL AMERICA	Antigua and Barbuda	0.1	2000	j
	Bahamas	nd	nd	
	Barbados	0.1	2003	m
	Belize	18.6	2000	j
	Canada	3300.0	1985	t
	Costa Rica	112.4	2000	j
	Cuba	38.1	2000	j
	Dominica	nd	nd	
	Dominican Republic	21.0	2000	j
	El Salvador	25.2	2001	l
	Grenada	nd	nd	
	Guatemala	111.3	2000	j
	Haiti	14.0	2000	j
	Honduras	95.9	2000	j
	Jamaica	9.4	2000	j
	Mexico	457.2	2000	j
	Nicaragua	196.7	2000	j
	Panama	148.0	2000	j
	Saint Kitts and Nevis	0.02	2000	j
	Trinidad and Tobago	3.8	2000	j
	United States of America	3069.0	1985	n
SOUTH AMERICA	Argentina	814.0	2000	j
	Bolivia	622.5	2000	j
	Brazil	8233.0	2000	j
	Chile	922.0	2000	j
	Colombia	2132.0	2000	j
	Ecuador	432.0	2000	j
	Guyana	241.0	2000	j
	Paraguay	336.0	2000	j
	Peru	1913.0	2000	j
	Suriname	122.0	2003	m
	Uruguay	139.0	2000	j
	Venezuela	1233.2	2000	j
ASIA	Afghanistan	65.0	1997	f
	Bahrain	0.1	2008	x
	Bangladesh	1210.6	1999	h
	Bhutan	95.0	1987	b
	Brunei	8.5	1999	h
	Cambodia	476.1	1999	h
	China	2738.8	2008	u
	India	1907.8	1999	h
	Indonesia	2838.0	1999	h

Region	Country	Annual Renewable Water Resources (km³/yr)	Year of Estimate	Source of Estimate
	Iran	137.5	2008	x
	Iraq	75.6	2008	x
	Israel	1.8	2008	x
	Japan	430.0	1999	h
	Jordan	0.9	2008	x
	Korea Democratic People's Republic	77.1	1999	h
	Korea Republic	69.7	1999	h
	Kuwait	0.02	2008	x
	Laos	333.6	2003	m
	Lebanon	4.5	2008	x
	Malaysia	580.0	1999	h
	Maldives	0.03	1999	h
	Mongolia	34.8	1999	h
	Myanmar	1045.6	1999	h
	Nepal	210.2	1999	h
	Oman	1.4	2008	x
	Pakistan	233.8	2003	k
	Philippines	479.0	1999	h
	Qatar	0.1	2008	x
	Saudi Arabia	2.4	2008	x
	Singapore	0.6	1975	d
	Sri Lanka	50.0	1999	h
	Syria	16.8	2008	x
	Taiwan	67.0	2000	r
	Thailand	409.9	1999	h
	Turkey	213.6	2008	x
	United Arab Emirates	0.2	2008	x
	Vietnam	891.2	1999	h
	Yemen	2.1	2008	x
EUROPE	Albania	41.7	2001	p
	Austria	84.0	2007	v
	Belgium	20.0	2007	v
	Bosnia and Herzegovina	37.5	2003	m
	Bulgaria	107.2	2010	v
	Croatia	105.5	1998	o, q
	Cyprus	0.3	2007	v
	Czech Republic	16.0	2007	v
	Denmark	16.3	2007	v
	Estonia	12.3	2007	v
	Finland	110.0	2007	v
	France	186.3	2007	v
	Germany	188.0	2007	v
	Greece	72.0	2007	v
	Hungary	116.4	2007	v
	Iceland	170.0	2007	v
	Ireland	46.8	2003	o
	Italy	175.0	2007	v
	Luxembourg	1.6	2007	v
	Macedonia	6.4	2001	p

continues

Data Table 1 *continued*

Region	Country	Annual Renewable Water Resources (km³/yr)	Year of Estimate	Source of Estimate
	Malta	0.07	2005	s
	Netherlands	89.7	2007	v
	Norway	389.4	2007	v
	Poland	63.1	2007	v
	Portugal	73.6	2007	v
	Romania	25.7	2007	v
	Slovakia	50.1	2007	v
	Slovenia	32.1	2007	v
	Spain	111.1	2007	v
	Sweden	183.4	2007	v
	Switzerland	53.5	2007	v
	United Kingdom	175.3	2007	v
	Serbia-Montenegro*	208.5	2003	m
FORMER SOVIET UNION	Russia	4498.0	1997	e,g
	Armenia	7.8	2008	x
	Azerbaijan	34.7	2008	x
	Belarus	58.0	1997	g
	Estonia	12.8	1997	g
	Georgia	63.3	2008	x
	Kazakhstan	109.6	1997	g
	Kyrgyzstan	46.5	1997	m
	Latvia	337.3	2007	v
	Lithuania	24.5	2007	v
	Moldova	11.7	1997	g
	Tajikistan	99.7	1997	m
	Turkmenistan	60.9	1997	m
	Ukraine	139.5	1997	g
	Uzbekistan	72.2	2003	m
OCEANIA	Australia	336.1	2005	w
	Fiji	28.6	1987	b
	New Zealand	397.0	1995	i
	Papua New Guinea	801.0	1987	b
	Solomon Islands	44.7	1987	b

*Referred to as Yugoslavia in previous volumes of *The World's Water.*

Freshwater Withdrawal by Country and Sector

Description

The use of water varies greatly from country to country and from region to region. Data on water use by regions and by different economic sectors are among the most sought after in the water resources area. Ironically, these data are often the least reliable and most inconsistent of all water-resources information. This table includes the data available on total freshwater withdrawals by country in cubic kilometers per year and cubic meters per person per year, using national population estimates from approximately the year of withdrawal. The table also gives the breakdown of that water use by the domestic, agricultural, and industrial sectors, in both percentage of total water use and cubic meters per person per year.

Data for a number of countries has been updated in the following table since the previous version of *The World's Water*. UN FAO AQUASTAT recently conducted an irrigation survey in Middle Eastern countries, with which data in this table was updated. Additionally, data for some countries was updated from country-specific sources. The data sources are explicitly identified.

"Withdrawal" typically refers to water taken from a water source for use. It does not refer to water "consumed" in that use. The domestic sector typically includes household and municipal uses as well as commercial and governmental water use. The industrial sector includes water used for power-plant cooling and industrial production. The agricultural sector includes water for irrigation and livestock.

Limitations

Extreme care should be used when applying these data. They come from a wide variety of sources and are collected using a wide variety of approaches, with few formal standards. As a result, this table includes data that are actually measured, estimated, modeled using different assumptions, or derived from other data. The data also come from different years, making direct intercomparisons difficult. For example, some water-use data are more than twenty years old.

As is noted in past volumes of *The World's Water*, the FAO AQUASTAT dataset, while the most comprehensive single database, contains inadequate information on sources and assumptions and often contains modeled rather than measured values. Data from this database should be used with great care and with appropriate caveats about their quality.

Another major limitation of these data is that they do not include the use of rainfall in agriculture. Many countries use a significant fraction of the rain falling on their territory for agricultural production, but this water use is neither accurately measured nor reported in this set. We repeat our regular call for a systematic reassessment of water-use data and for national and international commitments to collect and standardize this information. We note that budgetary constraints continue to delay any major new data initiatives.

SOURCES

a. FAO AQUASTAT estimates from http://www.fao.org (March 2004).
b. World Resources Institute. 1994. *World Resources 1994-1995*, in collaboration with the United Nations Environment Programme and the United Nations Development Programme. New York: Oxford University Press.
c. Eurostat Yearbook. 1997. Statistics of the European Union, EC/C/6/Ser.26GT, Luxembourg.
d. UN FAO. 1999. *Irrigation in Asia in Figures*. Rome, Italy: Food and Agriculture Organization, United Nations.
e. UN FAO. 2000. *Irrigation in Latin America and the Caribbean*. Rome, Italy: Food and Agricultural Organization, United Nations.
f. AQUASTAT. 2002. http://www.fao.org
g. Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A. 2009. Estimated Use of Water in the United States in 2005. U.S. Geological Survey Circular 1344.
h. Eurostat. 2011. Entry to Eurostat Statistical Database: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database.
i. FAO AQUASTAT estimates from http://www.fao.org (January 2011). See text for details.
j. Eurostat. 2005. Updated July 2005.
k. Environment Canada. Withdrawal Uses. http://www.ec.gc.ca/eau-water/default.asp?lang=En&n=851B096C-1
l. Hidalgo, H. 2010. Water Resources in Costa Rica: A Strategic View. Draft copy. Citing Ministerio de Salud et al. 2003.
m. Australian Bureau of Statistics. 2006. Water Account Australia 2004–2005. http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/3494F63DFEE158BFCA257233001CE732/$File/46100_2004-05.pdf
n. China Ministry of Water. Annual Report 2007–2008. *Ministry of Water Resources People's Republic of China, 2007–2008 Annual Report*. www.mwr.gov.cn/english/2007-2008.doc.
o. Frenken, K., ed. Estimates from FAO (2005). Irrigation in the Middle East Region in Figures. AQUASTAT Survey—2008.

Population data from the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World population prospects: The 2008 revision. Total population, both sexes. Estimates 2010. United Nations. http://www.un.org/esa/population/publications/wpp2008/wpp2008_highlights.pdf

Data Table 2. Freshwater Withdrawal by Country and Sector

Region	Country	Year	Total Freshwater Withdrawal (km^3/yr)	Per Capita Withdrawal ($m^3/p/yr$)	Domestic Use (%)	Industrial Use (%)	Agricultural Use (%)	Domestic Use $m^3/p/yr$	Industrial Use $m^3/p/yr$	Agricultural Use $m^3/p/yr$	Source	2010 Population (millions)
AFRICA	Algeria	2000	6.07	171	22	13	65	38	23	111	i	35.42
	Angola	2000	0.35	18	23	17	60	4	3	11	i	18.99
	Benin	2001	0.13	14	32	23	45	5	3	6	i	9.21
	Botswana	2000	0.19	96	41	18	41	39	17	39	i	1.98
	Burkina Faso	2000	0.80	49	13	1	86	6	0	42	i	16.29
	Burundi	2000	0.29	34	17	6	77	6	2	26	i	8.52
	Cameroon	2000	0.99	50	18	8	74	9	4	37	i	19.96
	Cape Verde	2000	0.02	39	7	2	91	3	1	36	i	0.51
	Central African Republic	2000	0.03	7	80	16	4	5	1	0	i	4.51
	Chad	2000	0.23	20	17	0	83	3	0	17	i	11.51
	Comoros	1999	0.01	14	48	5	47	7	1	7	i	0.69
	Congo, Democratic Republic (formerly Zaire)	2000	0.36	5	53	17	31	3	1	2	i	67.83
	Congo, Republic of	2000	0.03	8	59	29	12	5	2	1	i	3.76
	Cote D'Ivoire	2000	0.93	43	24	12	65	10	5	28	i	21.57
	Djibouti	2000	0.02	23	84	0	16	19	0	4	i	0.88
	Egypt	2000	68.30	809	8	6	86	62	49	695	i	84.47
	Equatorial Guinea	2000	0.11	159	83	16	1	132	25	2	i	0.69
	Eritrea	2004	0.58	111	5	0	95	6	0	105	i	5.22
	Ethiopia	2002	5.56	65	6	0	94	4	0	61	i	84.98
	Gabon	2000	0.12	80	50	8	42	40	6	34	i	1.50
	Gambia	2000	0.03	17	23	12	65	4	2	11	i	1.75
	Ghana	2000	0.98	40	24	10	66	10	4	27	i	24.33
	Guinea	2000	1.51	146	8	2	90	11	3	132	i	10.32

continues

Data Table 2. *continued*

Region	Country	Year	Total Freshwater Withdrawal (km³/yr)	Per Capita Withdrawal (m³/p/yr)	Domestic Use (%)	Industrial Use (%)	Agricultural Use (%)	Domestic Use m³/p/yr	Industrial Use m³/p/yr	Agricultural Use m³/p/yr	Source	2010 Population (millions)
	Guinea-Bissau	2000	0.18	109	13	5	82	14	5	90	i	1.65
	Kenya	2003	2.74	67	17	4	79	11	2	53	i	40.86
	Lesotho	2000	0.05	24	40	40	20	10	10	5	i	2.08
	Liberia	2000	0.11	27	27	18	55	7	5	15	i	4.10
	Libya	2000	4.27	652	14	3	83	91	20	541	i	6.55
	Madagascar	2000	14.96	743	3	2	96	21	12	710	i	20.15
	Malawi	2000	1.01	64	15	5	80	9	3	51	i	15.69
	Mali	2000	6.55	492	9	1	90	44	5	442	i	13.32
	Mauritania	2000	1.70	505	9	3	88	45	14	446	i	3.37
	Mauritius	2000	0.61	470	25	14	60	120	67	284	a	1.30
	Morocco	2000	12.60	389	10	3	87	39	12	339	i	32.38
	Mozambique	2000	0.63	27	11	2	87	3	1	23	i	23.41
	Namibia	2000	0.3	136	24	5	71	33	6	96	i	2.212
	Niger	2000	2.18	137	4	0	95	5	0	130	i	15.89
	Nigeria	2000	8.01	51	21	10	69	11	5	35	i	158.26
	Rwanda	2000	0.15	15	24	8	68	4	1	10	i	10.28
	Senegal	2002	2.22	173	4	3	93	7	5	161	i	12.86
	Sierra Leone	2000	0.38	65	5	3	92	3	2	60	i	5.84
	Somalia	2003	3.30	352	0	0	99	2	0	351	i	9.36
	South Africa	2000	12.50	248	31	6	63	77	15	156	i	50.49
	Sudan	2000	37.32	864	3	1	97	23	6	835	i	43.19
	Swaziland	2000	1.04	865	2	1	97	17	9	839	i	1.20
	Tanzania	2000	5.18	115	10	0	89	12	0	102	i	45.04
	Togo	2000	0.17	25	53	2	45	13	1	11	i	6.78

	Tunisia	2000	2.64	254	14	4	82	36	10	209	i	10.37
	Uganda	2002	0.30	9	43	17	40	4	2	4	i	33.80
	Zambia	2000	1.74	131	17	7	76	22	9	100	i	13.26
	Zimbabwe	2002	4.21	333	14	7	79	47	23	263	i	12.64
NORTH AND CENTRAL AMERICA	Antigua and Barbuda	1990	0.005	56	60	20	20	34	11	11	e	0.09
	Barbados	2000	0.09	351	33	44	22	117	155	77	i	0.26
	Belize	2000	0.15	479	7	73	20	34	350	96	i	0.313
	Canada	2006	45.08	1,330	20	69	12	260	913	157	k	33.89
	Costa Rica	2003	0.54	116				0	0	0	l	4.64
	Cuba	2000	8.20	732	19	12	69	139	89	503	i	11.20
	Dominica	1996	0.02	256	—	—	—				f	0.07
	Dominican Republic	2000	3.39	332	32	2	66	106	6	219	i	10.23
	El Salvador	2000	1.28	207	25	16	59	51	33	123	i	6.19
	Guatemala	2000	2.01	140	6	13	80	9	19	112	i	14.38
	Haiti	2000	0.99	97	5	1	94	4	1	92	i	10.19
	Honduras	2000	0.86	113	8	12	80	9	14	90	i	7.62
	Jamaica	2000	0.41	150	34	17	49	51	25	73	i	2.73
	Mexico	2008	79.80	721	14	9	77	101	67	553	i	110.65
	Nicaragua	2000	1.30	223	15	2	83	33	4	185	i	5.82
	Panama	2000	0.82	234	67	5	28	157	12	66	i	3.51
	Saint Lucia	1997	0.01	75	—	—	—				e	0.17
	Saint Vincent and the Grenadines	1995	0.01	92	—	—	—				e	0.11
	Trinidad and Tobago	2000	0.31	231	68	26	6	157	60	13	i	1.34
	United States of America	2005	482.20	1,518	13	46	41	193	699	626	g	317.64
SOUTH AMERICA	Argentina	2000	29.19	718	17	9	74	122	68	531	i	40.67
	Bolivia	2000	1.44	144	13	7	81	19	10	116	i	10.03
	Brazil	2006	58.07	297	28	17	55	83	52	162	i	195.42
	Chile	2000	12.55	732	11	25	64	83	184	465	i	17.13
	Colombia	2000	10.71	231	50	4	46	116	9	106	i	46.30

continues

Data Table 2. *continued*

Region	Country	Year	Total Freshwater Withdrawal (km^3/yr)	Per Capita Withdrawal (m^3/p/yr)	Domestic Use (%)	Industrial Use (%)	Agricultural Use (%)	Domestic Use m^3/p/yr	Industrial Use m^3/p/yr	Agricultural Use m^3/p/yr	Source	2010 Population (millions)
	Ecuador	2000	16.98	1,233	12	5	82	154	65	1014	i	13.77
	Guyana	2000	1.64	2,154	2	1	98	36	19	2111	i	0.76
	Paraguay	2000	0.49	76	20	8	71	15	6	54	i	6.46
	Peru	2000	20.13	682	8	10	82	57	69	557	i	29.50
	Suriname	2000	0.67	1,278	4	3	93	57	37	1183	i	0.52
	Uruguay	2000	3.15	934	2	1	96	22	11	901	i	3.37
	Venezuela	2000	8.37	288	6	7	47	17	20	137	i	29.04
ASIA	Afghanistan	2000	23.26	799	2	0	98	14	0	785	i	29.12
	Armenia	2006	2.83	915	30	4	66	274	40	601	o	3.09
	Azerbaijan	2005	12.21	1,367	4	19	76	55	260	1039	o	8.93
	Bahrain	2003	0.36	442	50	6	45	221	27	199	o	0.81
	Bangladesh	2008	35.87	253	10	2	88	25	5	222	i	141.82
	Bhutan	2000	0.43	607	5	1	94	30	7	571	i	0.71
	Brunei	1994	0.09	221	—	—	—				d	0.41
	Cambodia	2000	4.08	271	1	0	98	3	0	265	i	15.05
	China	2007	578.9	425	12	23	63	52	99	266	n	1,361.76
	Cyprus	2000	0.21	239	27	1	71	65	3	170	j	0.88
	Georgia	2005	1.62	384	22	13	65	85	50	250	o	4.22
	India	2010	761.00	627	7	2	90	46	14	567	i	1,214.46
	Indonesia	2000	82.78	356	8	1	91	28	2	325	i	232.52
	Iran	2004	93.30	1,243	7	1	92	85	12	1143	o	75.08
	Iraq	2000	66.00	2,097	7	15	79	147	315	1657	o	31.47
	Israel	2004	1.95	268	36	6	58	97	16	156	o	7.29

Japan	2000	88.43	696	20	18	62	137	124	435	i	127.00
Jordan	2005	0.94	145	31	4	65	45	6	95	o	6.47
Kazakhstan	2000	35.00	2,222	2	17	82	38	367	1817	i	15.75
Korea Democratic People's Republic	2000	9.02	376	20	25	55	75	95	207	i	23.99
Korea Republic	2002	25.47	525	26	12	62	136	63	326	i	48.50
Kuwait	2002	0.91	299	44	2	54	132	6	162	o	3.05
Kyrgyz Republic	2000	10.08	1,816	3	3	94	57	56	1703	i	5.55
Laos	2000	3.00	466	4	6	90	20	26	420	i	6.44
Lebanon	2005	1.31	308	29	11	60	89	34	185	o	4.25
Malaysia	2000	9.02	323	17	21	62	54	68	201	i	27.91
Maldives	1987	0.003	10	98	2	0	9	0	0	d	0.31
Mongolia	2000	0.44	163	20	27	52	33	44	84	i	2.70
Myanmar	2000	33.23	658	1	1	98	8	4	646	i	50.50
Nepal	2000	10.18	341	3	1	96	10	2	329	i	29.85
Oman	2003	1.32	455	10	1	88	45	5	400	o	2.91
Pakistan	2008	183.50	993	5	1	94	52	8	933	i	184.75
Palestine (Occupied Palestinian Territory)	2005	0.42	95	48	7	45	46	7	43	o	4.41
Philippines	2006	78.9	843	7	9	83	62	80	701	i	93.62
Qatar	2005	0.44	294	39	2	59	115	6	174	o	1.51
Saudi Arabia	2006	23.67	902	9	3	88	81	27	793	o	26.25
Singapore	1975	0.19	39	45	51	4	18	20	2	b	4.84
Sri Lanka	2000	12.61	618	2	2	95	15	15	588	i	20.41
Syria	2003	16.69	742	9	4	88	67	30	653	o	22.51
Tajikistan	2000	11.96	1,690	4	5	92	63	79	1549	i	7.07
Thailand	2007	57.31	841	5	5	90	40	41	760	i	68.14
Turkey	2003	40.10	530	15	11	74	78	58	393	o	75.71
Turkmenistan	2000	24.65	4,762	2	1	98	81	36	4645	i	5.18
United Arab Emirates	2005	4.00	849	15	2	83	127	17	705	o	4.71
Uzbekistan	2000	58.34	2,099	5	2	93	100	43	1956	i	27.79

continues

Data Table 2. *continued*

Region	Country	Year	Total Freshwater Withdrawal (km^3/yr)	Per Capita Withdrawal ($m^3/p/yr$)	Domestic Use (%)	Industrial Use (%)	Agricultural Use (%)	Domestic Use $m^3/p/yr$	Industrial Use $m^3/p/yr$	Agricultural Use $m^3/p/yr$	Source	2010 Population (millions)
	Vietnam	2000	71.39	802	8	24	68	62	194	546	i	89.03
	Yemen	2000	3.40	140	8	2	90	11	3	126	o	24.26
EUROPE	Albania	2000	1.71	540	27	11	62	144	60	335	i	3.17
	Austria	1999	3.67	438	35	64	1	154	280	4	j	8.39
	Belarus	2000	2.79	291	23	47	30	68	137	88	i	9.59
	Belgium	1998	7.44	695	13	85	1	93	594	9	h	10.70
	Bulgaria	2003	6.92	923	3	78	19	28	722	173	j	7.50
	Czech Republic	2002	1.91	183	41	57	2	75	105	4	j	10.41
	Denmark	2002	0.67	122	32	26	42	39	31	52	j	5.48
	Estonia	2002	1.41	1,053	56	39	5	586	415	52	j	1.34
	Finland	1999	2.33	436	14	84	3	59	365	12	j	5.35
	France	2000	33.16	529	16	74	10	83	394	52	j	62.64
	Germany	2001	38.01	463	12	68	20	57	314	92	j	82.06
	Greece	1997	8.70	778	16	3	81	127	25	626	j	11.18
	Hungary	2001	21.03	2,109	9	59	32	195	1237	677	j	9.97
	Iceland	2003	0.17	516	34	66	0	176	340	1	j	0.33
	Ireland	1994	1.18	257	23	77	0	58	199	0	j	4.59
	Italy	1998	41.98	699	18	37	45	127	256	315	j	60.10
	Latvia	2003	0.25	112	55	33	12	61	37	14	j	2.24
	Lithuania	2003	3.33	1,023	78	15	7	798	158	67	j	3.26
	Luxembourg	1999	0.06	116	42	45	13	49	52	15	j	0.49
	Macedonia	2000	2.27	1,111	—	—	—				j	2.04
	Malta	2000	0.02	49	74	1	25	36	0	12	j	0.41

	Moldova	2000	2.31	646	10	58	33	65	372	213	i	3.58
	Netherlands	2001	8.86	532	6	60	34	33	319	180	j	16.65
	Norway	1996	2.40	494	23	67	10	112	331	52	h	4.86
	Poland	2002	11.73	308	13	79	8	40	243	26	j	38.04
	Portugal	1998	11.09	1,033	10	12	78	99	125	809	j	10.73
	Romania	2003	6.50	307	9	34	57	26	105	175	j	21.19
	Russian Federation	2000	76.68	546	19	63	18	102	347	97	i	140.37
	Slovakia	2003	1.04	192							j	5.41
	Slovenia	2002	0.90	444	—	—	—				j	2.02
	Spain	2002	37.22	821	13	19	68	111	152	559	j	45.32
	Sweden	2002	2.68	288	37	54	9	106	157	26	j	9.29
	Switzerland	2002	2.52	332	24	74	2	80	245	6	j	7.59
	Ukraine	2000	37.53	826	12	35	52	100	292	433	i	45.43
	United Kingdom	1994	11.75	190	22	75	3	41	143	6	c	61.90
OCEANIA	Australia	2010	59.84	2,782	15	10	75	409	279	2093	m	21.51
	Fiji	2000	0.07	82	14	14	71	11	11	58	i	0.85
	New Zealand	2000	2.11	490	48	9	42	235	46	206	i	4.30
	Papua New Guinea	1987	0.10	15	56	43	1	8	6	0	b	6.89
	Solomon Islands	1987			40	20	40				b	0.54

Notes:
Figures may not add to totals due to independent rounding.
Population data: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World population prospects: the 2008 revision. Total population, both sexes. Estimates 2010. United Nations. http://esa.un.org/unpd/wpp2008/all-wpp-indicators_components.htm
U.S. data include freshwater only; previous data included saline water.
China data include Hong Kong.

DATA TABLE 3

Access to Safe Drinking Water by Country, 1970–2008

Description

Safe drinking water is one of the most basic human requirements. One of the Millennium Development Goals (MDGs) by 2015 is to reduce by half the proportion of people unable to reach or afford safe drinking water. As a result, estimates of access to safe drinking water are a cornerstone of most international assessments of progress, or lack thereof, toward solving global and regional water problems.

Data are given here for the percent of urban, rural, and total populations, by country, with access to safe drinking water for 1970, 1975, 1980, 1985, 1990, 1994, 2000, 2002, 2004, 2005, and 2008, the most recent year for which data are available. The World Health Organization (WHO) collected the data presented here over various periods. Most of the data presented were drawn from responses by national governments to WHO questionnaires. Participants in data collection include the Joint Monitoring Programme (JMP) of WHO, the United Nations Children's Fund, and the Water Supply and Sanitation Collaborative Council, which has continued sector monitoring and aims to support and strengthen the monitoring efforts of individual countries. The 40 largest countries in the developing world account for 90 percent of population in these regions. As a result, WHO spent extra effort to collect comprehensive data for these countries.

Data for 2000 and later reflect a significant change in definition. Data are now reported for populations without access to "improved" water supply. According to WHO, the following technologies were included in the assessment as representing "improved" water supply:

- Household connection
- Public standpipe
- Borehole
- Protected dug well
- Protected spring
- Rainwater collection

In comparison, "unimproved" drinking water sources refers to

- Unprotected well
- Unprotected spring

Rivers or ponds

Vendor-provided water

Bottled water

Tanker truck water

Limitations

A review of water and sanitation coverage data from the 1980s and 1990s shows that the definition of safe, or improved, water supply and sanitation facilities differs from one country to another and for a given country over time. Indeed, some of the data from individual countries often showed rapid and implausible changes in the level of coverage from one assessment to the next. This indicates that some of the data are also unreliable, irrespective of the definition used. Countries used their own definitions of "rural" and "urban."

For the 1996 data, two-thirds of the countries reporting indicated how they defined "access." At the time, the definition most commonly centered on walking distance or time from household to water source, such as a public standpipe, which varied from 50 to 2,000 meters and 5 to 30 minutes. Definitions sometimes included considerations of quantity, with the acceptable limit ranging from 15 to 50 liters per capita per day. The WHO considers safe drinking water to be treated surface water or untreated water from protected springs, boreholes, and wells.

WHO assessments since 2000 have attempted to shift from gathering information from water providers to only including consumer-based information. The current approach uses household surveys in an effort to assess the actual use of facilities. "Reasonable access" was broadly defined as the availability of at least 20 liters per person per day from a source within one kilometer of the user's dwelling. A drawback of this approach is that household surveys are not conducted regularly in many countries. Thus, direct comparisons between countries, and across time within the same country, are difficult. Direct comparisons are additionally complicated by the fact that these data hide disparities between regions and socioeconomic classes.

Access to water, as reported by WHO, does not imply that the level of service or quality of water is "adequate" or "safe." The assessment questionnaire did not include any methodology for discounting coverage figures to allow for intermittence of supply or poor quality of the water supplies. However, the instructions stated that piped systems should not be considered "functioning" unless they were operating at over 50 percent capacity on a daily basis; and that hand pumps should not be considered functioning unless they were operating for at least 70 percent of the time with a lag between breakdown and repair not exceeding two weeks. These aspects were taken into consideration when estimating coverage for countries for which national surveys had not been conducted. More details of the methods used, and their limitations, can be found at http://www.who.int/docstore/water_sanitation_health/Globassessment/GlobalTOC.htm.

SOURCES

United Nations Environment Programme (UNEP). 1989. *Environmental Data Report*. GEMS Monitoring and Assessment Research Centre. Oxford, United Kingdom: Basil Blackwell.

United Nations Environment Programme (UNEP). 1993–1994. *Environmental Data Report*. GEMS Monitoring and Assessment Research Centre in cooperation with the World Resources Institute and the UK Department of the Environment. Oxford, United Kingdom: Basil Blackwell.

World Health Organization (WHO). 1996. Water Supply and Sanitation Sector Monitoring Report: 1996 (Sector Status as of 1994). In collaboration with the Water Supply and Sanitation Collaborative Council and the United Nations Children's Fund, UNICEF, New York.

World Health Organization (WHO). 2000. Global Water Supply and Sanitation Assessment 2000 Report. http://www.who.int/docstore/water_sanitation_health/Globassessment/GlobalTOC.htm

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2004. Meeting the MDG Drinking Water and Sanitation Target: A Mid-term Assessment of Progress. http://www.who.int/water_sanitation_health/monitoring/jmp2004/en/index.html

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2006. Meeting the MDG Drinking Water and Sanitation Target: The Urban and Rural Challenge of the Decade. http://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2010. WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. http://www.wssinfo.org/data-estimates/table/

World Resources Institute (WRI). 1988. World Health Organization data, cited by the World Resources Institute, *World Resources 1988–89*. World Resources Institute and the International Institute for Environment and Development in collaboration with the United Nations Environment Programme. New York: Basic Books.

DATA TABLE 3 Access to Safe Drinking Water by Country, 1970–2008

	Fraction of Population with Access to Improved Drinking Water																																
	URBAN											RURAL											TOTAL										
Region and Country	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
AFRICA	66	68	69	77																													
Algeria	84	100		85			88	92	88	88	85		61		55			94	80	80	81	79		77		68			94	87	85	85	83
Angola			85	87	73	69	34	70	75	54	60			10	15	20	15	40	40	40	39	38			26	33	35	32	38	50	53	47	50
Benin	83	100	26	80	73	41	74	79	78	82	84	20	20	15	34	43	53	55	60	57	65	69	29	34	18	50	54	50	63	68	67	72	75
Botswana	71	95		84	100		100	100	100	99	99	26	39		46	88			90	90	90	90	29	45		53	91			95	95	95	95
Burkina Faso	35	50	27	43			84	82	94	91	95	10	23	31	69	70			44	54	65	72	12	25	31	67		78		51	61	70	76
Burundi	77		90	98	92	92	96	90	92	85	83			20	21	43	49		78	77	71	71			23	25	45	52		79	79	72	72
Cameroon	77			43	42		82	84	86	90	92	21			24	45		42	41	44	48	51	32			32	44		62	63	66	71	74
Cape Verde			100	83		70	64	86	86	86	85			21	50		34	89	73	73	82	82			25	52		51	74	80	80	84	84
Central African Republic				13	19	18	80	93	93	89	92					26	18	43	61	61	50	51					23	18	60	75	75	65	67
Chad	47	43				48	31	40	41	66	67	24	23				17	26	32	43	43	44	27	26				24	27	34	42	49	50
Comoros							98	90	92	91	91							95	96	82	96	97							96	94	86	95	95
Congo	63	81	42				71	72	84	95	95	6	9	7				17	17	27	34	34	27	38	20				51	46	58	71	71
Congo, Democratic Rep.	33	38		52	68	37	89	83	82	82	80	4	12		21	24	23	26	29	29	28	28	11	19		32	36	27	45	46	46	45	46
Cote D'Ivoire	98				57	59	90	98	97	92	93	29				80	81	65	74	74	67	68	44				71	72	77	84	84	79	80
Djibouti			50	50		77	100	82	76	95	98			20	20		100	100	67	59	55	52			43	45		90	100	80	73	89	92
Egypt	94		88		95	82	96	100	99	100	100	93		64		86	50	94	97	97	96	98	93		84		90	64	95	98	98	98	99
Equatorial Guinea			47		65	88	45	45	45	45						18	100	42	42	42	42						32	95	43	44	43	43	
Eritrea							63	72	74	74	74							42	54	57	57	57							46	57	60	60	61
Ethiopia	61	58		69			77	81	81	95	98		1		9			13	11	11	24	26	6	8		16			24	22	22	35	38
Gabon							73	95	95	95	95							55	47	47	43	41							70	87	88	86	87

continues

Data Table 3 *continued*

Region and Country	Fraction of Population with Access to Improved Drinking Water: URBAN 1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	RURAL 1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	TOTAL 1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Gambia	97		85	97	100		80	95	95	94	96	3			50	48		53	77	77	83	86	12			59	60	76	62	82	82	89	92
Ghana	86	86	72	93	63	70	87	93	88	89	90		14	33	39		49	49	68	64	68	74	35	35	45	56	21	56	64	79	75	78	82
Guinea	68	69	69	41	100	61	72	78	78	89	89			2	12	37	62	36	38	35	57	61		14	15	18	53	62	48	51	50	68	71
Guinea-Bissau			18	17		38	29	79	79	82	83			8	22		57	55	49	49	48	51			10	21		53	49	59	59	58	60
Kenya	100	100	85			67	87	89	83	85	83	2	4	15			49	31	46	46	48	52	15	17	26			53	49	62	61	56	59
Lesotho	100	65	37	65		14	98	88	92	96	97	1	14	11	30		64	88	74	76	79	81	3	17	15	36		52	91	76	79	83	85
Liberia	100			100		58		72	72	80	79	6			23		8		52	52	48	51	15			53		30		62	61	67	68
Libya	100	100	100				72	72				42	82	90				68	68				58	87	96				72	72			
Madagascar	67	76	80	81		83	85	75	77	71	71	1	14	7	17		10	31	34	35	27	29	11	25	21	31		29	47	45	50	40	41
Malawi			77	97		52	95	96	98	94	95			37	50		44	44	62	68	70	77			41	56		45	57	67	73	74	80
Mali	29		37	46	41	36	74	76	78	77	81				10	4	38	61	35	36	40	44				16	13	37	65	48	50	51	56
Mauritania	98		80	73		84	34	63	59	49	52	10		85			69	40	45	44	43	47	17		84			76	37	56	53	45	49
Mauritius	100	100	100	100	100	95	100	100	100	100	100	29	22	98	100	100	100	100	100	100			61	60	99	100	100	98	100	100	100		
Morocco	92		100	100	100	98	100	99	99	97	98	28			25	18	14	58	56	56	60	60	51			59	56	52	82	80	81	80	81
Mozambique				38		17	86	76	72	76	77				9		40	43	24	26	29	29				15		32	60	42	43	45	47
Namibia					90	87	100	98	98	99	99					37	42	67	72	81	82	88					52	57	77	80	87	88	92
Niger	37	36	41	35	98	46	70	80	80	89	96	19	26	32	49	45	55	56	36	36	37	39	20	27	33	47	56	53	59	46	46	45	48
Nigeria				100	100	63	81	72	67	76	75				20	22	26	39	49	31	40	42				38	49	39	57	60	48	57	58
Reunion																																	
Rwanda	81	84	48	79	84		60	92	92	80	77	66	68	55	48	67		40	69	69	63	62	67	68	55	50	68		41	73	74	66	65
Sao Tome and Principe								89	89	88	89				45				73	73	81	89				45				79	79	85	89
Senegal	87	56	77	79	65	82	92	90	92	91	92			25	38	26	28	65	54	60	51	52			43	53	42	50	78	72	76	68	69
Seychelles								100	100	94	100				95				75	75						95				87	88		
Sierra Leone	75		50	68	80	58	23	75	75	82	86	1		2	7	20	21	31	46	46	33	26	12		14	24	39	34	28	57	57	51	49
Somalia	17	77		58				32	32	58	67	14	22		22				27	27	11	9	15	38		34				29	29	28	30

South Africa							92	98	99	99	99							80	73	73	75	78						70	86	87	88	89	91
Sudan	61	96	100			66	86	78	78	68	64	13	43	31			45	69	64	64	53	52	19	50	51			50	75	69	70	59	57
Swaziland		83		100		41		87	87	90	92		29		7		44		42	54	56	61		37		31		43		52	62	64	69
Tanzania	61	88		90			80	92	85	82	80	9	36		42			42	62	49	45	45	13	39		53			54	73	62	54	54
Togo	100	49	70	100		74	85	80	80	86	87	5	10	31	41		58	38	36	36	40	41	17	16	38	54		63	54	51	52	58	60
Tunisia	92	93	100	100		100		94	99	99	99	17		17	31		89		60	82	84	84	49		60	70		99		82	93	94	94
Uganda	88	100		37	60	47	72	87	87	89	91	17	29		18	30	32	46	52	56	60	64	22	35		20	33	34	50	56	60	64	67
Zambia	70	86		76		64	88	90	90	87	87	22	16		41		27	48	36	40	42	46	37	42		58		43	64	55	58	58	60
Zimbabwe					95		100	100	98	99	99				32	80		77	74	72	72	72					84		85	83	81	82	82
NORTH & CENTRAL AMERICA & CARIBBEAN																																	
Anguilla									60																						60		
Antigua and Barbuda									95	95	95	95								89	89										91	91	
Aruba								100	100	100	99								100	100	100	100								100	100	100	100
Bahamas	100	100	100	100	98		99	98	98	98	98	12	13			75		86	86	86			65	65	100	100	90		96	97	97		
Barbados	95	100	99	100	100		100	100	100	100	100	100	100	98	99	100		100	100	100	100	100	98	100	99	99	100		100	100	100	100	100
Belize			99	100	95	96	83	100	100	97	99			36	26	53	82	69	82	82	94	100			68	64	74	89	76	91	91	95	99
British Virgin Islands					100			98	98	98	100					100			98	98	100	100								98	100	100	100
Canada							100	100	100	100	100							99	99	99	99	99							100	100	100	100	100
Cayman Islands			100	98						95	95																						
Costa Rica	98	100	100	100		85	98	100	100	100	100	59	56	82	83		99	98	92	92	90	91	74	72	90	91		92	98	97	97	96	97
Cuba	82	96			100	96	99	95	95	95	96	15				91	85	82	78	78	83	89	56				98	93	95	91	91	92	94
Dominican Republic	72	88	85	85	82	74	83	98	97	89	87	14	27	34	33	45	67	70	85	91	83	84	37	55	60	62	67	71	79	93	95	87	86
Dominica							100	100	100	96								100	90	90	93								100	97	97	95	
El Salvador	71	89	67	68	87	78	88	91	94	94	94	20	28	40	40	15	37	61	68	70	73	76	40	53	50	51	47	55	74	82	84	86	87
Grenada	100	100					97	97	97	96	97	47	77					93	93	93									94	95	95		
Guadeloupe							94	98	98	98	98							94	93	93									94	98	98		
Guatemala	88	85	90	72	92		97	99	99	97	98	12	14	18	14	43		88	92	92	88	90	38	39	46	37	62		92	95	95	92	94
Haiti		46	51	59	56	37	46	91	52	70	71		3	8	30	35	23	45	59	56	53	55		12	19	38	41	28	46	71	54	60	63
Honduras	99	99	93	56	85	81	97	99	95	95	95	10	13	40	45	48	53	82	82	81	74	77	34	41	59	49	64	65	90	90	87	94	86
Jamaica	100	100	55	99			81	98	98	98	98	48	79	46	93			59	87	88	88	89	62	86	51	96			71	93	93	93	94

continues

Data Table 3 *continued*

Region and Country	Fraction of Population with Access to Improved Drinking Water: URBAN											RURAL											TOTAL										
	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Martinique										100	100																						
Mexico	71	70	90	99	94	91	94	97	100	96	96	29	49	40	47		62	63	72	87	83	87	54	62	73	83	69	83	86	91	97	93	94
Montserrat								100	100	100	100								100	100	100	100								100	100	100	100
Netherlands Antilles																																	
Nicaragua	58	100	67	76		81	95	93	90	97	98	16	14	6	11		27	59	65	63	66	68	35	56	39	48		61	79	81	79	83	85
Panama	100	100	100	100			88	99	99	97	97	41	54	62	64			86	79	79	83	83	69	77	81	82		83	87	91	90	93	93
Puerto Rico																																	
Saint Kitts								99	99	100	100								99	99	99	100								99	100	100	100
Saint Lucia								98	98	99	97								98	98	98	98								98	98	98	98
Saint Vincent																				93													
Trinidad/Tobago	100	79	100	100	100			92	92	97	98	95	100	93	95	88			88	88	93	93	96	93	97	98	96		86	91	91	93	94
Turks/Caicos Islands				87				100	100	97	98				68				100	100	100	98				77				100	100	98	98
United States of America							100	100	100	100	100							100	100	100	94	94							100	100	100	99	99
United States Virgin Islands											100											100											100
SOUTH AMERICA																																	
Argentina	69	76	61	63			85	97	98	98	98	12	26	17	17			30		80	80	80	56	66	54	56			79		96	96	97
Bolivia	92	81	69	75	76	78	93	95	95	95	96	2	6	10	13	30	22	55	68	68	63	67	33	34	36	43	53	55	79	85	85	84	86
Brazil	78	87	83	85	95	85	95	96	96	98	99	28		51	56	61	31	54	58	57	81	84	55		72	77	87	72	87	89	90	95	97
Chile	67	78	100	98		94	99	100	100	99	99	13	28	17	29		37	66	59	58	75	75	56	70	84	87		85	94	95	95	96	96
Colombia	88	86	93	100	87	88	98	99	99	99	99	28	33	73	76	82	48	73	71	71	73	73	63	64	86		86	76	91	92	93	92	92
Ecuador	76	67	79	81	63	82	81	92	97	96	97	7	8	20	31	44	55	51	77	89	86	88	34	36	50	57	55	70	71	86	94	92	94
French Guiana							88	88	88									71	71	71									84	84	84		
Guyana	100	100	100	100	100	90	98	83	83	96	98	63	75	60	65	71	45	91	83	83	90	93	75	84	72	76	81	61	94	83	83	92	94
Paraguay	22	25	39	53	61		95	100	99	98	99	5	5	9	8	9		58	62	68	93	66	11	13	21	28	34		79	83	86	83	86

Peru	58	72	68	73	68	74	87	87	89	90	90	8	15	18	17	24	24	51	66	65	58	61	35	47	50	55	55	60	77	81	83	81	82
Suriname			100	71			94	98	98	97	97			79	94			96	73	73	78	81			88	83			95	92	92	92	93
Uruguay	100	100	96	95	100		98	98	100	100	100	59	87	2	27			93	93	100	95	100	92	98	81	85	89		98	98	100	100	100
Venezuela	92		93	93		80	88	85	85	94		38		53	65	36	75	58	70	70	75		75		86	89		79	84	83	83	93	
ASIA																																	
Afghanistan	18	40	28	38	40	39	19	19	63	66	78	1	5	8	17	19	5	11	11	31	33	39	3	9	8	17	23	12	13	13	39	41	48
Armenia								99	99	99	98								80	80	89	93								92	92	95	96
Azerbaijan								95	95	88	88								59	59	66	71								77	77	77	80
Bahrain	100	100		100	100			100	100	100	100	94	100		100	0							99	100		100							
Bangladesh	13	22	26	24	39	100	99	82	82	85	85	47	61	40	49	89	97	97	72	72	78	78	45	56	39	46	81	97	97	75	74	80	80
Bhutan			50		60	75	86	86	86	99	99			5	19	30	54	60	60	60	88	88			7		32	64	62	62	62	91	92
Brunei Darus			100											95																			
Cambodia							53	58	64	75	81							25	29	35	51	56							30	34	41	56	61
China					87	93	94	92	93	98	98					68	89	66	68	67	78	82					73	90	75	77	77	86	89
Cyprus	100	94		100	100		100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
East Timor								73	77	80	86								51	56	57	63								52	58	63	69
Gaza Strip									94	91	91									88	91	91									92	91	91
Georgia								90	96	99	100								61	67	92	96								76	82	96	98
Hong Kong			100		100									95		96											100						
India	60	80	77	76	86	85	92	96	95	95	96	6	18	31	50	69	79	86	82	83	81	84	17	31	42	56	73	81	88	86	86	85	88
Indonesia	10	41	35	43	35	78	91	89	87	90	89	1	4	19	36	33	54	65	69	69	70	71	3	11	23	38	34	62	76	78	77	80	80
Iran	68	76	82		100	89	99	98	99	98	98	11	30	50		75	77	89	83	84			35	51	66		89	83	95	93	94		
Iraq	83	100		100	93		96	97	97	93	91	7	11	54	54	41		48	50	50	53	55	51	66		86	78	44	85	81	81	80	79
Israel								100	100	100	100							100	100	100	100	100							100	100	100	100	100
Japan								100	100	100	100								100	100	100	100								100	100	100	100
Jordan	98		100	100	100		100	91	99	98	98	59		65	88	97		84	91	91	91	91	77		86	96	99	89	96	91	97	96	96
Kazakhstan							98	96	97	99	99							82	72	73	91	90							91	86	86	96	95
Korea Democratic People's Republic							100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Korea Republic	84	95	86	90	100		97	97	97	99	100	38	33	61	48	76		71	71	71	83	88	58	66	75	75	93		92	92	92	96	98
Kuwait	60	100	86	97						99	99			100							100	100	51	89	87							99	99
Kyrgyzstan							98	98	98	99	99							66	66	66	80	85							77	76	77	87	90

continues

Data Table 3 *continued*

Region and Country	Fraction of Population with Access to Improved Drinking Water: URBAN											RURAL											TOTAL										
	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Laos	97	100	28		47	40	59	66	79	74	72	39	32	20		25	39	100	38	43	47	51	48	41	21		29	39	90	43	51	54	57
Lebanon						100	100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Macau																																	
Malaysia	100	100	90	96	96			96	100	100	100	1	6	49	76	66		94	94	96	99	99	29	34	63	84	79			95	99	100	100
Maldives			11	58	77	98	100	99	98	99	99			3	12	68	86	100	78	76	86	86			2	21		89	100	84	83	90	91
Mongolia					100		77	87	87	94	97					58		30	30	30	45	49					82		60	62	62	73	76
Myanmar (Burma)	35	31	38	36	79	36	88	95	80	75	75	13	14	15	24	72	39	60	74	77	69	69	18	17	21	27	74	38	68	80	78	71	71
Nepal	53	85	83	70	66	66	85	93	96	93	93		5	7	25	34	41	80	82	89	85	87	2	8	11	28	38	44	81	84	90	86	88
Oman		100		90			41	81		90	92		48		49			30	72		76	77		52		53		63	39	79		86	88
Pakistan	77	75	72	83	82	77	96	95	96	95	95	4	5	20	27	42	52	84	87	89	86	87	21	25	35	44	55	60	88	90	91	89	90
Philippines	67	82	49	49	93	93	92	90	87	93	93	20	31	43	54	72	77	80	77	82	85	87	36	50	45	52	81	85	87	85	85	90	91
Qatar	100	100	76		100			100	100	100	100	75	83	43					100	100	100	99	95	97	71					100	100	100	100
Saudi Arabia	100	97	92	100			100	97	97	97	97	37	56	87	88			64					49	64	90	94			95				
Singapore			100	100	100		100	100	100	100	100														100	100	100		100	100	100		
Sri Lanka	46	36	65	82	80	43	91	99	98	97	98	14	13	18	29	55	47	80	72	74	84	88	21	19	28	40	60	46	83	78	79	86	90
Syria	98		98			92	94	94	98	95	94	50		54			78	64	64	87	82	84	71		74			85	80	79	93	89	89
Tajikistan								93	92	93	94								47	48	57	61								58	59	67	70
Thailand	60	69	65	56			89	95	98	99	99	10	16	63	66	85		77	80	100	97	98	17	25	63	64			80	85	99	98	98
Turkey			95				82	96	98	99	100			62				84	87	93	92	96			76				83	93	96	97	99
Turkmenistan								93	93	97	97								54	54	72									71	72	84	
United Arab Emirates			95						100	100	100							100	100	100	100	100							100	100	100	100	100
Uzbekistan							96	97		98	98							78	84		82	81							85	89		88	87
Vietnam				70	47	53	81	93	99	97	99			32	39	33	32	50	67	80	85	92				45	36	36	56	73	85	88	94
Yemen A R	45		100	100			85	74	71	75	72	2		18	25			64	68	65	58	57	4		31	40			69	69	67	63	62
Yemen Dem	88		85				85					43		25				64					57		52				69				

OCEANIA																																	
American Samoa							100											100											100				
Australia							100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Cook Islands			100	99	100		100	98	98	97	101				88	100		100	88	88	88					92			100	95	94	94	
Fiji	78	89	94		96	100	43		43			15	56	66		69	100	51		51			37	69	77		80	100	47		47		
French Polyneisa					100		100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Guam								100	100	100	100							100	100	100	100	100							100	100	100	100	100
Kiribati			93		91		82	77	77	78				25		63		25	53	53	54								47	64	65	65	
Marshall Islands					100			80	82	93	92					45			95	96	101	98								85	87	95	94
Micronesia						100		95	95	94	97					38	100		94	94	94							100		94	94	94	
Nauru										89	88																						
New Caledonia																																	
New Zealand							100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Niue					0	100	100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Northern Mariana Islands					100			98	98	98	98					0			97	97	90	100								98	99	97	98
Palau					100		100	79	79	78						97		20	94	94	98								79	84	85	84	
Papua New Guinea	44	30	55	95	94	84	88	88	88	87	87	72	19	10	15	20	17	32	32	32	33	33	70	20	16	26	32	28	42	39	39	40	40
Pitcairn																																	
Samoa	86	100	97		100		95	91	90	90			23	94		77		100	88	87	87		17	43					99	88	88	88	
Solomon Islands			96		82		94	94	94	95				45		58		65	65	65	65						62		71	70	70	70	
Tokelau						100									100		100		89	88	83	84						100			88		
Tonga	100	100	86	99	92	100	100	100	100	98	100	53	71	70	99	98	100	100	100	100	99	100	63	83	17	99	96	100	100	100	100	99	100
Tuvalu				100		100	100	94	94	100	100				100		95	100	92	92	99	99						98	100	93	100	100	100
Vanuatu			65	95			63	85	86	95	95			53	54			94	52	52	74	79				64			88	60	60	79	83
Wallis and Futuna Islands																						100	100	99									100
Western Samoa			97	75										94	67											69							
EUROPE																																	
Albania								99	99	98	96								95	94	97	98								97	96	97	97
Bosnia and Herzegovina									99	100	100									96	97	98									97	98	99
Bulgaria									100	100	100									97	100	100									99	100	100
Estonia									100	99	99									99	97	97									100	98	98

continues

Data Table 3 *continued*

Region and Country	Fraction of Population with Access to Improved Drinking Water																																
	URBAN											RURAL											TOTAL										
	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Hungary								100	100	100	100									97	100	100									99	100	100
Latvia									100	100	100									96	96	96									99	99	99
Montenegro										100	100										96	96										98	98
Netherlands								100	100	100	100									97	100	100									99	100	100
Republic of Moldova								97	97	96	96								88	88	85	85								92	92	90	90
Romania								91	91										16	16										57	57		
Russian Federation								99	100	98	98								88	88	89	89								96	97	96	96
Serbia										99	99										98	98										99	99
Serbia and Montenegro									99	99										86	86										93	93	
Slovakia									100	100	100									97	100	100									99	100	100
Ukraine								100	99	99	98								94	91	95	97								98	96	98	98

Sources: UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, Calculated from UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010

The UN considers all European countries, except those shown, to have 100 percent water supply and sanitation coverage.

DATA TABLE 4

Access to Sanitation by Country, 1970–2008

Description

Adequate sanitation is also a fundamental requirement for basic human well-being, and improving access is one of the Millennium Development Goals (MDGs). Data are given here for the percent of urban, rural, and total populations, by country, with access to sanitation services for 1970, 1975, 1980, 1985, 1990, 1994, 2000, 2002, 2004, 2005, and 2008, the most recent year for which data are available. The World Health Organization (WHO) collected these data over various periods. Most of the data presented were drawn from responses by national governments to WHO questionnaires. Participants in data collection include the JMP, the United Nations Children's Fund, and the Water Supply and Sanitation Collaborative Council, which has continued sector monitoring and aims to support and strengthen the monitoring efforts of individual countries. Countries used their own definitions of "rural" and "urban."

For all WHO Assessments since 2000, new definitions were provided for "improved" sanitation with allowance for acceptable local technologies. The 40 largest countries in the developing world account for 90 percent of population. As a result, WHO spent extra effort to collect comprehensive data for these countries. The excreta disposal system was considered adequate if it was private or shared (but not public) and if it hygienically separated human excreta from human contact. The following technologies were included in the 2000 assessment as representing improved sanitation:

Connection to a public sewer

Connection to septic system

Pour-flush latrine

Simple pit latrine

Ventilated improved pit latrine

In comparison, unimproved sanitation facilities refer to:

Public or shared latrine

Open pit latrine

Bucket latrine

Limitations

As is the case with drinking water data, definitions for access to sanitation vary from country to country, and from year to year within the same country. Countries generally regard sanitation facilities that break the fecal-oral transmission route as adequate. In urban areas, adequate sanitation may be provided by connections to public sewers or by household systems such as pit privies, flush latrines, septic tanks, and communal toilets. In rural areas, pit privies, pour-flush latrines, septic tanks, and communal toilets are considered adequate. Direct comparisons between countries and across time within the same country are difficult and are additionally complicated by the fact that these data hide disparities among regions and socioeconomic classes.

WHO Assessments since 2000 have attempted to shift from gathering information from water providers only to including consumer-based information. The current approach uses household surveys in an effort to assess the actual use of facilities. Access to sanitation services, as reported by WHO, does not imply that the level of service is "adequate" or "safe." The assessment questionnaire did not include any methodology for discounting coverage figures to allow for intermittence or poor quality of the service provided. More details of the methods used, and their limitations, can be found at http://www.who.int/docstore/water_sanitation_health/Globassessment/GlobalTOC.htm.

SOURCES

United Nations Environment Programme (UNEP). 1989. *Environmental Data Report*. GEMS Monitoring and Assessment Research Centre. Oxford, United Kingdom: Basil Blackwell.

United Nations Environment Programme (UNEP). 1993–1994. *Environmental Data Report*. GEMS Monitoring and Assessment Research Centre in cooperation with the World Resources Institute and the UK Department of the Environment. Oxford, United Kingdom: Basil Blackwell.

World Health Organization (WHO). 1996. *Water Supply and Sanitation Sector Monitoring Report: 1996 (Sector Status as of 1994)*. In collaboration with the Water Supply and Sanitation Collaborative Council and the United Nations Children's Fund. New York: UNICEF.

World Health Organization (WHO). 2000. Global Water Supply and Sanitation Assessment 2000 Report. http://www.who.int/docstore/water_sanitation_health/Globassessment/GlobalTOC.htm

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2004. Meeting the MDG Drinking Water and Sanitation Target: A Mid-term Assessment of Progress. http://www.who.int/water_sanitation_health/monitoring/jmp2004/en/index.html

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2006. Meeting the MDG Drinking Water and Sanitation Target: The Urban and Rural Challenge of the Decade.

World Health Organization (WHO) and United Nations Children's Fund (UNICEF). 2010.

WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. http://www.wssinfo.org/data-estimates/table and http://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf

World Resources Institute (WRI). 1988. World Health Organization data, cited by the World Resources Institute, *World Resources 1988–89*. World Resources Institute and the International Institute for Environment and Development in collaboration with the United Nations Environment Programme. New York: Basic Books.

Data Table 4 Access to Sanitation by Country, 1970–2008

Region and Country	Fraction of Population with Access to Improved Sanitation																																
	URBAN											RURAL											TOTAL										
	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
AFRICA	47	75	57	75																													
Algeria	13	100		80			90	99	99	98	98	6	50		40			47	82	82	86	88	9	67		57			73	92	92	94	95
Angola			40	29	25	34	70	56	56	80	86			15	16	20	8	30	16	16	15	18			20	19	21	16	44	30	31	50	57
Benin	83		48	58	60	54	46	58	59	22	24	1		4	20	35	6	6	12	11	3	4	14		16	33	45	20	23	32	33	11	12
Botswana				93	100			57	57	72	74				28	85			25	25	36	39				40	89			41	42	57	60
Burkina Faso	49	47	38	44		42	88	45	42	32	33			5	6		11	16	5	6	6	6	4	4	7	9		18	29	12	13	11	11
Burundi	96		40	84	64	60	79	47	47	49	49			35	56	16	50		35	35	46	46			35	58	18	51		36	36	46	46
Cameroon				100			99	63	58	58	56				1			85	33	43	35	35				43			92	48	51	47	47
Cape Verde			34	32		40	95	61	61	65	65			10	9		10	32	19	19	34	38			11	10		24	71	42	43	52	54
Central African Republic	64	100			45		43	47	47	39	43	96	100			46		23	12	12	23	28	72	100			46	46	31	27	27	29	34
Chad	7	9				73	81	30	24	23	23		1				7	13	0	4	4	4	1	1				21	29	8	9	9	9
Comoros							98	38	41	49	50							98	15	29	29	30							98	23	33	35	36
Congo	8	10					14	14	28	31	31	6	9						2	25	29	29	6	9						9	27	30	30
Congo, Democratic Republic	5	65			46	23	53	43	42	23	23	5	6		9	11	4	6	23	25	19	23	5	22			21	9	20	29	30	20	23
Cote D'Ivoire	23				81	59		61	46	37	36					100	51		23	29	11	11	5				92	54		40	37	23	23
Djibouti			43	78		77	99	55	88	65	63			20	17		100	50	27	50	18	10			39	64		90	91	50	82	58	56
Egypt					80	20	98	84	86	97	97			10		26	5	91	56	58	90	92					50	11	94	68	70	93	94
Equatorial Guinea					54	61	60	60	60	60						24	48	46	46	46	46						33	54	53	53	53	51	
Eritrea							66	34	32	52	52							1	3	3	4	4							13	9	9	13	14
Ethiopia	67	56		96			58	19	44	28	29	8	8		96			6	4	7	7	8	14	14					15	6	13	10	12
Gabon							25	37	37	34	33							4	30	30	30	30							21	36	36	33	33
Gambia					100	83	41	72	72	67	68					27	23	35	46	46	63	65					44	37	37	53	53	65	67
Ghana	92	95	47	51	63	53	62	74	27	17	18	40	40	17	16	60	36	64	46	11	6	7	55	56	26	30	61	42	63	58	18	11	13
Guinea	70		54				94	25	31	31	34	2		1		0		41	6	11	10	11	13		11			70	58	13	18	17	19

continues

Data Table 4 *continued*

Region and Country	Fraction of Population with Access to Improved Sanitation																																
	URBAN											**RURAL**											**TOTAL**										
	1970	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**	**1970**	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**	**1970**	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**
Guinea-Bissau			21	29		32	88	57	57	47	49			13	18		17	34	23	23	8	9			15	21		20	47	34	35	20	21
Kenya	85	98	89			69	96	56	46	27	27	45	48	19			81	81	43	41	31	32	50	55	30			77	86	48	43	30	31
Lesotho	44	51	13	22		1	93	61	61	39	40	10	12	14	14		7	96	32	32	25	25	11	13	14	15		6	92	37	37	28	29
Liberia	100			6		38		49	49	24	25	9			2		2		7	7	4	4	19					18		26	27	16	17
Libya	100	100	100				97	97	97	97	97	54	69	72				30	96	96	96	96	67	79	88				97	97	97	97	97
Madagascar	88		9	55		50	70	49	48	15	15		9				3	70	27	26	9	10						15	42	33	34	11	11
Malawi			100			70	96	66	62	51	51			81			51	98	42	61	55	57			83			53	77	46	61	54	56
Mali	63		79	90	81	58	93	59	59	44	45				3	10	21	100	38	39	31	32	8			19	27	31	69	45	46	35	36
Mauritania	100		5	8			44	64	49	45	50							19	9	8	9	9	7						33	42	34	24	26
Mauritius	51	63	100	100	100	100	100	100	95	93	93	99	100	90	86	100	100	99	99	94	90	90	77	82	94	92	100	100	99	99	94	91	91
Morocco	75			62	100	69	100	83	88	83	83	4			16		18	42	31	52	50	52	29					40	75	61	73	68	69
Mozambique				53		70	69	51	53	37	38				12		70	26	14	19	4	4				20			43	27	32	15	17
Namibia					24		96	66	50	61	60					11		17	14	13	15	17					15		41	30	25	31	33
Niger	10	30	36		71	71	79	43	43	32	34		1	3		4	4	5	4	4	4	4	1	3	7		17	15	20	12	13	9	9
Nigeria					80	61	85	48	53	36	36				5	11	21	45	30	36	29	28					35	36	63	38	44	32	32
Reunion																																	
Rwanda	83	87	60	77	88		12	56	56	47	50	52	56	50	55	17		8	38	38	49	55	53	57	51	56	21		8	41	42	49	54
Sao Tome and Principe								32	32	29	30				15				20	20	17	19				15				24	25	24	26
Senegal			100	87	57	83	94	70	79	68	69			2		38	40	48	34	34	36	38			36		46	58	70	52	57	49	51
Seychelles										96	97								100	100													
Sierra Leone			31	60	55	17	23	53	53	23	24			6	10	31	8	31	30	30	6	6			12	24	39	11	28	39	39	12	13
Somalia		77		44				47	48	50	52		35		5				14	14	7	6		47		18				25	26	22	23
South Africa						79	99	86	79	83	84						12	73	44	46	64	65						46	86	67	65	75	77
Sudan	100	100	73	73		79	87	50	50	56	55	4	10				4	48	24	24	19	18	16	22				22	62	34	34	34	34
Swaziland		99		100		36		78	59	61	61		25		25		37		44	44	50	53		36		45		36		52	48	53	55

Tanzania		88		93			98	54	53	31	32		14		58			86	41	43	22	21		17	66				90	46	47	24	24
Togo	4	36	24	31		57	69	71	71	24	24		12	10	9		13	17	15	15	4	3	1	15	13	14		26	34	34	35	12	12
Tunisia	100		100	84		100		90	96	96	96	34			16		85		62	65	64	64	62			55		96		80	85	85	85
Uganda	84	82		32	32	75	96	53	54	37	38	76	95		30	60	55	72	39	41	48	49	76	94		30	57	57	75	41	43	47	48
Zambia	12	87		76		40	99	68	59	59	59	18	16		34		10	64	32	52	41	43	16	42		55		23	78	45	55	47	49
Zimbabwe					95		99	69	63	57	56				15	22		51	51	47	37	37					43		68	57	53	44	44
NORTH & CENTRAL AMERICA & CARIBBEAN																																	
Anguilla										99	99									99											99		
Antigua and Barbuda									98	98	98	98								94	94										95	95	
Aruba																																	
Bahamas	100	100	88	100	98		93	100	100	100	100	13	13			2		94	100	100	100	100	66	65	88	100	63		93	100	100	100	100
Barbados	100	100		100	100		100	99	99	100	100	13	13			2		94	100	100	100	100	66	65	88	100	63		93	100	100	100	100
Belize			62	87	76	23	59	71	71	89	93			75	45	22	87	21	25	25	84	86			69	66	50	57	42	47	47	86	90
British Virgin Islands					100			100	100	100	100	13	13			2		94	100	100	100	100	66	65	88	100	63		93	100	100	100	100
Canada							100	100	100	100	100							99	99	99	99	99							100	100	100	100	100
Cayman Islands			94	96						96	96				94								96										
Costa Rica	66	94	99	99		85	98	89	89	95	95	43	93	84	89		99	95	97	97	95	96	52	93	91	95		92	96	92	92	95	95
Cuba	57	100			100	71	96	99	99	92	94					68	51	91	95	95	78	81					92	66	95	98	98	89	91
Dominican Republic	63	74	25	41	95	76	75	67	81	86	87	54	16	4	10	75	83	64	43	73	72	74	58	42	15	23	87	78	71	57	78	81	83
Dominica								86	86	80									75	75	84									83	84	80	
El Salvador	66	71	48	82	85	78	88	78	77	89	89	18	17	26	43	38	59	78	40	39	79	83	37	39	35	58	59	68	83	63	62	85	87
Grenada							96	96	96	96	96							97	97	97	97	97							97	97	96	97	98
Guadeloupe							61		61	95	95							61		64									61		64		
Guatemala			45	41	72		98	72	90	88	89	11	16	20	12	52		76	52	82	69	73			30	24	60		85	61	86	78	81
Haiti			42	42	44	42	50	52	57	28	24	43	1	10	13	17	16	16	23	14	12	10			19	21	25	24	28	34	30	19	17
Honduras	64	53	49	24	89	81	94	89	87	78	80	9	13	26	34	42	53	57	52	54	56	62	24	26	35	30	63	65	77	68	69	66	71
Jamaica	100	100	12	92			98	90	91	82	82	92	91	2	90			66	68	69	84	84	94	94	7	91			84	80	80	83	83
Martinique										95	95																						
Mexico			77	77	85	81	87	90	91	88	90	13	14	12	13		26	32	39	41	61	68			55	58		66	73	77	79	82	85

continues

Data Table 4 *continued*

	Fraction of Population with Access to Improved Sanitation																																
	URBAN											RURAL											TOTAL										
Region and Country	**1970**	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**	**1970**	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**	**1970**	**1975**	**1980**	**1985**	**1990**	**1994**	**2000**	**2002**	**2004**	**2005**	**2008**
Montserrat								96	96	96	96								96	96	96	96								96	100	100	100
Netherlands Antilles																																	
Nicaragua			34	35		34	96	78	56	62	63	8	24		16		27	68	51	34	35	37				27		31	84	66	47	50	52
Panama	87	78	83	99			87	89	89	75	75	69	76	59	61			94	51	51	51	51	78	77	71	81		86	99	72	73	68	69
Puerto Rico																																	
Saint Kitts								96	96	96	96								96	96	96	96								96	95	96	96
Saint Lucia								89	89										89	89										89	89		
Saint Vincent																			96	96	96	96											
Trinidad/Tobago					100			100	100	92	92					92			100	100	92	92					97		88	100	100	92	92
Turks/Caicos Islands		51	83	96	100				98	94	98	98	96	97	88	95				94	98			81	92	93	98				96	96	
United States of America							100	100	100	100	100							100	100	100	99	99							100	100	100	100	100
United States Virgin Islands																																	
SOUTH AMERICA																																	
Argentina	87	100	80	75			89		92	91	91	79	83	35	35			48		83	77	77	85	97		69			85		91	90	90
Bolivia	25		37	33	38	58	82	58	60	33	34	4	9	4	10	14	16	38	23	22	9	9	12		18	21	26	41	66	45	46	24	25
Brazil	85			86	84	55	85	83	83	86	87	24		1	1	32	3	40	35	37	37	37	58			63	71	44	77	75	75	78	80
Chile	33	36	100	100		82	98	96	95	98	98	10	11	10	4			93	64	62	83	83	29	32	83	84			97	92	91	96	96
Colombia	75	73	93	96	84	76	97	96	96	81	81	8	13	4	13	18	33	51	54	54	53	55	47	48	61		64	63	85	86	86	74	74
Ecuador			73	98	56	87	70	80	94	95	96		7	17	29	38	34	37	59	82	81	84			43	65	48	64	59	72	89	90	92
French Guiana							85		57									57		85									79		78		
Guyana	95	99	73	100	97		97	86	86	85	85	92	94	80	79	81		81	60	60	78	80	93	96	78	86	86		87	70	70	80	81
Paraguay	16	28	95	89	31		95	94	94	88	90			80	83	60		95	58	61	39	40	6	10	86	85	46		95	78	80	69	70
Peru	52		57	67	76	62	90	72	74	79	81	16		0	12	20	10	40	33	32	33	36	36		36	49	59	44	76	62	63	66	68
Suriname			100	78			100	99	99	90	90			79	48			34	76	76	66	66			88	62			83	93	94	84	84

Uruguay	97	97	59	59			96	95	100	99	100	13	17	6	59			89	85	99	96	99	82	83	51	59			95	94	100	99	100
Venezuela			60	57		64	86	71	71	94		45		12	5	72	30	69	48	48	57				52	50		58	74	68	68	91	
ASIA																																	
Afghanistan	69	63		5	13	38	25	16	49	56	60	16	15				1	8	5	29	29	30	21	21				8	12	8	34	35	37
Armenia								96	96	95	95								61	61	79	80								84	83	89	90
Azerbaijan								73	73	55	51								36	36	34	39								55	54	45	45
Bahrain				100	100			100	100	100	100				100	0										100							
Bangladesh	87	40	21	24	40	77	82	75	51	57	56			1	3	4	30	44	39	35	48	52	6	5	3	5	10	35	53	48	39	50	53
Bhutan					80	66	65	65	65	87	87					3	18	70	70	70	54	54					7	41	69	70	70	64	65
Brunei Darus																																	
Cambodia			100				58	53	53	60	67			76				10	8	8	15	18							18	16	17	24	29
China					100	58	68	69	69	58	58					81	7	24	29	28	50	52					86	21	38	44	44	53	55
Cyprus	100	94		100	96		100	100	100	100	100	92	95		100	100		100	100	100	100	100	95	95		100	98		100	100	100	100	100
East Timor								65	66	68	86								30	33	35	40								33	36	44	50
Gaza Strip									78	91	91									61	84	84									73	89	89
Georgia								96	96	96	96								69	91	94	93								83	94	95	95
Hong Kong					90											50											88						
India	85	87	27	31	44	70	73	58	59	54	54	1	2	1	2	3	14	14	18	22	18	21	18	20	7	9	14	29	31	30	33	28	31
Indonesia	50	60	29	33	79	73	87	71	73	66	67	4	5	21	38	30	40	52	38	40	33	36	12	15	23	37	44	51	66	52	55	49	52
Iran	100	100	96		100	89	86	86				48	59	43		35	37	74	78				70	78	69		72	67	81	84			
Iraq	82	75		100	96		93	95	95	76	76		1		11			31	48	48	61	66	47	47		74		36	79	80	79	71	73
Israel								100	100	100	100										100	100										100	100
Japan								100	100	100	100										100	100										100	100
Jordan			94	92	100		100	94	94	98	98			34		100		98	85	87	96	97			70		100	95	99	93	93	98	98
Kazakhstan							100	87	87	97	97							98	52	52	98	98							99	72	72	97	97
Korea Democratic People's Republic								99	58	58									100	60	60									99	59	59	
Korea Republic	59	80	100	100	67		76			100	100										100	100										100	100
Kuwait			100	100						100	100										100	100										100	100
Kyrgyzstan							100	75	75	94	94							100	51	51	93	93							100	60	59	93	93
Laos		10	13		30	70	84	61	67	77	86		2	4		8	13	34	14	20	30	38		3	5		12	24	46	24	30	43	53
Lebanon						100	100	100	100	100	100						100	92	87	87	87							100	99	98	98	98	

continues

Data Table 4 *continued*

Fraction of Population with Access to Improved Sanitation

URBAN

Region and Country	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Macau											
Malaysia	100	100	100	100	94				95	96	96
Maldives		21	60	100	95	95	100	100	100	100	100
Mongolia					100		46	75	75	64	64
Myanmar (Burma)	45	38	38	33	50	42	65	96	88	86	75
Nepal	14	14	16	17	34	51	75	68	62	50	51
Oman	100	100		88			98	97	97	97	97
Pakistan	12	21	42	51	53	53	94	92	92	72	72
Philippines	90	76	81	83	79		92	81	80	78	80
Qatar	100	100			100			100	100	100	100
Saudi Arabia	67	91	81	100			100	100	100	100	100
Singapore			80	99	99		100	100	100	100	100
Sri Lanka	76	68	80	65	68	33	91	98	98	87	88
Syria			74			77	98	97	99	96	96
Tajikistan								71	70	95	95
Thailand	65	58	64	78			97	97	98	95	95
Turkey			56				98	94	96	97	97
Turkmenistan								77	77	99	99
United Arab Emirates			93					100	98	98	98
Uzbekistan							100	73	78	99	100
Vietnam	100				23	43	87	84	92	88	94
Yemen A R			60	83			99	76	86	89	94
Yemen Dem			70				99				

RURAL

Region and Country	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Macau											
Malaysia	43	43	55	60	94		41	98	93	95	95
Maldives			1	2	4	26	58	42	42	88	96
Mongolia					47		2	37	37	30	32
Myanmar (Burma)					13	40	39	63	72	79	79
Nepal			1	1	3	16	20	20	30	24	27
Oman		5		25			61	61			
Pakistan			2	6	12	19	42	35	41	25	29
Philippines	40	44	67	56	63		71	61	59	65	69
Qatar	16	100			85			100	100	100	100
Saudi Arabia	11	35	50	33			100				
Singapore											
Sri Lanka	61	55	63	39	45	58	80	89	89	88	92
Syria			28			35	81	56	81	90	95
Tajikistan								47	45	92	94
Thailand	8	36	41	46	86		96	100	99	96	96
Turkey							70	62	72	73	75
Turkmenistan								50	50	97	97
United Arab Emirates			22					100	95	95	95
Uzbekistan							100	48	61	96	100
Vietnam		2	55		10	15	70	26	50	61	67
Yemen A R							31	14	28	29	33
Yemen Dem			15				31				

TOTAL

Region and Country	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Macau											
Malaysia	59	60	70	75	94				94	96	96
Maldives		3	13	22		44	56	58	59	92	98
Mongolia					78		30	59	59	49	50
Myanmar (Burma)	35	33	20	24	22	41	46	73	77	81	81
Nepal	1	1	1		6	20	27	27	35	28	31
Oman		12		31		76	92	89			
Pakistan	3	6	13	19	25	30	61	54	59	41	45
Philippines	57	56	75	67	70		83	73	72	73	76
Qatar	83	100						100	100	100	100
Saudi Arabia	21	47	70	82			100				
Singapore			80	99			100	100	100		
Sri Lanka	64	59	67	44	50	52	83	91	91	88	91
Syria			50			56	90	77	90	93	96
Tajikistan								53	51	93	94
Thailand	17	40	45	52			96	99	99	96	96
Turkey							91	83	88	89	90
Turkmenistan								62	62	98	98
United Arab Emirates			80					100	98	97	97
Uzbekistan							100	57	67	97	100
Vietnam	26				13	21	73	41	61	68	75
Yemen A R							45	30	43	46	52
Yemen Dem			35				45				

OCEANIA																																	
American Samoa																																	
Australia							100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Cook Islands			100	100	100		100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Fiji	100	100	85		91	100	75	99	87			87	93	60		65	85	12	98	55			91	96	70		75	92	43	98	72		
French Polyneisa					98		99	99	97	99	99					95		97	97	99	97	97							98	98	98	98	98
Guam								99	98	99	99								98	99	98	98								99	99	98	99
Kiribati					91	100	54	59	59	49						49	100	44	22	22	22							100	48	39	40	35	
Marshall Islands					100			93	93	82	83					45			59	58	51	53								82	82	72	73
Micronesia					99	100		61	61	61						46	100		14	14	15							100		28	28	26	
Nauru										50	50																						
New Caledonia																																	
New Zealand																																	
Niue					0	100	100	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Northern Mariana Islands					100			94	96	94						71		92	96	94	96	96								94	95	94	
Palau					95		100	96	96	96	96					100		100	52	52	52								100	83	80	79	
Papua New Guinea	100	100	96	99	57	82	92	67	67	73	71	5	5	3	35		11	80	41	41	42	41	14	18	15	44		22	82	45	44	46	45
Pitcairn																																	
Samoa	100	100	86		100		95	100	100	100	100							100	100	100	100	100							100	100	100	100	100
Solomon Islands			80		73		98	98	98	98	98			21		2		18	18	18	18						13		34	31	31	32	
Tokelau						100								41			100		74	78	82	92						100			78		
Tonga	100	100	97	99	88	100		98	98	98	98	100	100	94	40	78	100		96	96	96	96	100	100	19	52	82	100		97	96	96	97
Tuvalu			100	81		90	100	92	93	87	88			80	73		85	100	83	84	80	81						87	100	88	90	82	81
Vanuatu			95	86			100	78	78	63	66			68	25			100	42	42	43	48				40			100	50	50	48	53
Wallis and Futuna Islands											80												96	96									80
Western Samoa			86	88										83	83											84							
EUROPE																																	
Albania								99	99										81	84										89	91		
Belarus									93											61											84		
Bosnia and Herzegovina										99											92											95	
Bulgaria									100											96											99		
Czech Republic									99											97											98		

continues

Data Table 4 *continued*

Region and Country	Fraction of Population with Access to Improved Sanitation																																
	URBAN											RURAL											TOTAL										
	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008	1970	1975	1980	1985	1990	1994	2000	2002	2004	2005	2008
Estonia									97											96											97		
Hungary								100	100										85	85										95	95		
Latvia									82											71											78		
Republic of Moldova									86	86										52	52										68	68	
Romania								86	89										10											51			
Russian Federation								93	93										70	70										87	87		
Serbia and Montenegro									97	97										77	77										87	87	
Slovakia									100											98											99		
Ukraine								100	98										97	93										99	96		

Sources:, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, UNEP 1989, WRI 1988, Calculated from UNEP 1993, WHO 1996, WHO 2000, WHO/UNICEF 2004, WHO/UNICEF 2006, WHO/UNICEF 2010, WHO/UNICEF 2010

MDG Progress on Access to Safe Drinking Water by Region

(proportion of population using an improved water source)

Description

The Millennium Development Goals (MDGs)—adopted by the United Nations in 2000—established a set of targets for improving the lives of the world's poor, ranging from eradicating extreme hunger to reducing child mortality and ensuring environmental sustainability. These targets, agreed to by all countries and leading development institutions throughout the world, consist of eight goals and 21 targets.

In 2010, the human right to safe water and sanitation was formally recognized by the UN General Assembly and the UN Human Rights Council, but this basic right is not being met universally. In many parts of the world, particularly sub-Saharan Africa and Oceania, a lack of clean water adversely affects human health and development. Using 1990 as a baseline, one target of goal 7 of the MDGs seeks to reduce by half the proportion of people without sustainable access to safe drinking water by 2015.

At the global level, we are on track to meet the target for improving access to safe drinking water; however, not all regions are performing as well as others. Europe, Latin America, the Caribbean, and much of Asia have met or are on track to meet the established targets. But in Oceania, there has been no progress or conditions have worsened, while Northern and sub-Saharan Africa and South-Eastern Asia have not made sufficient progress to be on track with the target. The global community must intensify efforts in these regions if they hope to achieve the established 2015 targets.

Limitations

These data give a good picture of the current lack of access to improved water services, but comparison from different assessments should be done with extreme care, or not at all, because of changing definitions.

Country-reported data may reflect national definitions of "improved," unlike survey data, which were standardized as much as possible. For example, in many African countries, the population "without access" to improved sanitation means people with no access to any sanitary facility. In Latin America and the Caribbean, however, it is more likely that those "without access" in fact have a sanitary facility, but the facility is deemed unsatisfactory by local or national authorities. Low coverage figures for Latin

America and the Caribbean may in part be a reflection of the comparatively narrow definitions used within that region.

Changes in the source of data also complicate comparisons over time. Prior to 2000, for example, data collected by WHO was provider based and was collected from service providers, such as utilities, ministries, and water agencies. The data shown here, however, are sometimes user based and were collected from household surveys and censuses. User-based data are more likely to include improvements installed by households or local communities and give a more complete picture of water supply and sanitation coverage.

SOURCES

United Nations. 2007. The Millennium Development Goals Report. http://mdgs.un.org/unsd/mdg/Resources/Static/Data/2007%20Stat%20Annex%20current%20indicators.pdf

United Nations. 2007. MDG Progress Chart 2007. http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2007/MDG_Report_2007_Progress_Chart_en.pdf.

United Nations. 2010. The Millennium Development Goals Report. http://www.un.org/millenniumgoals/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf

United Nations Statistics Division. 2010. Millennium Development Goals: 2010 Progress Chart. http://unstats.un.org/unsd/mdg/Resources/Static/Products/Progress2010/MDG_Report_2010_Progress_Chart_En.pdf

Data Table 5 MDG Progress on Access to Safe Drinking Water by Region (proportion of population using an improved water source)

	1990			2004			2008			2015 Target			
	Urban	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*On target?*
Northern Africa	95	82	89	96	86	91	98	87	92	98	91	95	Progress insufficient to meet target
Sub-Saharan Africa	82	36	49	80	42	56	83	47	60	91	68	75	Progress insufficient to meet target
Latin America and the Caribbean	93	60	83	96	73	91	97	80	93	97	80	92	Progress sufficient to meet target
Eastern Asia	99	59	71	93	67	78	98	82	89	100	80	86	Target met or close to being met
Southern Asia	90	66	72	94	81	85	95	83	87	95	83	86	Target met or close to being met
Southeastern Asia	93	68	76	89	77	82	81	92	86	97	84	88	Progress insufficient to meet target
Western Asia	94	70	85	97	79	91	96	78	90	97	85	93	Progress sufficient to meet target
Oceania	92	39	51	80	40	51	92	37	50	96	70	76	No progress or deterioration
Commonwealth of Independent States	97	84	92	99	80	92	98	87	94	99	92	96	Progress sufficient to meet target in Europe; progress insufficient to meet target in Asia

DATA TABLE 6

MDG Progress on Access to Sanitation by Region

(proportion of population using an improved sanitation facility)

Description

The Millennium Development Goals (MDGs)—adopted by the United Nations in 2000—established a set of targets for improving the lives of the world's poor, ranging from eradicating extreme hunger to reducing child mortality and ensuring environmental sustainability. These targets, agreed to by all countries and leading development institutions throughout the world, consist of eight goals and 21 targets.

Adequate sanitation is also now a recognized human right, but like access to safe drinking water, this basic right is not universal. In many parts of the world, particularly the poor in rural and peri-urban areas, a lack of basic sanitation adversely affects human health and development. Using 1990 as a baseline, one target of goal 7 of the MDGs seeks to reduce by half the proportion of people without sustainable access to sanitation by 2015.

Meeting the sanitation targets has proven to be more challenging than meeting the water target. While an estimated 2.6 billion people lacked access to basic sanitation in 1990, experts predict that 2.1 billion will still lack access to this basic right by 2015 (Ki Moon 2008). Some areas are performing better than others, highlighting a growing regional disparity in access to sanitation. A majority of regions, however, are not on track to meet established targets, and in Oceania and many former Soviet Union countries, there has been no progress or conditions have worsened.

Limitations

These data give a good picture of the current lack of access to improved sanitation services, but comparison from different assessments should be done with extreme care, or not at all, because of changing definitions.

Country-reported data may reflect national definitions of "improved," unlike survey data, which were standardized as much as possible. For example, in many African countries, the population "without access" to improved sanitation means people with no access to any sanitary facility. In Latin America and the Caribbean, however, it is more likely that those "without access" in fact have a sanitary facility but the facility is deemed unsatisfactory by local or national authorities. Low coverage figures for Latin

America and the Caribbean may in part be a reflection of the comparatively narrow definitions used within that region.

Changes in the source of data also complicate comparisons over time. Prior to 2000, for example, data collected by WHO came from service providers, such as utilities, ministries, and water agencies. The data shown here, however, are sometimes user based and were collected from household surveys and censuses. User-based data are more likely to include improvements installed by households or local communities and give a more complete picture of water supply and sanitation coverage.

SOURCES

Ki-Moon, B. 2008. Secretary-General, in message for World Water Day. March 5. United Nations, New York.

United Nations. 2007. The Millennium Development Goals Report. http://mdgs.un.org/unsd/mdg/Resources/Static/Data/2007%20Stat%20Annex%20current%20indicators.pdf

United Nations. 2007. MDG Progress Chart 2007. http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2007/MDG_Report_2007_Progress_Chart_en.pdf

United Nations. 2010. The Millennium Development Goals Report. http://www.un.org/millenniumgoals/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf

United Nations Statistics Division. 2010. Millennium Development Goals: 2010 Progress Chart. http://unstats.un.org/unsd/mdg/Resources/Static/Products/Progress2010/MDG_Report_2010_Progress_Chart_En.pdf

Data Table 6 MDG Progress on Access to Sanitation by Region (proportion of population using an improved sanitation facility)

	1990			2004			2008			2015 Target			
	Urban	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*Urban*	*Rural*	*Total*	*On target?*
Northern Africa	84	47	65	91	62	77	94	83	89	92	74	83	Already met the target or very close to meeting the target
Sub-Saharan Africa	52	24	32	53	28	37	44	24	31	76	62	66	Progress insufficient to reach the target if prevailing trends persist
Latin America and the Caribbean	81	36	68	86	49	77	86	55	80	91	68	84	Progress insufficient to reach the target if prevailing trends persist
Eastern Asia	64	7	24	69	28	45	61	53	56	82	54	62	Progress insufficient to reach the target if prevailing trends persist
Southern Asia	54	8	20	63	27	38	57	26	36	77	54	60	Progress insufficient to reach the target if prevailing trends persist
Southeastern Asia	70	40	49	81	56	67	79	60	69	85	70	75	Progress sufficient to reach the target if prevailing trends persist
Western Asia	97	55	81	96	59	84	94	67	85	99	78	91	Progress insufficient to reach the target if prevailing trends persist
Oceania	80	46	54	80	43	53	81	45	53	90	73	77	No progress or deterioration
Commonwealth of Independent States	92	63	82	92	67	83	93	83	—	96	82	91	Europe: No progress or deterioration; Asia: Progress insufficient to reach the target if prevailing trends persist

Under-5 Mortality Rate by Cause and Country, 2008

Description

This table presents data from the World Health Organization (WHO) on the under-5 mortality rate and cause of death. Under-5 mortality rate provides an indication of child health and overall development; reducing under-5 mortality is one objective of the Millennium Development Goals. Information on the cause of death provides information needed to prioritize and evaluate various intervention methods and assess progress toward meeting national and international goals. In all regions, as noted below, a leading cause of death in children under the age of five is diarrheal disease.

Under-5 mortality is defined as the probability of a child born in a specific year or period dying before reaching the age of five. The measure is derived from a life table and expressed as a rate per 1,000 live births. The rates are calculated based on data from civil registration, census, and/or household surveys. Data on the cause of death are based on information provided on the medical certificate and recorded by the civil registration system. Epidemiological studies and modeling are used in countries with incomplete or no data.

There is tremendous regional variation in the probability of death. Under-5 mortality rates are highest in African countries, at an estimated 142 deaths per 1,000 live births, and lowest in Europe, at about 14 deaths per 1,000 live births. Of all countries, Angola has the highest mortality rate, 220 deaths per 1,000 live births, while Iceland and Singapore have the lowest mortality, at 3 deaths per 1,000 live births each.

The cause of death is also subject to significant variation. Death from water-related diseases (e.g., diarrheal diseases and malaria) is highest in the African region, accounting for 34 percent of all under-5 mortalities. In Southeast Asia, water-related diseases are also high, accounting for 21 percent of all under-5 mortalities. Deaths from water-related diseases are lowest in Europe, accounting for only 5 percent of all under-5 mortalities. Within Europe, rates are highest among the former Soviet Union countries.

Limitations

Data are collected from a variety of sources. In some cases, the age and cause of death are collected from surveys and are thus subject to some degree of error. As noted by the World Health Organization, “there clearly is substantial variation in data quality and consistency across countries.”

SOURCES

World Health Organization. 2010. World Health Statistics 2010. http://www.who.int/whosis/whostat/2010/en/index.html

World Health Organization. 2010. Health Statistics and Health Information Systems: Mortality Data. http://www.who.int/healthinfo/statistics/mortality/en/

Data Table 7 Under-5 Mortality Rate by Cause and Country, 2008

		Distribution of causes of death among children aged <5 years[a,b] (%)										
	Under-5 mortality rate (per 1,000 live births)	HIV/ AIDS	Diarrheal diseases	Measles	Malaria	Pneu- monia	Prema- turity	Birth asphyxia	Neo- natal sepsis	Congenital abnor- malities	Other diseases	Injuries
2008												
African Region	**142**	**4**	**18**	**1**	**16**	**17**	**9**	**8**	**5**	**2**	**17**	**2**
Algeria	41	0	13	1	0	19	22	13	6	8	17	2
Angola	220	2	25	1	8	20	6	6	5	2	23	3
Benin	121	1	13	0	23	19	1	6	2	3	19	2
Botswana	31	0	7	0	1	12	23	11	4	10	27	5
Burkina Faso	169	1	19	0	20	21	6	5	3	2	21	3
Burundi	168	2	24	1	9	17	7	7	6	2	21	4
Cameroon	131	5	16	1	19	18	8	6	4	2	18	2
Cape Verde	29	0	8	6	0	14	24	12	5	9	19	3
Central African Republic	173	7	17	0	14	20	9	7	4	2	18	1
Chad	209	3	22	0	19	19	6	6	3	1	19	1
Comoros	105	0	20	0	0	22	16	9	6	3	22	2
Congo	127	5	14	0	24	16	11	6	4	3	15	2
Côte d'Ivoire	114	4	13	0	21	17	12	9	6	3	14	1
Democratic Republic of the Congo	199	1	19	1	17	20	10	7	4	3	17	2
Equatorial Guinea	147	3	9	9	28	12	10	7	4	3	12	1
Eritrea	58	4	21	2	0	19	11	7	4	3	24	5
Ethiopia	109	3	23	0	7	15	9	11	9	2	19	3
Gabon	77	10	6	1	29	11	15	8	4	4	10	1
Gambia	106	1	14	1	23	16	11	8	5	3	15	3
Ghana	76	3	9	2	26	10	12	11	9	4	11	2
Guinea	146	2	14	3	24	17	8	8	6	2	14	1
Guinea-Bissau	195	2	19	2	18	18	8	6	5	2	18	2
Kenya	128	5	21	1	11	16	8	8	6	2	20	3
Lesotho	79	17	10	0	0	13	16	13	10	4	14	2
Liberia	144	3	17	2	16	17	10	8	6	2	18	1
Madagascar	106	0	22	0	4	21	11	9	7	2	21	2
Malawi	100	14	11	0	17	13	10	8	6	3	16	2
Mali	194	1	19	0	21	19	8	7	4	2	17	2
Mauritania	118	1	16	0	13	20	13	9	6	3	17	2
Mauritius	16	1	2	0	0	7	23	14	5	22	22	4
Mozambique	130	14	12	0	12	18	10	9	6	3	15	2
Namibia	42	18	6	7	5	14	18	8	4	6	13	2
Niger	167	0	20	0	18	22	7	6	3	1	21	2
Nigeria	186	3	19	0	20	16	8	8	6	2	17	1
Rwanda	112	1	23	1	6	15	9	10	8	3	20	4
Sao Tome and Principe	97	0	15	1	1	26	12	8	5	4	26	3
Senegal	108	1	15	3	19	18	10	8	5	3	17	2
Seychelles	11	0	0	0	0	10	37	6	0	14	29	4
Sierra Leone	194	1	21	5	13	20	8	6	4	1	19	3

continues

Data Table 7 *continued*

	Distribution of causes of death among children aged <5 years[a,b] (%)											
	Under-5 mortality rate (per 1,000 live births)	HIV/ AIDS	Diarrheal diseases	Measles	Malaria	Pneu- monia	Prema- turity	Birth asphyxia	Neo- natal sepsis	Congenital abnor- malities	Other diseases	Injuries
South Africa	67	46	9	0	0	9	12	7	2	3	10	2
Swaziland	83	49	8	0	0	12	8	5	3	3	12	1
Togo	98	6	12	0	26	15	11	9	5	3	12	2
Uganda	135	5	16	2	22	14	7	7	5	2	16	4
United Republic of Tanzania	103	9	12	0	16	14	10	10	8	3	16	3
Zambia	148	12	15	1	15	15	7	7	6	2	17	3
Zimbabwe	96	21	9	8	3	13	12	8	4	3	16	2
Region of the Americas	**18**	**1**	**7**	**0**	**0**	**12**	**22**	**8**	**5**	**16**	**23**	**6**
Antigua and Barbuda	12	0	1	0	0	7	48	7	1	20	11	5
Argentina	15	0	1	0	0	7	30	5	6	25	20	7
Bahamas	13	1	1	0	0	9	12	14	9	19	25	11
Barbados	11	4	0	0	0	2	37	16	5	13	17	6
Belize	19	4	7	0	0	11	18	9	4	15	20	11
Bolivia (Plurinational State of)	54	0	15	0	0	18	16	13	8	5	22	3
Brazil	22	0	5	0	0	9	23	10	7	15	26	5
Canada	6	0	0	0	0	1	27	12	2	24	27	6
Chile	9	0	0	0	0	6	25	5	3	35	21	6
Colombia	20	0	4	0	0	12	19	7	7	17	25	7
Costa Rica	11	0	1	0	0	5	23	9	6	30	22	3
Cuba	6	0	1	0	0	11	10	7	9	24	31	8
Dominica	10	0	0	0	0	4	32	11	8	27	14	4
Dominican Republic	33	1	9	0	0	18	26	11	4	9	18	3
Ecuador	25	1	6	0	0	17	22	9	2	16	22	6
El Salvador	18	4	4	0	0	14	21	9	1	19	22	7
Grenada	15	0	1	0	0	12	38	14	3	19	11	2
Guatemala	34	3	19	0	0	20	19	5	1	5	24	5
Guyana	61	6	15	0	1	17	16	9	7	8	17	4
Haiti	72	5	20	0	1	20	11	10	6	2	23	2
Honduras	31	1	10	0	0	18	22	12	5	9	19	4
Jamaica	31	4	14	0	0	23	13	5	1	9	26	5
Mexico	17	0	6	0	0	13	17	7	5	22	22	9
Nicaragua	27	1	9	0	0	20	22	8	2	13	21	4
Panama	23	1	6	0	0	13	16	6	5	24	22	6
Paraguay	28	1	9	0	0	17	24	13	5	10	18	4
Peru	24	1	4	0	0	16	25	10	2	16	20	6
Saint Kitts and Nevis	15	0	0	0	0	2	33	29	3	10	15	7
Saint Lucia	15	0	0	0	0	1	52	23	2	10	10	2
Saint Vincent and the Grenadines	13	1	2	0	0	1	36	11	11	7	24	7
Suriname	27	2	6	0	1	10	22	10	6	12	23	8
Trinidad and Tobago	35	6	1	0	0	6	22	7	7	21	22	9

	Distribution of causes of death among children aged <5 years[a,b] (%)											
	Under-5 mortality rate (per 1,000 live births)	**HIV/ AIDS**	**Diarrheal diseases**	**Measles**	**Malaria**	**Pneu- monia**	**Prema- turity**	**Birth asphyxia**	**Neo- natal sepsis**	**Congenital abnor- malities**	**Other diseases**	**Injuries**
United States of America	8	0	0	0	0	3	30	5	3	23	26	11
Uruguay	16	0	2	0	0	7	20	4	6	28	22	11
Venezuela (Bolivarian Republic of)	18	0	7	0	0	10	23	9	8	19	14	9
Eastern Mediterranean Region	**78**	**0**	**18**	**1**	**3**	**19**	**15**	**10**	**7**	**6**	**18**	**3**
Afghanistan	257	0	29	1	0	26	5	5	4	2	25	4
Bahrain	12	0	1	0	0	1	24	7	1	43	14	10
Djibouti	95	6	19	0	0	19	11	9	6	7	20	2
Egypt	23	0	5	0	0	11	33	6	1	18	21	5
Iran (Islamic Republic of)	32	1	10	0	0	16	27	9	4	14	16	4
Iraq	45	0	12	0	0	20	23	12	5	8	16	5
Jordan	20	0	4	0	0	11	35	6	2	19	18	5
Kuwait	11	0	1	0	0	4	28	3	2	48	11	4
Lebanon	13	1	2	0	0	8	30	6	1	24	20	8
Libyan Arab Jamahiriya	17	0	4	0	0	9	30	6	1	22	21	7
Morocco	36	0	12	0	0	17	21	15	8	10	14	3
Oman	12	0	2	0	0	7	32	6	1	25	19	7
Pakistan	89	0	16	0	0	18	17	15	12	7	14	2
Palau	15	0	4	0	0	10	21	8	1	20	26	9
Saudi Arabia	21	0	5	0	0	10	31	6	1	19	19	8
Somalia	200	0	22	5	6	19	8	8	5	3	21	2
Sudan	109	2	11	0	25	16	18	7	2	4	13	3
Syrian Arab Republic	16	0	5	0	0	11	26	5	1	22	23	7
Tunisia	21	0	5	0	0	10	30	6	1	20	21	6
United Arab Emirates	8	0	1	0	0	5	31	6	1	29	20	7
Yemen	69	0	20	1	0	18	17	12	5	5	19	3
European Region	**14**	**0**	**5**	**0**	**0**	**14**	**20**	**9**	**3**	**17**	**25**	**6**
Albania	14	0	2	0	0	18	14	7	1	22	26	11
Andorra	4	0	0	0	0	5	20	8	1	34	23	10
Armenia	23	0	2	0	0	17	26	10	2	17	22	4
Austria	4	0	0	0	0	1	25	9	0	32	25	7
Azerbaijan	36	0	11	0	0	22	22	10	5	7	21	2
Belarus	13	0	1	0	0	4	10	6	2	30	30	17
Belgium	5	0	1	0	0	1	14	8	2	32	31	10
Bosnia and Herzegovina	15	0	1	0	0	14	24	10	1	24	19	7
Bulgaria	11	0	2	0	0	21	17	9	2	18	25	6
Croatia	5	0	1	0	0	4	20	7	5	36	20	6
Cyprus	4	0	0	0	0	4	23	6	1	35	22	9
Czech Republic	4	0	1	0	0	5	14	13	3	23	29	12
Denmark	4	0	1	0	0	1	34	9	0	31	20	4

continues

Data Table 7 *continued*

	Under-5 mortality rate (per 1,000 live births)	Distribution of causes of death among children aged <5 years[a,b] (%)										
		HIV/AIDS	Diarrheal diseases	Measles	Malaria	Pneumonia	Prematurity	Birth asphyxia	Neonatal sepsis	Congenital abnormalities	Other diseases	Injuries
Estonia	6	1	0	0	0	2	10	10	4	27	24	21
Finland	3	0	0	0	0	4	19	6	3	37	24	6
France	4	0	1	0	0	2	13	12	3	26	37	7
Georgia	30	0	6	0	0	19	27	13	5	11	16	3
Germany	4	0	0	0	0	1	33	7	2	28	23	6
Greece	3	0	0	0	0	8	35	4	0	36	9	9
Hungary	7	0	0	0	0	7	24	5	1	26	32	6
Iceland	3	0	0	0	0	0	7	10	8	24	49	3
Ireland	5	0	0	0	0	0	15	5	2	48	25	5
Israel	5	0	0	0	0	2	19	6	2	40	29	4
Italy	4	0	0	0	0	1	23	7	3	31	30	5
Kazakhstan	30	0	2	0	0	17	1	1	0	15	57	7
Kyrgyzstan	38	0	14	0	0	22	18	12	4	7	20	3
Latvia	9	0	1	0	0	7	7	25	1	30	21	8
Lithuania	7	0	0	0	0	6	12	7	4	35	18	17
Luxembourg	3	0	0	0	0	0	26	17	1	19	24	13
Malta	7	0	0	0	0	6	24	8	0	29	18	15
Monaco	4	0	0	0	0	4	22	9	1	32	23	9
Montenegro	9	0	0	0	0	9	26	11	1	28	17	6
Netherlands	5	0	0	0	0	2	18	12	6	28	28	6
Norway	3	0	3	0	0	0	14	17	3	28	26	9
Poland	7	0	0	0	0	5	30	7	4	35	14	6
Portugal	4	1	0	0	0	6	22	10	1	32	19	8
Republic of Moldova	17	0	2	0	0	23	4	7	6	31	14	14
Romania	13	0	1	0	0	33	12	4	0	21	20	8
Russian Federation	11	0	1	0	0	7	13	8	3	24	31	13
San Marino	2	0	0	0	0	0	0	0	0	0	100	0
Serbia	8	0	0	0	0	6	39	12	1	22	15	3
Slovakia	7	0	0	0	0	11	28	4	1	29	19	8
Slovenia	3	0	0	0	0	2	24	8	12	20	30	4
Spain	4	0	0	0	0	2	17	7	4	30	34	6
Sweden	3	0	1	0	0	2	12	10	3	33	34	3
Switzerland	5	0	0	0	0	1	23	10	3	28	30	5
Tajikistan	64	0	19	0	0	21	15	9	5	4	24	3
The former Yugoslav Republic of Macedonia	11	0	3	0	0	5	44	10	2	25	6	3
Turkey	22	0	1	0	0	14	30	11	2	18	18	5
Turkmenistan	48	0	13	0	0	23	18	10	6	6	22	3
Ukraine	15	1	1	0	0	4	11	7	2	28	32	13
United Kingdom	6	0	0	0	0	3	36	7	1	26	23	4
Uzbekistan	38	0	12	0	0	21	22	10	5	8	20	3
South-East Asia Region	**63**	**0**	**13**	**4**	**1**	**19**	**14**	**11**	**7**	**3**	**23**	**4**
Bangladesh	54	0	11	1	2	14	17	18	16	4	16	2

	Under-5 mortality rate (per 1,000 live births)	Distribution of causes of death among children aged <5 years[a,b] (%) HIV/AIDS	Diarrheal diseases	Measles	Malaria	Pneu-monia	Prema-turity	Birth asphyxia	Neo-natal sepsis	Congenital abnor-malities	Other diseases	Injuries
Bhutan	81	0	14	0	0	24	14	11	7	4	22	4
Democratic People's Republic of Korea	55	0	12	0	0	20	21	12	7	6	19	2
India	69	0	13	4	0	20	14	10	7	3	25	3
Indonesia	41	0	15	0	1	22	19	10	5	6	19	2
Maldives	28	0	9	0	0	16	26	11	5	9	20	4
Myanmar	122	1	13	0	2	13	14	11	9	2	13	22
Nepal	51	1	15	0	0	14	17	18	14	4	15	2
Sri Lanka	17	0	3	1	0	10	22	8	1	19	19	16
Thailand	14	2	2	0	1	10	30	11	2	21	17	5
Timor-Leste	93	0	13	5	11	10	12	16	12	3	14	2
Western Pacific Region	**21**	**0**	**4**	**0**	**0**	**18**	**16**	**14**	**2**	**10**	**26**	**9**
Australia	5	0	0	0	0	2	22	9	1	24	33	8
Brunei Darussalam	7	0	2	0	0	1	15	7	2	36	24	13
Cambodia	89	0	7	1	1	28	11	10	8	2	29	3
China	21	0	3	0	0	17	15	17	2	10	25	11
Cook Islands	15	0	0	0	0	15	15	0	0	19	31	20
Fiji	18	1	5	0	0	13	23	9	1	18	24	7
Japan	3	0	1	0	0	6	9	5	2	39	28	11
Kiribati	48	0	17	0	0	24	15	8	3	7	23	4
Lao People's Democratic Republic	61	0	7	3	0	27	9	11	6	4	31	3
Malaysia	6	4	1	0	0	6	22	8	1	26	23	9
Marshall Islands	36	0	9	0	0	23	17	6	2	9	29	5
Micronesia (Federated States of)	39	0	4	0	0	29	17	7	3	5	30	4
Mongolia	41	0	4	0	0	29	14	5	1	7	35	5
Nauru	45	0	3	0	0	18	27	16	9	9	13	5
New Zealand	6	0	0	0	0	5	26	11	3	25	21	10
Niue	28	0	0	0	0	5	32	14	4	19	23	2
Papua New Guinea	69	3	5	2	7	22	11	11	6	3	25	3
Philippines	32	0	7	0	0	24	19	7	2	8	29	4
Qatar	8	0	2	0	0	6	24	5	1	26	25	11
Republic of Korea	5	0	0	0	0	4	26	5	4	21	28	12
Samoa	26	0	7	0	0	20	20	8	2	11	27	5
Singapore	3	0	0	0	0	13	25	1	3	35	19	5
Solomon Islands	36	0	4	1	6	26	18	6	2	6	29	3
Tonga	19	0	6	0	0	15	20	8	2	17	25	7
Tuvalu	36	0	1	0	0	16	17	8	2	14	34	7
Vanuatu	33	0	7	1	2	23	20	7	1	8	26	4
Vietnam	14	3	2	2	0	10	27	10	2	19	20	5

Source: World Health Statistics 2010. http://www.who.int/whosis/whostat/2010/en/index.html

[a] Individual percentages may not add up to 100% due to rounding.

[b] Mortality data. 2010. Geneva, Switzerland: World Health Organization. www.who.int/healthinfo/statistics/mortality/en/

Infant Mortality Rate by Country (per 1,000 live births)

Description

This table presents data from the UN Inter-agency Group for Child Mortality Estimation on the infant mortality rates over time, by country. Data are presented for 1960, 1970, 1980, 1990, 2000, 2005, 2007, 2008, and 2009. Infant mortality is defined as the probability of a child born in a specific year or period dying before reaching the age of one and is expressed as a rate per 1,000 live births. Depending on the type of data available, it may be calculated based on registrations of births and deaths, or household survey methods. More information on the methodology used to calculate infant mortality rates can be found at http://www.childinfo.org/mortality_methodology.html.

The long time frame over which data are available for infant mortality rates in some countries allows for an understanding of trends over time. Not surprisingly, infant mortality rates have dropped in most countries over time; however, there are some exceptions. The data indicate that in the Congo, although rates have fallen since 1960, they have increased by 14 deaths per 1,000 live births since 1980. Since 2000, Congo, Saint Lucia, Chad, and Trinidad and Tobago have all had increases in infant mortality rates. Countries with the largest declines in infant mortality rates since 1980 include Egypt, Maldives, and Timor-Leste, all of which have declined by more than 100. Since 2000, rates in Niger, Maldives, Timor-Leste, Rwanda, and Liberia have all dropped by more than 30.

Limitations

Most data for infant mortality rate estimates in developing countries are from household surveys. Appropriate confidence intervals, therefore, should be taken into account when comparing these data across years or countries, and the data are sometimes affected by non-sampling errors.

SOURCES

United Nations Children's Fund (UNICEF). 2010. http://www.childinfo.org/

Data Table 8 Infant Mortality Rate by Country (per 1,000 live births)

Country or territory	1960	1970	1980	1990	2000	2005	2007	2008	2009
Afghanistan	243	214	189	167	148	140	137	135	134
Albania	119	80	55	41	23	17	15	14	14
Algeria	150	126	94	51	40	33	31	30	29
Andorra	—	—	—	7	4	3	3	3	3
Angola	—	—	158	153	126	110	104	101	98
Antigua and Barbuda	—	—	—	—	17	13	12	11	11
Argentina	60	58	38	25	19	15	14	14	13
Armenia	—	75	61	48	32	24	22	21	20
Australia	20	18	11	8	5	5	5	4	4
Austria	37	25	14	8	4	4	4	4	3
Azerbaijan	—	91	84	78	58	40	34	32	30
Bahamas	—	—	27	17	13	11	9	9	9
Bahrain	143	56	24	14	11	10	10	10	10
Bangladesh	163	158	137	102	66	51	46	43	41
Barbados	—	—	23	15	13	11	10	10	10
Belarus	—	24	22	20	15	13	12	11	11
Belgium	30	20	12	9	5	4	4	4	4
Belize	—	73	52	35	23	19	17	16	16
Benin	—	152	126	111	89	81	78	76	75
Bhutan	—	171	123	91	68	59	56	54	52
Bolivia	155	150	111	84	62	49	44	42	40
Bosnia and Herzegovina	—	—	31	21	14	13	13	13	13
Botswana	121	92	60	46	66	47	44	44	43
Brazil	115	95	72	46	28	22	19	18	17
Brunei Darussalam	—	—	16	9	6	6	6	6	5
Bulgaria	—	28	20	14	14	11	10	9	8
Burkina Faso	181	153	129	110	102	96	93	92	91
Burundi	146	135	114	114	107	104	103	102	101
Cambodia	—	—	104	85	80	73	71	69	68
Cameroon	—	127	102	91	96	95	95	95	95
Canada	28	19	10	7	5	5	5	5	5
Cape Verde	—	105	71	49	33	27	25	24	23
Central African Republic	182	145	119	115	119	115	114	113	112
Chad	—	—	135	120	122	124	124	124	124
Chile	106	76	32	18	9	8	7	7	7
China	—	83	46	37	30	22	19	18	17
Colombia	92	67	38	28	22	19	17	17	16
Comoros	—	133	109	90	81	78	76	76	75
Congo	116	88	67	67	74	77	79	80	81
Cook Islands	84	48	24	16	15	14	14	14	13
Costa Rica	86	60	28	16	12	10	10	10	10
Côte d'Ivoire	—	158	113	105	97	89	86	85	83
Croatia	—	—	—	11	7	6	5	5	5
Cuba	40	33	19	10	7	5	5	5	4
Cyprus	—	—	19	9	5	4	4	4	3
Czech Republic	—	—	—	10	4	4	3	3	3
Democratic People's Republic of Korea	—	—	—	23	42	26	26	26	26

continues

Data Table 8 *continued*

Country or territory	1960	1970	1980	1990	2000	2005	2007	2008	2009
Democratic Republic of the Congo	—	145	130	126	126	126	126	126	126
Denmark	22	14	8	8	5	4	4	4	3
Djibouti	—	—	109	95	84	79	77	76	75
Dominica	—	49	10	15	14	10	9	9	8
Dominican Republic	112	88	69	48	32	29	28	27	27
Ecuador	121	94	69	41	28	24	22	21	20
Egypt	204	158	120	66	38	25	21	20	18
El Salvador	134	112	86	48	28	20	17	16	15
Equatorial Guinea	—	—	—	120	102	94	91	90	88
Eritrea	—	—	112	92	58	46	43	41	39
Estonia	—	—	18	13	8	6	5	5	4
Ethiopia	—	136	127	124	91	77	72	69	67
Fiji	—	—	33	19	16	16	16	16	15
Finland	22	13	7	6	4	3	3	3	3
France	24	15	10	7	4	4	4	3	3
Gabon	—	—	83	68	61	56	54	53	52
Gambia	205	180	133	104	93	85	82	80	78
Georgia	—	—	55	41	31	28	27	27	26
Germany	—	22	13	7	4	4	4	4	4
Ghana	126	110	92	76	68	55	51	49	47
Greece	38	28	18	9	6	4	3	3	3
Grenada	—	—	—	33	18	14	13	13	13
Guatemala	141	113	96	57	39	35	34	33	33
Guinea	—	195	165	137	111	98	93	90	88
Guinea-Bissau	—	—	—	142	129	121	118	117	115
Guyana	—	59	53	47	39	33	31	30	29
Haiti	—	149	133	105	81	71	67	65	64
Holy See	—	—	—	—	—	—	—	—	-
Honduras	137	118	73	43	33	28	27	26	25
Hungary	48	36	22	15	8	6	6	5	5
Iceland	17	12	7	6	3	2	2	2	2
India	160	126	103	84	68	57	54	52	50
Indonesia	128	103	78	56	40	34	32	31	30
Iran (Islamic Republic of)	—	129	89	55	38	31	28	27	26
Iraq	109	88	60	42	38	37	36	36	35
Ireland	31	19	12	8	6	4	4	4	4
Israel	—	—	16	10	6	4	4	4	3
Italy	43	29	14	8	5	4	4	3	3
Jamaica	57	48	37	28	27	26	26	26	26
Japan	32	13	7	5	3	3	3	3	2
Jordan	105	74	49	32	25	23	22	22	22
Kazakhstan	—	—	61	51	38	31	28	27	26
Kenya	120	93	70	64	66	59	57	56	55
Kiribati	—	107	83	65	49	42	40	38	37
Kuwait	81	46	25	14	11	9	9	8	8
Kyrgyzstan	—	—	89	63	44	37	34	33	32

Country or territory	1960	1970	1980	1990	2000	2005	2007	2008	2009
Lao People's Democratic Republic	—	141	127	108	64	53	49	48	46
Latvia	—	—	16	12	12	8	8	7	7
Lebanon	54	44	37	33	21	15	13	12	11
Lesotho	146	132	98	74	86	78	72	66	61
Liberia	200	174	157	165	134	100	90	85	80
Libyan Arab Jamahiriya	172	98	55	32	23	19	18	17	17
Liechtenstein	—	—	—	9	5	3	2	2	2
Lithuania	—	—	17	12	8	7	6	5	5
Luxembourg	—	19	10	8	4	3	2	2	2
Madagascar	—	108	105	102	65	50	45	43	41
Malawi	217	193	150	129	99	82	75	71	69
Malaysia	66	41	26	16	9	7	6	6	6
Maldives	—	—	115	80	43	20	15	13	11
Mali	—	183	160	139	120	109	105	103	101
Malta	37	25	15	10	6	6	6	6	6
Marshall Islands	86	74	64	39	32	30	30	30	29
Mauritania	—	132	94	81	77	76	75	75	74
Mauritius	68	63	32	21	17	13	14	15	15
Mexico	95	79	55	36	22	18	16	15	15
Micronesia (Federated States of)	—	—	—	45	38	34	33	32	32
Monaco	—	—	—	7	4	4	4	3	3
Mongolia	—	131	101	73	49	33	29	26	24
Montenegro	—	—	—	15	13	9	9	8	8
Morocco	128	118	99	69	46	39	36	35	33
Mozambique	—	185	173	155	123	109	102	99	96
Myanmar	—	122	94	84	63	58	56	55	54
Namibia	—	66	59	49	50	40	37	35	34
Nauru	—	—	—	—	41	38	37	36	36
Nepal	197	158	130	99	63	48	43	41	39
Netherlands	16	13	9	7	5	5	4	4	4
New Zealand	24	17	13	9	6	6	5	5	5
Nicaragua	130	111	80	52	34	27	24	23	22
Niger	—	146	147	144	107	88	82	79	76
Nigeria	—	—	126	126	114	97	91	89	86
Niue	—	—	—	—	—	—	—	—	-
Norway	18	13	8	7	4	3	3	3	3
Occupied Palestinian Territory	—	—	57	35	26	25	25	25	25
Oman	—	129	78	37	18	12	11	10	9
Pakistan	—	136	117	101	85	76	73	72	71
Palau	—	—	26	18	14	14	13	13	13
Panama	72	47	34	25	20	17	17	16	16
Papua New Guinea	143	107	81	67	57	54	53	53	52
Paraguay	67	57	47	34	25	22	21	20	19
Peru	142	112	87	62	35	26	22	21	19
Philippines	63	58	53	41	29	28	27	27	26
Poland	58	32	21	15	8	7	6	6	6
Portugal	80	55	23	12	6	4	3	3	3

continues

Data Table 8 *continued*

Country or territory	1960	1970	1980	1990	2000	2005	2007	2008	2009
Qatar	—	61	32	17	13	11	10	10	10
Republic of Korea	96	41	17	8	6	5	5	5	5
Republic of Moldova	—	—	41	30	21	17	16	15	15
Romania	—	44	27	25	19	16	12	11	10
Russian Federation	—	33	28	23	21	15	13	12	11
Rwanda	122	126	121	103	108	85	78	74	70
Saint Kitts and Nevis	—	—	43	22	18	15	14	14	13
Saint Lucia	—	—	26	16	14	16	18	18	19
Saint Vincent and the Grenadines	—	—	45	19	19	14	13	12	11
Samoa	—	—	56	40	28	24	23	22	21
San Marino	—	—	—	14	6	2	1	1	1
Sao Tome and Principe	—	74	68	62	56	54	53	52	52
Saudi Arabia	—	—	66	35	20	19	19	18	18
Senegal	124	114	91	73	61	55	53	52	51
Serbia	—	—	—	25	11	8	7	7	6
Seychelles	71	50	23	13	12	12	11	11	11
Sierra Leone	223	211	185	166	150	134	128	126	123
Singapore	36	22	12	6	3	2	2	2	2
Slovakia	—	—	—	13	8	7	6	6	6
Slovenia	—	—	—	9	4	4	3	3	2
Solomon Islands	139	73	42	31	30	30	30	30	30
Somalia	—	—	—	109	109	109	109	109	109
South Africa	—	—	68	48	54	52	47	45	43
Spain	39	21	13	8	4	4	4	4	4
Sri Lanka	73	56	34	23	17	15	14	13	13
Sudan	120	103	86	78	73	71	70	70	69
Suriname	—	59	51	44	33	28	26	25	24
Swaziland	145	122	88	67	71	69	58	53	52
Sweden	16	11	7	6	3	3	3	2	2
Switzerland	22	15	8	7	5	4	4	4	4
Syrian Arab Republic	134	87	56	30	19	16	15	15	14
Tajikistan	—	—	98	91	75	62	57	54	52
TFYR Macedonia	—	—	—	32	17	13	11	11	10
Thailand	102	71	46	27	17	14	13	13	12
Timor-Leste	—	—	176	138	84	61	54	51	48
Togo	156	123	100	89	78	70	67	66	64
Tonga	—	34	25	19	18	17	17	17	17
Trinidad and Tobago	60	46	36	30	30	31	31	31	31
Tunisia	174	126	72	40	23	20	19	18	18
Turkey	162	150	105	69	36	25	22	20	19
Turkmenistan	—	—	106	81	59	49	45	43	42
Tuvalu	—	—	51	42	35	31	30	30	29
Uganda	131	116	112	111	94	86	83	81	79
Ukraine	—	28	23	18	17	15	14	14	13
United Arab Emirates	149	62	25	15	10	8	7	7	7
United Kingdom	23	18	12	8	6	5	5	5	5
United Republic of Tanzania	142	125	106	99	86	77	73	70	68

Country or territory	1960	1970	1980	1990	2000	2005	2007	2008	2009
United States of America	26	20	13	9	7	7	7	7	7
Uruguay	51	46	36	21	15	13	12	12	11
Uzbekistan	—	—	85	61	53	40	36	34	32
Vanuatu	114	74	49	33	21	17	16	15	14
Venezuela (Bolivarian Republic of)	62	49	37	27	20	17	16	16	15
Viet Nam	—	—	45	39	24	21	20	20	20
Yemen	—	207	128	88	73	59	55	53	51
Zambia	126	107	98	108	99	94	91	88	86
Zimbabwe	95	76	67	54	69	63	60	58	56

Source: Downloaded from http://www.childinfo.org/mortality_imrcountrydata.php.

Death and DALYs from Selected Water-Related Diseases, 2000 and 2004

Description

Measuring the scope of water-related diseases has always been a challenge because of the vast extent of the problem, discrepancies in reporting, the quality of health care in different parts of the world, and a lack of standard indicators. In 1993, the Harvard School of Public Health in collaboration with the World Health Organization (WHO) and the World Bank began a new assessment of the "global burden of disease" (GBD). This effort introduced a new indicator—the "disability adjusted life year" (DALY)—to quantifying the burden of disease. The DALY is a measure of population health that combines in a single indicator years of life lost from premature death and years of life lived with disabilities. Data Table 9 lists deaths and DALYs from selected water-related diseases, as reported by the WHO for 2000 and 2004 (the most recent year for which comprehensive data is available). One DALY can be thought of as one lost year of "healthy" life. Most estimates of water-related deaths appear to fall between two and five million deaths per year. Of these deaths, the vast majority are of small children struck by virulent but preventable diarrheal diseases, as shown in this table. International policy interest in such indicators is increasing, and the WHO World Health Reports now use deaths and DALYs as basic measures of well-being and health. DALYs are reported as "standard DALYs," using 3 percent discounting and age weights. As the table indicates, little progress has been made since 2000 in curbing death and DALYs from diarrheal diseases.

Limitations

Deaths and illnesses from water-related diseases are inadequately monitored and reported. A wide range of estimates of deaths is available in the public literature, ranging from 2 million to 12 million deaths per year. The current best estimate of water-related deaths from diarrheal diseases is around 2 million per year (as shown in Data Table 9), but this estimate must be qualified. First of all, huge numbers of cases of diarrheal diseases are not reported at all, suggesting that some—perhaps many—deaths may be misreported as well. Second, the WHO International Classification of Disease System simplified deaths to a single cause, defined as “the disease or injury which initiated the train of morbid events leading directly to death.” But it is well-known that diarrhea is a contributing cause of death in many circumstances. Third, other deaths from water-related disease are also poorly monitored in some places and for some diseases.

This table excludes mortality and DALYs associated with water-related insect vectors, such as malaria, onchocerciasis, and dengue fever. While few deaths from trachoma are reported, approximately six million cases of blindness or severe complications occur annually.

SOURCES

World Health Organization (WHO). 2001. World Health Report 2001—Mental Health: New Understanding, New Hope. Version 2 data tables on the Global Burden of Disease, Geneva, January 2004. http://www.who.int/whr2001/2001/

World Health Organization (WHO). 2008. The Global Burden of Disease: 2004 Update. Disease and Injury Regional Estimates for 2004. http://www.who.int/healthinfo/global_burden_disease/estimates_regional/en/index.html

Data Table 9 Deaths and DALYS from Selected Water-Related Diseases, 2000 and 2004

	2000		2004	
	Deaths	**DALYs**	**Death**	**DALYs**
Diarrheal diseases	2,019,585	63,345,722	2,163,283	72,776,516
Childhood cluster diseases				
Poliomyelitis	1,136	188,543	1,195	34,399
Diphtheria	5,527	187,838	5,091	173,575
Tropical-cluster diseases				
Trypanosomiasis	49,129	1,570,242	52,347	1,672,728
Schistosomiasis	15,335	1,711,522	41,087	1,707,144
Trachoma	72	3,892,326	108	1,334,414
Intestinal nematode infections				
Ascariasis	4,929	1,204,384	2,455	1,850,781
Trichuriasis	2,393	1,661,689	1,828	1,012,138
Hookworm disease	3,477	1,785,539	242	1,091,589
Other intestinal infections	1,692	53,222	1,957	58,158
TOTAL	**2,103,274**	**75,601,028**	**2,269,593**	**81,711,443**

Source (2004 data): http://www.who.int/healthinfo/global_burden_disease/estimates_regional/en/index.html

DATA TABLE 10

Overseas Development Assistance for Water Supply and Sanitation, by Donating Country

Description

The annual Overseas Development Assistance for Water Supply and Sanitation is listed here, by donating country (and European Union institutions), for the years 2004 through 2009. Shown are the total amounts committed, in current U.S. dollars in millions.

Overseas Development Assistance, or Official Development Assistance (ODA), is the term given to funding that flows to countries or to multilateral institutions for the purpose of providing aid to countries. This funding is provided by official agencies and governments for promoting economic development and welfare and is “concessional in character and conveys a grant element of at least 25 percent.” ODA can take various forms, including technical assistance, investment projects, debt forgiveness or rescheduling, equity investments, and other assistance. The OECD Development Assistance Committee identifies seven subsectors in the “water supply and sanitation” category. Data Table 11 provides a breakdown of ODA for water supply and sanitation by these subsectors.

Limitations

ODA does not constitute all the funding that flows to developing countries, such as other public sector or private sector flows; hence these numbers do not reflect all funding for water projects.

SOURCE

Organization for Economic Cooperation and Development. 2010. Query Wizard for International Development Statistics. http://stats.oecd.org/qwids/

Data Table 10 Overseas Development Assistance for Water Supply and Sanitation, by Donating Country

	Amount Committed in Millions of Dollars					
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
Australia	30.19	34.50	6.43	15.01	13.90	44.68
Austria	20.08	16.77	20.40	24.15	36.58	23.16
Belgium	24.70	37.79	55.16	47.98	102.96	61.33
Canada	79.76	41.09	18.54	24.33	46.96	73.85
Denmark	245.43	98.90	144.62	31.66	19.01	164.95
Finland	6.05	43.34	44.17	30.59	51.18	54.32
France	175.50	114.85	237.42	391.23	359.65	802.77
Germany	435.75	382.26	497.14	593.96	906.44	820.47
Greece	1.39	0.52	1.03	2.78	0.76	2.99
Ireland	19.15	16.83	16.91	22.80	28.15	17.47
Italy	5.89	69.00	54.50	59.69	163.41	55.94
Japan	709.47	2,128.66	1,250.89	1,930.07	1,668.24	2,786.04
Korea	78.31	101.56	80.76	74.52	269.70	67.81
Luxembourg	14.38	12.43	10.27	12.95	19.02	22.29
Netherlands	146.50	191.69	455.15	359.27	373.08	196.51
New Zealand	1.76	2.16	2.77	3.58	3.21	2.58
Norway	32.26	42.53	28.02	46.60	44.65	40.66
Portugal	2.17	2.48	0.63	1.57	0.32	0.42
Spain	78.47	58.02	69.03	121.45	577.07	577.77
Sweden	43.77	68.73	64.32	46.72	76.90	75.37
Switzerland	31.57	35.77	31.74	34.31	49.28	43.06
United Kingdom	29.46	44.26	51.16	104.88	160.66	109.54
United States	954.69	1,023.27	817.79	432.14	846.78	461.91
EU Institutions	413.17	687.16	726.55	490.50	170.28	528.11
Total	**3,579.87**	**5,254.57**	**4,685.40**	**4,902.74**	**5,988.19**	**7,034.00**

Source: Organization for Economic Cooperation and Development (OECD). 2010. Query Wizard for International Development Statistics. http://stats.oecd.org/qwids/

DATA TABLE 11

Overseas Development Assistance for Water Supply and Sanitation, by Subsector (total of all donating countries)

Description

The allocation of total Overseas Development Assistance (ODA) commitments by all donating countries to the seven water and sanitation subsectors are provided in this table. The OECD Development Assistance Committee identifies seven subsectors in the “water supply and sanitation” category:

Water resources policy and administrative management

Water resources protection

Water supply and sanitation: large systems

Basic drinking water supply and basic sanitation

River development

Waste management/disposal

Education and training in water supply and sanitation

By far the largest expenditure is for large-scale water supply and sanitation projects; basic water supply and sanitation projects generally receive less than half as much funding as large-scale projects. One concern of many analysts is that much ODA is directed to serving wealthier populations, or improving services to populations that are already at least partly served by existing systems, and hence does not contribute to meeting the water- and sanitation-related Millennium Development Goals.

Limitations

ODA does not constitute all the funding that flows to developing countries, such as other public sector or private sector flows; hence these numbers do not reflect all funding for water projects.

SOURCES

Organization for Economic Cooperation and Development (OECD). 2010. Query Wizard for International Development Statistics. http://stats.oecd.org/qwids/

Data Table 11 Overseas Development Assistance for Water Supply and Sanitation, by Subsector (total of all donating countries)

	Amount Committed in Millions of Dollars					
Water Supply and Sanitation Sector	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Water resources policy and administrative management	526.76	894.96	806.28	749.27	1,021.86	971.59
Water resources protection	51.49	79.08	46.49	66.10	129.65	118.48
Water supply and sanitation: large systems	1,170.21	1,863.51	2,023.18	1,891.52	2,533.14	2,793.44
Basic drinking water supply and basic sanitation	509.80	846.29	797.95	1,065.23	1,265.42	1,226.58
River development	35.11	58.16	105.22	147.46	218.43	283.34
Waste management/disposal	106.48	113.63	105.46	121.48	163.86	128.81
Education and training in water supply and sanitation	18.98	24.02	28.74	34.35	42.74	34.45
Total, Water Supply and Sanitation	**2,418.83**	**3,879.64**	**3,913.32**	**4,075.41**	**5,375.10**	**5,556.70**

Source: Organization for Economic Cooperation and Development (OECD). 2010. Query Wizard for International Development Statistics. http://stats.oecd.org/qwids/

DATA TABLE 12

Organic Water Pollutant (BOD) Emissions by Country (% from various industries), 2005

Description

Total organic water pollutant emissions by country, broken down into the percentage contributed by different industry types, is provided in this table. Organic water pollutant emissions are measured by biochemical oxygen demand (BOD), which refers to the amount of oxygen that is required by bacteria to break down the wastes. More recent data are available for some countries, but we choose to present data from 2005 because more complete data are available for that year, allowing for greater comparison across countries.

Limitations

Data are collected by the World Bank's Development Research Group. Differences in reporting practices and timing of reporting may cause inconsistent comparisons across countries. Data are not available for all countries.

SOURCES

World Bank. 2010. Data from World Bank and UNIDO's Industry Database. http://data.worldbank.org/indicator

Data Table 12 Organic Water Pollution (BOD) Emissions by Country (% from various industries), 2005

Country	Total BOD emissions in kg per day	% of total BOD emissions by industry type: Food	Chemical	Clay and glass	Metal	Other	Paper and pulp	Textile	Wood
Afghanistan	—	—	—	—		—	—	—	
Albania	3,349	42.5	0.0	0.0	0.0	0.0	0.0	57.5	0.0
Argentina	—	—	—	—	—	—	—	—	—
Aruba	—	—	—	—		—	—	—	—
Austria	84,769	12.5	9.2	5.9	5.7	49.0	7.1	4.5	5.9
Azerbaijan	18,107	18.1	19.3	6.5	9.6	29.3	2.4	13.7	1.2
The Bahamas	—	—	—	—	—	—	—	—	—
Bangladesh	—	—	—	—	—	—	—	—	—
Belgium	97,883	15.7	17.3	5.5	6.4	38.3	7.8	6.9	2.2
Bolivia	—	—	—	—	—	—	—	—	—
Botswana	3,440	70.5	0.0	0.0	0.0	21.1	2.9	5.6	0.0
Bulgaria	100,634	17.6	7.1	4.3	3.6	28.7	4.2	31.4	3.0
Cambodia	—	—	—	—	—	—	—	—	—
Canada	—	—	—	—	—	—	—	—	—
Chile	95,243	36.0	13.4	3.5	7.0	17.8	6.2	9.3	6.8
Colombia	86,992	21.3	17.3	5.3	2.3	19.9	8.9	24.1	0.9
Croatia	41,209	17.9	9.5	5.9	3.3	35.1	7.2	16.2	4.8
Cyprus	8,000	37.4	9.2	9.4	0.3	21.1	9.2	6.0	7.4
Czech Republic	148,863	10.6	10.0	6.3	5.2	52.1	4.5	7.4	3.9
Denmark	60,522	16.2	12.4	4.4	1.4	48.1	11.3	2.2	4.0
Dominican Republic	—	—	—	—	—	—	—	—	—
Ecuador	44,748	46.4	12.8	4.4	1.8	12.3	7.8	12.3	2.2
Egypt	—	—	—	—	—	—	—	—	—
Eritrea	2,871	31.8	8.6	14.8	0.3	16.4	4.1	24.1	0.0
Estonia	16,458	15.8	7.8	4.7	0.3	36.4	7.3	10.9	16.9
Ethiopia	24,137	29.7	10.7	8.3	1.6	12.8	6.9	28.6	1.4
Fiji	—	—	—	—	—	—	—	—	—
Finland	61,566	8.8	8.6	4.1	4.8	48.7	15.6	2.8	6.7
France	578,173	16.2	15.0	3.8	3.3	46.9	7.4	5.1	2.3
Germany	954,219	11.8	12.0	3.4	3.8	57.4	7.2	2.5	2.0
Ghana	—	—	—	—	—	—	—	—	—
Greece	—	—	—	—	—	—	—	—	—
Haiti	—	—	—	—	—	—	—	—	—
Hungary	115,075	15.8	10.5	3.8	2.7	46.9	6.4	10.5	3.4
Indonesia	764,028	21.5	13.0	3.9	1.3	19.8	4.0	29.0	7.4
Iran	160,776	16.1	12.8	13.8	7.1	35.5	2.8	11.2	0.7
Iraq	—	—	—	—	—		—	—	
Ireland	34,146	21.6	17.2	5.8	1.3	38.6	10.1	1.9	3.5
Israel	—	—	—	—	—	—	—	—	—
Italy	475,760	9.0	10.5	5.5	3.5	49.2	5.2	14.2	2.9
Japan	1,122,694	15.1	11.2	3.6	3.2	52.6	7.1	5.3	2.0
Jordan	27,112	21.9	15.0	11.3	2.7	23.9	6.4	16.1	2.7
Kazakhstan	—	—	—	—	—	—	—	—	—
Korea, Republic of	316,969	6.5	12.3	3.1	4.3	57.2	5.5	10.2	0.9
Kyrgyz Republic	11,513	23.5	8.3	15.2	7.1	25.8	6.2	12.2	1.8

continues

Data Table 12 *continued*

Country	Total BOD emissions in kg per day	% of total BOD emissions by industry type: Food	Chemical	Clay and glass	Metal	Other	Paper and pulp	Textile	Wood
Lao P.D.R.	—	—	—	—	—	—	—	—	—
Latvia	29,931	21.7	5.2	3.6	2.4	26.1	7.3	13.5	20.2
Lebanon	—	—	—	—	—	—	—	—	—
Lesotho	13,208	3.5	1.4	0.5	1.0	2.4	0.5	90.7	
Lithuania	42,872	20.3	7.1	4.2	0.8	30.3	4.9	21.3	11.1
Luxembourg	3,830	24.4	37.0	4.4	1.0	18.3	14.2	0.6	0.0
Madagascar	88,887	7.6	12.4	2.8	0.3	10.0	1.6	58.9	6.3
Malawi	—	—	—	—		—	—	—	—
Malaysia	208,441	9.5	16.2	3.9	2.9	47.5	5.2	6.8	7.9
Malta	4,232	18.3	10.2	4.5	0.3	46.0	8.9	11.2	0.5
Mauritius	351	0.0	0.0		0.0	86.3	13.7	0.0	0.0
Mexico	—	—	—	—	—	—	—	—	—
Moldova	22,390	95.6	0.0	0.0	0.0	1.0	3.4	0.0	
Morocco	72,779	16.0	9.3	7.1	0.9	16.3	3.0	45.5	1.9
Nepal	—	—	—	—	—	—	—	—	—
Netherlands	122,052	18.4	14.8	4.1	1.2	42.5	13.8	2.6	2.5
New Zealand	64,193	30.1	8.3	3.2	2.4	28.5	13.3	6.5	7.8
Norway	—	—	—	—	—	—	—	—	—
Oman	6,498	22.1	16.1	23.4	3.9	19.8	6.2	6.2	2.2
Panama	13,719	55.7	7.0	4.0	0.9	14.2	11.7	4.8	1.7
Paraguay	—	—	—	—	—	—	—	—	—
Philippines	97,900	33.1	13.2	6.2	5.8	32.4	6.3	3.1	0.0
Poland	364,549	18.8	11.1	5.4	3.1	40.6	5.2	11.0	4.8
Portugal	105,041	15.1	6.6	5.0	1.7	38.5	7.2	19.1	6.8
Qatar	3,328	9.1	18.8	29.4	5.5	13.6	1.3	2.3	20.0
Romania	235,124	12.7	6.7	4.0	4.8	34.4	3.2	28.9	5.2
Russian Fed.	1,425,913	17.5	11.7	7.9	9.8	37.3	4.8	6.8	4.3
Rwanda	—	—	—	—		—		—	—
Saudi Arabia	—	—	—	—	—	—	—	—	—
Senegal	—	—	—	—	—	—	—	—	—
Singapore	34,458	5.2	12.0	1.4	0.0	72.3	6.0	2.6	0.5
Slovak Republic	51,428	10.7	8.8	5.9	7.6	46.8	4.8	11.5	3.9
Slovenia	28,767	8.9	11.4	3.9	4.1	48.1	6.5	12.1	4.9
South Africa	191,929	15.5	11.2	5.3	5.9	38.8	6.5	12.6	4.3
Spain	379,728	15.2	10.8	7.9	3.1	42.4	7.9	9.0	3.7
Sri Lanka	—	—	—	—	—	—	—	—	—
Sudan	—	—	—	—	—	—	—	—	—
Sweden	97,622	8.7	9.9	2.5	5.4	54.4	12.2	1.4	5.4
Syrian Arab Republic	—	—	—	—	—	—	—	—	—
Tajikistan	—	—	—	—	—	—	—	—	—
Thailand	—	—	—	—	—	—	—	—	—
Tonga	—	—	—	—	—	—	—	—	—
Trinidad and Tobago	—	—	—	—	—	—	—	—	—
Turkey	—	—	—	—	—	—	—	—	-
Uganda	—	—	—	—		—	—	—	-
Ukraine	527,203	19.0	10.3	6.4	14.6	36.8	4.1	6.6	2.2

		% of total BOD emissions by industry type							
Country	**Total BOD emissions in kg per day**	**Food**	**Chemical**	**Clay and glass**	**Metal**	**Other**	**Paper and pulp**	**Textile**	**Wood**
United Kingdom	521,716	14.9	13.5	3.6	2.7	46.1	12.5	4.3	2.5
United States	1,889,365	12.0	13.1	3.7	3.4	50.6	8.3	4.7	4.1
Vietnam	470,233	14.3	6.6	7.1	1.4	22.9	3.7	40.3	3.7
Yemen	1,282	30.4	0.0	0.0		0.0	69.6	0.0	0.0
Zimbabwe	—	—	—	—	—	—	—	—	—

Source: World Bank and UNIDO's Industry Database. http://data.worldbank.org/indicator

From: 1998 study by H. Hettige, M. Mani, and D. Wheeler, Industrial Pollution in Economic Development: Kuznets Revisited (available at www.worldbank.org/nipr). The data were updated through 2005 by the World Bank's Development Research Group.

Catalog Source: World Development Indicators.

DATA TABLE 13

Top Environmental Concerns of the American Public: Selected Years, 1997-2010 (% Who Worry "A Great Deal")

Description

This table presents a time series of the top environmental concerns of the American people as determined from consistent long-term polling. The data are expressed as the percentage of respondents who worried about a particular environmental problem "a great deal." For over a decade, the Gallup polling organization has evaluated the perceptions, beliefs, and policy priorities of different public audiences on a wide range of issues. One of these is the environmental concerns of the average American. A series of consistent survey questions has been asked almost every year to elicit the environmental problems that Americans find most worrisome.

According to Gallup, the survey questions were presented as follows: "I'm going to read you a list of environmental problems. As I read each one, please tell me if you personally worry about this problem a great deal, a fair amount, only a little, or not at all. First, how much do you personally worry about—[RANDOM ORDER]?" The list of environmental problems read has changed somewhat over time, varying between 12 and 8 environmental problems. The full list of environmental problems includes the following:

Pollution of drinking water

Pollution of rivers, lakes, and reservoirs

Contamination of soil and water by toxic waste

Maintenance of nation's supply of freshwater for household needs

Loss of natural habitat for wildlife

Air pollution

Damage to Earth's ozone layer

Loss of tropical rain forests

Extinction of plant and animal species

Urban sprawl and loss of open space

Greenhouse effect or global warming

Acid rain

In 2009 and 2010, loss of natural habitat for wildlife, damage to the Earth's ozone layer, urban sprawl and loss of open space, and acid rain were excluded from the list of environmental problems read.

Consistently, the most serious concerns have been expressed about water-related problems, including pollution of drinking water; pollution of rivers, lakes, and reservoirs; and maintenance of the nation's supply of freshwater for household needs. Around half of all respondents worry "a great deal" about each of these three problems. In 2010, Americans were less worried than they were in 2009 about each of the eight environmental concerns in the poll, and for all environmental concerns but global warming and maintenance of the nation's freshwater, levels of worry were the lowest ever measured by Gallup.

Limitations

All polls have limitations. According to Gallup, the results of these polls are typically based on telephone interviews with a sample of around 1,000 national adults, age 18 and older. This sampling approach produces results with a 95 percent confidence level and a margin of sampling error of ±3 percentage points. They also note that in addition to sampling error, "question wording and practical difficulties in conducting surveys can introduce error or bias into the findings of public opinion polls."

SOURCES

Gallup News. Environment page. http://www.gallup.com/tag/Environment.aspx

Jones, J. 2010. In U.S., many environmental issues at 20-year-low concern: Worry about all eight measures tested is down from last year. *Gallup News*, March 16, 2010. http://www.gallup.com/poll/126716/Environmental-Issues-Year-Low-Concern.aspx

Saad, L. Global warming on public's back burner. *Gallup News*, April 20, 2004. http://www.gallup.com/poll/11398/Global-Warming-Publics-Back-Burner.aspx

Data Table 13 Top Environmental Concerns of the American Public: Selected Years, 1997–2010

	(% who worry "a great deal")											
Issue	**1997**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2006**	**2007**	**2008**	**2009**	**2010**
Pollution of drinking water	NA	68	72	64	57	54	53	54	58	53	59	50
Pollution of rivers, lakes, and reservoirs	NA	61	66	58	53	51	48	52	53	50	52	46
Contamination of soil and water by toxic waste	NA	63	64	58	53	51	48	51	52	50	52	44
Maintenance of nation's supply of freshwater for household needs	NA	NA	42	35	50	49	47	49	51	48	49	45
Loss of natural habitat for wildlife										44		
Air pollution	42	52	59	48	45	42	39	44	46	43	45	38
Damage to Earth's ozone layer	33	44	49	47	38	35	33	40	43	39		
Loss of tropical rain forests	NA	49	51	44	38	39	35	40	43	40	42	33
Extinction of plant and animal species	NA	NA	45	43	35	34	36	34	39	37	37	31
Urban sprawl and loss of open space										33		
Greenhouse effect or global warming	24	34	40	33	29	28	26	36	41	37	33	28
Acid rain	NA	29	34	28	25	24	20	24	25	23		

Top Environmental Concerns Around the World; Concern for Water Issues (% "Very Concerned") for Seven Major Countries

Description

In 2009, GlobeScan conducted a comprehensive global public opinion survey (commissioned by Circle of Blue) on viewpoints about a number of environmental concerns. Table 14a presents the results of that survey, ranking environmental concerns in each of fifteen countries based on responses to the question, "How serious a problem do you consider each of the following issues to be?" The poll found water issues to be a top environmental concern in many countries; freshwater pollution or freshwater supply was the top environmental concern in all but 3 of 15 countries in which the poll was conducted. Table 14b shows the quantitative survey results for seven major countries as a percent of people "very concerned" about a set of water issues. The water issues are "water pollution," "lack of safe drinking water," "lack of water for agriculture," and the "high cost of water." Water quality and lack of safe drinking water consistently scores high as a concern; water prices is less of a concern, especially in wealthier countries, where typical consumers pay a small percentage of their income for water and water services.

The poll surveyed 1,000 people in each of 15 countries. In about half of the countries (Brazil, Canada, China, France, Mexico, United Kingdom, and United States), the surveys were conducted over the telephone. In the remaining countries (Chile, India, Kenya, Nigeria, Philippines, Russia, and Turkey), surveys were conducted face to face.

The list of environmental concerns that respondents to the survey were asked about includes the following:

Water pollution

Depletion of natural resources

Freshwater shortage

Air pollution

Climate change

Loss of animal/plant species

Auto emissions

Limitations

GlobeScan notes: "Samples reflect the distribution of age, gender, level of education and socioeconomic status, according to the latest census information for the areas sampled. To ensure complete representation of general population opinion, sample deviations from population statistics are weighted back to census data." Still, as noted above, all surveys have limitations, including sampling errors and errors or bias introduced by such factors as the wording of the question.

SOURCES

Circle of Blue and GlobeScan. 2009. Water Views. http://www.circleofblue.org/waternews/2009/world/waterviews-water-tops-climate-change-as-global-priority/

Data Table 14a Top Environmental Concerns Around the World

Country	#1 Concern	#2 Concern	#3 Concern	#4 Concern	#5 Concern	#6 Concern	#7 Concern
Brazil	Water pollution	Air pollution	Depletion of natural resources; freshwater shortage	Auto emissions	Climate change	Loss of animal/ plant species	
Canada	Water pollution	Depletion of natural resources	Freshwater shortage	Air pollution	Climate change	Loss of animal/ plant species	Auto emissions
Chile	Freshwater shortage	Depletion of natural resources	Air pollution; loss of animal/plant species; water pollution	Climate change	Auto emissions		
China	Water pollution	Auto emissions	Freshwater shortage	Climate change; Depletion of natural resources	Air pollution; Loss of animal/ plant species		
France	Water pollution	Freshwater shortage	Depletion of natural resources	Air pollution	Loss of animal/ plant species	Climate change	Auto emissions
Germany	Depletion of natural resources	Water pollution	Climate change	Freshwater storage	Loss of animal/ plant species	Air pollution	Auto emissions
India	Freshwater shortage	Water pollution	Air pollution	Loss of animal/ plant species	Depletion of natural resources	Auto emissions	Climate change
Kenya	Freshwater shortage	Air pollution	Water pollution	Depletion of natural resources	Climate change	Loss of animal/ plant species	Auto emissions
Mexico	Freshwater shortage	Water pollution	Depletion of natural resources	Air pollution	Climate Change	Auto emissions	
Nigeria	Water pollution	Air pollution	Fresh water shortage	Depletion of natural resources	Loss of animal/ plant species	Climate change	Auto emissions
Philippines	Auto emissions	Depletion of natural resources	Air pollution	Climate change	Water pollution	Loss of animal/ plant species	Freshwater shortage
Russia	Water pollution	Depletion of natural resources	Air pollution	Freshwater shortage	Loss of animal/ plant species	Auto emissions	Climate change
Turkey	Freshwater shortage	Climate change	Depletion of natural resources	Water pollution	Air pollution	Loss of animal/ plant species	Auto emissions
United Kingdom	Depletion of natural resources	Fresh water shortage	Loss of animal/ plant species	Climate change	Water pollution	Air pollution	Auto emissions
United States	Freshwater shortage	Water pollution	Depletion of natural resources	Loss of animal/ plant species	Air pollution	Climate Change	Auto emissions

Source: http://www.circleofblue.org/waternews/waterviews/global-waterviews-on-qlikview/

Data Table 14b Concern for Water Issues (% "Very Concerned") for Seven Major Countries

	Water pollution	Lack of safe drinking water	Lack of water for agriculture	High cost of water
Canada	67	65	53	36
China	63	59	44	43
India	68	67	64	60
Mexico	71	84	75	34
Russia	57	42	30	41
United Kingdom	53	61	47	42
United States	57	56	47	35

Source: http://www.circleofblue.org/waternews/wp-content/uploads/2009/08/circle_of_blue_globescan.pdf

DATA TABLE 15

Satisfaction With Local Water Quality, by Country, 2006-2007

Description

This table presents the results of an international Gallup poll on the respondents' satisfaction with water quality in their community, conducted in 2006 and 2007. The data are expressed as the percent of respondents that answered "satisfied" to the question, "In the city or area that you live, are you satisfied or dissatisfied with the quality of water?" The survey was conducted through telephone and face-to-face interviews with randomly selected samples of typically 1,000 residents, age 15 and older.

The survey found that in most countries a majority of people are satisfied with their water; in 29 countries, however, more than half of the population is dissatisfied with their water quality. In sub-Saharan Africa, more than half of the respondents indicated that they were dissatisfied with their water in 18 of 31 countries in which the survey was conducted.

Limitations

All polls have limitations, including sampling errors and biases introduced through question wording and in conducting the survey. According to Gallup: "For results based on samples of this size, one can say with 95% confidence that the maximum error attributable to sampling and other random effects is ±3 percentage points. The margin of error in countries in sub-Saharan Africa is ±5."

SOURCE

Ray, J. Water quality an issue around the world: Satisfaction lowest in Sub-Saharan Africa. *Gallup News*, March 19, 2008. http://www.gallup.com/poll/105211/Water-Quality-Issue-Around-World.aspx

Data Table 15 Satisfaction With Local Water Quality, by Country, 2006–2007

	% Satisfied		% Satisfied
Sub-Saharan Africa		Kyrgyzstan	63
Chad	21	Vietnam	63
Niver	29	Taiwan	64
Ethiopia	29	Armenia	68
Liberia	30	India	68
Tanzania	35	Saudi Arabia	69
Sierra Leone	36	Uzbekistan	71
Angola	38	Hong Kong	72
Central African Republic	40	Mongolia	73
Togo	41	Malaysia	74
Congo	42	South Korea	74
Mali	44	China	75
Zambia	44	Indonesia	75
Burkina Faso	45	Japan	75
Mauritania	46	Laos	75
Kenya	47	Nepal	79
Madagastcar	48	Philippines	79
Benin	48	United Arab Emirates	79
Cameroon	49	Bangladesh	83
Uganda	54	Thailand	83
Rwanda	55	Australia	85
Sudan	57	Sri Lanka	87
Senegal	59	New Zealand	90
Burundi	60	Myanmar	91
Mozambiquw	62	**Latin America and the Caribbean**	
Zimbabwe	62	Haiti	44
Ghana	63	Guyana	54
Niger	66	Dominican Republic	55
Botswana	78	Puerto Rico	58
Makawi	79	Cuba	59
South Africa	81	Belize	63
Namibia	82	Nicaragua	65
Asia		Peru	65
Lebanon	35	Argentina	66
Cambodia	43	Honduras	69
Yemen	43	El Salvador	70
Jordan	47	Mexico	70
Kazakhstan	49	Ecuador	71
Palestinian territories	49	Guatemala	72
Kuwait	53	Trinidad and Tobago	72
Israel	54	Colombia	77
Afganistan	55	Brazil	79
Azerbaijan	58	Bolivia	80
Pakistan	58	Chile	82
Tajikistan	58	Panama	83
Cyprus	60	Venezuela	83
Georgia	60	Costa Rica	87
Iran	61	Paraguay	87
Turkey	62		

	% Satisfied		% Satisfied
Latin America and the Caribbean *continued*			
Jamaica	89	**Commonwealth of Independent States**	
Uruguay	91	Ukraine	26
Central, Southern, and Southeast Europe		Russia	30
Albania	46	Kazakhstan	49
Serbia	46	Moldova	51
Bulgaria	57	Belarus	57
Montenegro	61	Azerbaijan	58
Kosovo	61	Tajikistan	58
Macedonia	63	Georgia	60
Romania	68	Kyrgyzstan	63
Bosnia	69	Armenia	68
Western Europe, the United States, Canada, and Northern Europe		Uzbekistan	71
		Middle East/North Africa	
Belgium	81	Lebanon	35
France	81	Yemen	43
Ireland	87	Jordan	47
United States	87	Palestinian territories	49
Canada	87	Algeria	53
United Kingdom	91	Kuwait	53
Netherlands	92	Israel	54
Estonia	61	Egypt	55
Finland	93	Iran	61
Denmark	94	Turkey	62
Norway	94	Tunisia	67
Sweden	94	Saudi Arabia	70
		Morocco	76
		United Arab Emirates	79

*Note: Some countries are listed in more than one region.

DATA TABLE 16

Extinct (or Extinct in the Wild) Freshwater Animal Species

Description

This table presents a list of freshwater animal species that are extinct or extinct in the wild, as compiled by the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. A wide range of human activities, from water pollution to alterations of hydrologic regimes, have contributed to the endangerment and extinction of aquatic species. In 1994, the IUCN introduced a “scientifically rigorous approach” to listing the conservation status (e.g., threatened, endangered, extinct, extinct in the wild) of species. Assessments are normally conducted by specialty groups within the IUCN. The Freshwater Unit has conducted several comprehensive regional assessments and plans in future work to apply the complete a comprehensive assessment worldwide (IUCN 2011).

Limitations

It is important to note that the conservation status of only a small fraction of the world’s freshwater species has been assessed. Therefore, this list should be understood to be a list of *known* extinct or extinct in the wild species. With ongoing assessments, many more species are likely to be found to be extinct. And although it is extremely unusual, on rare occasions remnant populations of species thought to be extinct are rediscovered.

SOURCES

International Union for Conservation of Nature (IUCN). 2010. IUCN Red List of Threatened Species Database. http://www.iucnredlist.org/

International Union for Conservation of Nature (IUCN). 2011. About the Freshwater Biodiversity Unit. http://cms.iucn.org/about/work/programmes/species/our_work/about_freshwater/what_we_do_freshwater/

Data Table 16 Extinct (or Extinct in the Wild) Freshwater Animal Species

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
ARTHROPODA	CRUSTACEA	AMPHIPODA	CRANGONYCTIDAE	Stygobromus	lucifugus	Rubious Cave Amphipod	EX	1996
ARTHROPODA	CRUSTACEA	AMPHIPODA	PARAMELITIDAE	Austrogammarus	australis		EX	1996
ARTHROPODA	CRUSTACEA	CALANOIDA	DIAPTOMIDAE	Tropodiaptomus	ctenopus		EX	1996
ARTHROPODA	CRUSTACEA	CYCLOPOIDA	CYCLOPIDAE	Afrocyclops	pauliani		EX	1996
ARTHROPODA	CRUSTACEA	DECAPODA	ASTACIDAE	Pacifastacus	nigrescens	Sooty Crayfish	EX	2010
ARTHROPODA	CRUSTACEA	DECAPODA	ATYIDAE	Syncaris	pasadenae	Pasadena Freshwater Shrimp, Pasadena Shrimp	EX	1996
ARTHROPODA	CRUSTACEA	DECAPODA	CAMBARIDAE	Cambarellus	alvarezi		EX	2010
ARTHROPODA	CRUSTACEA	DECAPODA	CAMBARIDAE	Cambarellus	chihuahuae		EX	2010
ARTHROPODA	CRUSTACEA	DECAPODA	CAMBARIDAE	Procambarus	angustatus	Sandhills Crayfish	EX	2010
ARTHROPODA	CRUSTACEA	ISOPODA	SPHAEROMATIDAE	Thermosphaeroma	thermophilum	Socorro Isopod	EW	1996
ARTHROPODA	CRUSTACEA	PODOCOPIDA	CANDONIDAE	Namibcypris	costata		EX	1996
ARTHROPODA	CRUSTACEA	PODOCOPIDA	CYPRIDIDAE	Liocypris	grandis		EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Hygrotus	artus	Mono Lake Diving Beetle	EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Megadytes	ducalis		EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Rhantus	novacaledoniae		EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Rhantus	orbignyi		EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Rhantus	papuanus		EX	1996
ARTHROPODA	INSECTA	COLEOPTERA	DYTISCIDAE	Siettitia	balsetensis	Perrin's Cave Beetle	EX	1996
ARTHROPODA	INSECTA	EPHEMEROPTERA	EPHEMERIDAE	Pentagenia	robusta	Robust Burrowing Mayfly, Robust Pentagenian Burrowing Mayfly	EX	1996
ARTHROPODA	INSECTA	EPHEMEROPTERA	SIPHLONURIDAE	Acanthometropus	pecatonica	Pecatonica River Mayfly	EX	1996
ARTHROPODA	INSECTA	ODONATA	COENAGRIONIDAE	Megalagrion	jugorum	Maui Upland Damselfly	EX	1996
ARTHROPODA	INSECTA	ODONATA	LIBELLULIDAE	Sympetrum	dilatatum	St. Helena Darter	EX	1996
ARTHROPODA	INSECTA	PLECOPTERA	CHLOROPERLIDAE	Alloperla	roberti	Robert's Stonefly	EX	1996
ARTHROPODA	INSECTA	TRICHOPTERA	HYDROPSYCHIDAE	Hydropsyche	tobiasi	Tobias' Caddisfly	EX	1996
ARTHROPODA	INSECTA	TRICHOPTERA	LEPTOCERIDAE	Triaenodes	phalacris	Athens Caddisfly	EX	1996

continues

Data Table 16 *continued*

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
ARTHROPODA	INSECTA	TRICHOPTERA	LEPTOCERIDAE	Triaenodes	phalacris	Athens Caddisfly	EX	1996
ARTHROPODA	INSECTA	TRICHOPTERA	LEPTOCERIDAE	Triaenodes	tridonata	Three-tooth Caddisfly	EX	1996
ARTHROPODA	INSECTA	TRICHOPTERA	RHYACOPHILIDAE	Rhyacophila	amabilis	Castle Lake Caddisfly	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CATOSTOMIDAE	Chasmistes	muriei	Snake River Sucker	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CATOSTOMIDAE	Moxostoma	lacerum	Harelip Sucker	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Acanthobrama	hulensis		EX	2006
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Acanthobrama	telavivensis		EW	2006
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Alburnus	akili	Gokce Baligi	EX	2006
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Barbus	microbarbis		EX	2006
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Chondrostoma	scodrense		EX	2006
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Cyprinus	yilongensis		EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Epalzeorhynchos	bicolor	Redtailed Black Shark, Red-tailed Labeo, Red Tailed Shark, Redtail Shark, Redtail Sharkminnow	EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Evarra	bustamantei	Mexican Dace	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Evarra	eigenmanni	Mexican Dace	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Evarra	tlahuacensis	Mexican Dace	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Gila	crassicauda	Thicktail Chub	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Lepidomeda	altivelis	Pahranagat Spinedace	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Notropis	amecae	Ameca Shiner	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Notropis	aulidion	Durango Shiner	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Notropis	orca	Phantom Shiner	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Notropis	saladonis	Sardinita De Salado	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Pogonichthys	ciscoides	Clear Lake Splittail	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Rhinichthys	deaconi	Las Vegas Dace	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Romanogobio	antipai	Danube Delta Gudgeon	EX	2008
CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Stypodon	signifer	Stumptooth Minnow	EX	1996

CHORDATA	ACTINOPTERYGII	CYPRINIFORMES	CYPRINIDAE	Telestes	ukliva		EX	2006
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	alvarezi		EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	ceciliae		EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	inmemoriam	Cachorrito De La Trinidad	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	latifasciatus	Perrito De Parras	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	longidorsalis	Cachorrito De Charco Palmal	EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Cyprinodon	spp.	Perritos De Sandia	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Empetrichthys	merriami	Ash Meadows Killifish	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	CYPRINODONTIDAE	Megupsilon	aporus	Cachorrito Enano De Potosi	EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	FUNDULIDAE	Fundulus	albolineatus	Whiteline Topminnow	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	GOODEIDAE	Ameca	splendens	Goodeid	EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	GOODEIDAE	Characodon	garmani	Parras Characodon	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	GOODEIDAE	Skiffia	francesae	Tiro	EW	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	POECILIIDAE	Aplocheilichthys	sp. nov. ‘Naivasha’		EX	2004
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	POECILIIDAE	Gambusia	amistadensis	Amistad Gambusia	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	POECILIIDAE	Gambusia	georgei	San Marcos Gambusia	EX	1996
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	POECILIIDAE	Pantanodon	madagascariensis		EX	2004
CHORDATA	ACTINOPTERYGII	CYPRINODONTIFORMES	POECILIIDAE	Priapella	bonita	Guayacon Ojiazul	EX	1996
CHORDATA	ACTINOPTERYGII	GASTEROSTEIFORMES	GASTEROSTEIDAE	Gasterosteus	crenobiontus	Techirghiol Stickleback	EX	2008
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Ctenochromis	pectoralis		EX	1996
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Ptychochromis	sp. nov. ‘Kotro’		EX	2004
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Ptychochromoides	itasy		EX	2004
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Tristramella	intermedia		EX	2006
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Tristramella	magdelainae		EX	2006
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Xystichromis	bayoni		EX	1996
CHORDATA	ACTINOPTERYGII	PERCIFORMES	CICHLIDAE	Yssichromis	sp. nov. ‘argens’		EW	1996
CHORDATA	ACTINOPTERYGII	PERCIFORMES	PERCIDAE	Etheostoma	sellare	Maryland Darter	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	RETROPINNIDAE	Prototroctes	oxyrhynchus	New Zealand Grayling	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	alpenae	Longjaw Cisco	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	bezola	Bezoule	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	fera	Féra	EX	2008

continues

Data Table 16 *continued*

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	gutturosus	Bodensee Kilch	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	hiemalis	Gravenche	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	johannae	Deepwater Cisco	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	nigripinnis	Blackfin Cisco	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	oxyrinchus	Houting	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Coregonus	restrictus	Férit, Kröpfer	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Salmo	pallaryi		EX	2006
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Salvelinus	agassizi	Silver Trout	EX	1996
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Salvelinus	neocomensis		EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Salvelinus	profundus	Tiefseesaibling	EX	2008
CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE	Stenodus	leucichthys	Beloribitsa	EW	2008
CHORDATA	ACTINOPTERYGII	SCORPAENIFORMES	COTTIDAE	Cottus	echinatus	Utah Lake Sculpin	EX	1996
CHORDATA	ACTINOPTERYGII	SILURIFORMES	TRICHOMYCTERIDAE	Rhizosomichthys	totae		EX	1996
CHORDATA	AMPHIBIA	ANURA	ALYTIDAE	Discoglossus	nigriventer	Hula Painted Frog	EX	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Adenomus	kandianus		EX	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Anaxyrus	baxteri	Wyoming Toad	EW	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Atelopus	ignescens		EX	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Atelopus	longirostris		EX	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Atelopus	vogli		EX	2004
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Incilius	holdridgei	Holdridge's Toad	EX	2008
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Incilius	periglenes	Golden Toad	EX	2008
CHORDATA	AMPHIBIA	ANURA	BUFONIDAE	Nectophrynoides	asperginis	Kihansi Spray Toad	EW	2009
CHORDATA	AMPHIBIA	ANURA	CRAUGASTORIDAE	Craugastor	chrysozetetes		EX	2004
CHORDATA	AMPHIBIA	ANURA	CRAUGASTORIDAE	Craugastor	escoces		EX	2008
CHORDATA	AMPHIBIA	ANURA	DICROGLOSSIDAE	Nannophrys	guentheri		EX	2004
CHORDATA	AMPHIBIA	ANURA	HYLIDAE	Phrynomedusa	fimbriata		EX	2004
CHORDATA	AMPHIBIA	ANURA	MYOBATRACHIDAE	Rheobatrachus	silus	Southern Gastric Brooding Frog, Southern Platypus Frog	EX	2004

CHORDATA	AMPHIBIA	ANURA	MYOBATRACHIDAE	Rheobatrachus	vitellinus	Eungella Gastric-brooding Frog, Northern Gastric Brooding Frog	EX	2004
CHORDATA	AMPHIBIA	ANURA	MYOBATRACHIDAE	Taudactylus	diurnus	Mount Glorious Day Frog, Mount Glorious Torrent Frog, Southern Day Frog	EX	2004
CHORDATA	AMPHIBIA	ANURA	RANIDAE	Lithobates	fisheri	Las Vegas Leopard Frog	EX	2004
CHORDATA	AMPHIBIA	CAUDATA	PLETHODONTIDAE	Plethodon	ainsworthi	Ainsworth's Salamander	EX	2004
CHORDATA	AMPHIBIA	CAUDATA	SALAMANDRIDAE	Cynops	wolterstorffi	Yunnan Lake Newt	EX	2004
CHORDATA	AVES	Anseriformes	Anatidae	Alopochen	kervazoi	Reunion Shelduck, Réunion Shelduck	EX	2008
CHORDATA	AVES	Anseriformes	Anatidae	Alopochen	mauritianus	Mauritius Shelduck, Mauritian Shelduck	EX	2008
CHORDATA	AVES	Anseriformes	Anatidae	Anas	marecula	Amsterdam Duck, Amsterdam Island Duck	EX	2008
CHORDATA	AVES	Anseriformes	Anatidae	Anas	theodori	Mauritius Duck, Mauritian Duck	EX	2008
CHORDATA	AVES	Anseriformes	Anatidae	Mergus	australis	Auckland Islands Merganser, Auckland Island Merganser	EX	2008
CHORDATA	AVES	Ciconiiformes	Ardeidae	Ixobrychus	novaezelandiae	Black-backed Bittern, New Zealand Bittern, New Zealand Little Bittern	EX	2008
CHORDATA	AVES	Ciconiiformes	Ardeidae	Nycticorax	duboisi	Reunion Night-heron, Réunion Night-heron	EX	2008
CHORDATA	AVES	Ciconiiformes	Ardeidae	Nycticorax	mauritianus	Mauritius Night-heron	EX	2008
CHORDATA	AVES	Ciconiiformes	Ardeidae	Nycticorax	megacephalus	Rodrigues Night-heron	EX	2008
CHORDATA	AVES	Gruiformes	Rallidae	Fulica	newtoni	Mascarene Coot	EX	2008
CHORDATA	AVES	Gruiformes	Rallidae	Porphyrio	coerulescens	Reunion Gallinule, Réunion Gallinule	EX	2008
CHORDATA	AVES	Gruiformes	Rallidae	Porphyrio	kukwiedei	New Caledonia Gallinule	EX	2008
CHORDATA	AVES	Gruiformes	Rallidae	Porzana	monasa	Kosrae Crake	EX	2008
CHORDATA	AVES	Podicipediformes	Podicipedidae	Podiceps	andinus	Colombian Grebe	EX	2008

continues

Data Table 16 *continued*

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
CHORDATA	AVES	Podicipediformes	Podicipedidae	Podilymbus	gigas	Atitlan Grebe, Atitlán Grebe, Giant Grebe, Giant Pied-billed Grebe	EX	2008
CHORDATA	CEPHALASPIDOMORPHI	PETROMYZONTIFORMES	PETROMYZONTIDAE	Eudontomyzon	sp. nov. 'migratory'	Ukrainian Migratory Lamprey	EX	2008
CHORDATA	MAMMALIA	CETARTIODACTYLA	CERVIDAE	Elaphurus	davidianus	Père David's Deer, Pere David's Deer	EW	2008
CHORDATA	MAMMALIA	CETARTIODACTYLA	CERVIDAE	Rucervus	schomburgki	Schomburgk's Deer	EX	2008
CHORDATA	MAMMALIA	CETARTIODACTYLA	HIPPOPOTAMIDAE	Hippopotamus	lemerlei	Madagascan Dwarf Hippopotamus, Malagasy Hippo	EX	2008
CHORDATA	MAMMALIA	CETARTIODACTYLA	HIPPOPOTAMIDAE	Hippopotamus	madagascariensis	Madagascan Dwarf Hippopotamus, Madagascan Pygmy Hippo, Malagasy Hippo	EX	2008
CHORDATA	REPTILIA	TESTUDINES	PELOMEDUSIDAE	Pelusios	seychellensis	Seychelles Black Terrapin, Seychelles Mud Turtle, Seychelles Terrapin	EX	2003
CHORDATA	REPTILIA	TESTUDINES	TRIONYCHIDAE	Nilssonia	nigricans	Black Soft-shell Turtle, Black Softshell Turtle	EW	2002
MOLLUSCA	BIVALVIA	UNIONOIDA	IRIDINIDAE	Chambardia	letourneuxi		EX	2007
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Alasmidonta	mccordi	Coosa Elktoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Alasmidonta	robusta	Carolina Elktoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Alasmidonta	wrightiana	Ochlockonee Arcmussel	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Elliptio	nigella	Recovery Pearly Mussel, Winged Spike	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	arcaeformis	Arc-form Pearly Mussel, Sugarspoon	EX	2000

MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	biemarginata	Angled Riffleshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	flexuosa	Arcuate Pearly Mussel, Leafshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	haysiana	Acorn Pearly Mussel, Acornshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	lenior	Narrow Catspaw, Stone's Pearly Mussel	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	lewisii	Forkshell, Lewis Pearly Mussel	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	personata	Fine-rayed Pearlymussel, Fine-rayed Pearly Mussel, Round Combshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	propinqua	Nearby Pearlymussel, Nearby Pearly Mussel, Tennessee Riffleshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	sampsonii	Sampson's Naiad, Sampson's Pearly Mussel, Sampson's Riffleshell, Wabash Riffleshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	stewardsonii	Cumberland Leafshell, Steward's Pearly Mussel	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Epioblasma	turgidula	Turgid-blossom, Turgid-blossom Naiad, Turgid-blossom Pearly Mussel, Turgid Riffle Shell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Lampsilis	binominata	Lined Pocketbook	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Medionidus	mcglameriae	Tombigbee Moccasinshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	altum	Highnut	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	avellanum	Hazel Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	bournianum	Scioto Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	flavidulum	Yellow Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	hagleri	Brown Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	hanleyianum	Georgia Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	johannis	Alabama Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	murrayense	Coosa Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	nucleopsis	Longnut	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	rubellum	Warrior Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	taitianum	Heavy Pigtoe, Judge Tait's Mussel	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	troschelianum	Alabama Clubshell	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Pleurobema	verum	True Pigtoe	EX	2000
MOLLUSCA	BIVALVIA	UNIONOIDA	UNIONIDAE	Unio	cariei		EX	1996

continues

Data Table 16 *continued*

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
MOLLUSCA	GASTROPODA	ARCHITAENIOGLOSSA	CYCLOPHORIDAE	Cyclophorus	horridulum		EX	1996
MOLLUSCA	GASTROPODA	ARCHITAENIOGLOSSA	CYCLOPHORIDAE	Cyclosurus	mariei		EX	1996
MOLLUSCA	GASTROPODA	HYGROPHILA	PHYSIDAE	Physella	microstriata	Fish Lake Physa	EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Amphigyra	alabamensis	Shoal Sprite	EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Neoplanorbis	carinatus		EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Neoplanorbis	smithi		EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Neoplanorbis	umbilicatus		EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Planorbella	multivolvis	Acorn Ramshorn	EX	2000
MOLLUSCA	GASTROPODA	HYGROPHILA	PLANORBIDAE	Rhodacme	filosa	Wicker Ancylid	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	COCHLIOPIDAE	Heleobia	spinellii		EX	2009
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Beddomeia	tumida		EX	1996
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Belgrandiella	intermedia		EX	1996
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Bythinella	gibbosa		EX	2009
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Bythinella	limnopsis		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Bythinella	mauritanica		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Bythinella	microcochlia		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Bythinella	punica		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Clappia	cahabensis	Cahaba Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Clappia	umbilicata	Umbilicate Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Fluvidona	dulvertonensis		EX	1996
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Graecoanatolica	macedonica		EX	2002
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Hydrobia	gracilis		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Littoridina	gaudichaudii		EX	1996
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Marstonia	olivacea	Olive Marstonia	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Mercuria	letourneuxiana		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Ohridohauffenia	drimica		EX	2009
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Posticobia	norfolkensis		EX	1996

MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	barratei		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	desertorum		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	doumeti		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	globulina		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	latasteana		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	oudrefica		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	ragia		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pseudamnicola	singularis		EX	2007
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Pyrgulopsis	nevadensis	Corded Purg	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Somatogyrus	alcoviensis	Reverse Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Somatogyrus	amnicoloides	Oachita Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Somatogyrus	crassilabris	Thick-lipped Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	LITTORINIMORPHA	HYDROBIIDAE	Somatogyrus	wheeleri	Channeled Pebblesnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Athearnia	crassa	Boulder Snail	EX	1996
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	brevis	Short-spired Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	clausa	Closed Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	fusiformis	Fusiform Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	gibbera		EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	hartmaniana	High-spired Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	impressa	Constricted Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	jonesi	Hearty Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	lachryma		EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	laeta	Ribbed Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	macglameriana		EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	pilsbryi	Rough-lined Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	pupaeformis	Pupa Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	pygmaea	Pygmy Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	vanuxemiana	Cobble Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Elimia	varians	Puzzle Elimia	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	excisa	Excised Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	lewisii	Striate Slitshell	EX	2000

continues

Data Table 16 *continued*

Phylum	Class	Order	Family	Genus	Species	Common names (English)	Red List status	Year assessed
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	lewisii	Striate Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	pagoda	Pagoda Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	pumila	Ribbed Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	pyramidata	Pyramid Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Gyrotoma	walkeri	Round Slitshell	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	clipeata	Agate Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	compacta	Oblong Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	foremanii	Interrupted Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	formosa	Maiden Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	ligata	Rotund Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	lirata	Lyrate Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	occultata	Bigmouth Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	showalterii	Coosa Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	torrefacta		EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	PLEUROCERIDAE	Leptoxis	vittata	Striped Rocksnail	EX	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	THIARIDAE	Aylacostoma	chloroticum		EW	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	THIARIDAE	Aylacostoma	guaraniticum		EW	2000
MOLLUSCA	GASTROPODA	SORBEOCONCHA	THIARIDAE	Aylacostoma	stigmaticum		EW	2000
PLATYHELMINTHES	TURBELLARIA	TRICLADIDA	GEOPLANIDAE	Romankenkius	pedderensis	Lake Pedder Planarian	EX	1996

Note: EX: Extinct; EW: Extinct in the wild.

Source: Downloaded from IUCN RedList database.

Permission of use granted by William Darwall PhD, manager, IUCN Species Programme—Freshwater Unit.

DATA TABLE 17

U.S. Federal Water-Related Agency Budgets

Description

In the U.S., direct federal responsibilities over water management are shared across about 30 agencies in 10 different departments, plus numerous independent agencies, councils, commissions, and offices. No estimates of actual federal spending on water-related activities are available. The data here show the total federal budget authority for those agencies that are most involved in water policy and management. Calculating the federal water-related budget based on agency budgets greatly overestimates water-related spending because some of these agencies spend little of their total budget on water-related activities. The U.S. Coast Guard, for example, plays only a very minor role in freshwater management.

These budget data were collected largely from departmental budgets, some of which report budget data using different reporting methods. There are multiple ways in which to report budgets; here, they are reported in terms of "budget authority," or the amount of money that Congress allows an agency to commit to spend. In most cases, the actual amount of money spent (the "outlay") is significantly lower than the budget authority. However, whereas outlays are important for understanding actual monetary flows at the federal level, budget authority gives a good indication of the importance that the U.S. president and Congress place on different roles of the government, because it reflects their approval of spending for various priorities.

Limitations

These data are intended to give a rough approximation of federal spending on water. These data were collected from a wide variety of sources, and budget reporting methods may vary among agencies. In some cases, as noted above, data are not presented in common terms, limiting the ability to compare budgets across agencies. Furthermore, because data are presented at the agency rather than program level, in some cases actual spending on water-related activities is far lower than the total budget presented.

SOURCES

Note: All Web links accessed November 2010.

a. http://www.gpoaccess.gov/usbudget/fy11/pdf/hist.pdf
b. http://www.obpa.usda.gov/budsum/fy09budsum.pdf

c. http://www.obpa.usda.gov/budsum/FY10budsum.pdf
d. http://www.obpa.usda.gov/budsum/FY11budsum.pdf
e. http://www.osec.doc.gov/bmi/budget/FY2009BIB.html
f. http://www.osec.doc.gov/bmi/BUDGET/10BIB/BA-OUTLAYS.pdf
g. http://www.osec.doc.gov/bmi/BUDGET/11BIB/BA-OUTLAYS.pdf
h. http://www.hhs.gov/budget/09budget/2009BudgetInBrief.pdf
i. http://www.hhs.gov/asrt/ob/docbudget/2010budgetinbrief.pdf
j. http://dhhs.gov/asfr/ob/docbudget/2011budgetinbrief.pdf
k. http://www.dhs.gov/xlibrary/assets/budget_bib-fy2009.pdf
l. http://www.gpoaccess.gov/usbudget/fy10/pdf/hist.pdf
m. http://www.dhs.gov/xlibrary/assets/budget_bib_fy2011.pdf
n. http://www.hud.gov/offices/cfo/reports/2009/cjs/introduction.pdf
o. http://hud.gov/budgetsummary2011/budget-authority-by-prog.pdf
p. http://www.doi.gov/budget/2009/09Hilites/A001.pdf
q. http://www.doi.gov/budget/2010/10Hilites/A001.pdf
r. http://www.doi.gov/budget/2011/11Hilites/A001.pdf
s. http://www.usdoj.gov/jmd/2009summary/pdf/fy2009-bud-sum.pdf
t. http://www.usdoj.gov/jmd/2010summary/pdf/summary-bud-authority.pdf
u. http://www.justice.gov/jmd/2011summary/html/budget-authority-appropriation.htm
v. http://www.whitehouse.gov/omb/budget/fy2009/pdf/appendix/lab.pdf
w. http://www.whitehouse.gov/omb/budget/fy2010/assets/lab.pdf
x. http://www.gpoaccess.gov/usbudget/fy11/index.html
y. http://www.usaid.gov/policy/budget/cbj2009/101416.pdf
z. http://www.gpoaccess.gov/usbudget/fy11/pdf/budget/state.pdf
aa. http://www.dot.gov/bib2009/pdf/bib2009.pdf
bb. http://www.dot.gov/budget/2010/bib2010.htm
cc. http://www.dot.gov/budget/2011/
dd. http://www.whitehouse.gov/omb/budget/fy2009/pdf/appendix/eop.pdf
ee. http://www.whitehouse.gov/omb/budget/fy2010/assets/eop.pdf
ff. http://www.gpoaccess.gov/usbudget/fy11/index.html
gg. http://www.whitehouse.gov/omb/budget/fy2009/pdf/appendix/oia.pdf
hh. http://www.dot.gov/budget/2010/bib2010.htm
ii. http://www.dot.gov/bib2009/pdf/bib2009.pdf
ff. http://www.gpoaccess.gov/usbudget/fy11/index.html
jj. http://www.whitehouse.gov/omb/budget/fy2009/pdf/appendix/leg.pdf
kk. http://www.whitehouse.gov/omb/budget/fy2010/assets/leg.pdf
ll. http://www.state.gov/documents/organization/100033.pdf
mm. http://www.state.gov/documents/organization/122511.pdf
nn. http://www.state.gov/documents/organization/137844.pdf
oo. http://www.state.gov/documents/organization/124295.pdf

Data Table 17 U.S. Federal Water-Related Agency Budgets

	Budget Authority, Dollars in Millions (appropriations reported where marked with *)									
	FY 2007		FY 2008		FY 2009		FY 2010 (est.)		FY 2011 (est.)	
Department of Agriculture										
Farm Services Agency	4,105	b	3,302	c	15,601	d	14,658	d	14,220	d
Economic Research Service	75	b	78	c	80	d	82	d	87	d
Nat. Resources Conservation Service	2,620	b	3,378	c	3,471	d	3,892	d	3,993	d
U.S. Forest Service	5,719	b	6,236	c	7,103	d	6,151	d	6,145	d
Rural Utilities Service	(2,068)	b	775	c	4,464	d	694	d	643	d
Department of Commerce										
Economic Development Administration	281	e	774	f	448	g	293	g	286	g
National Oceanic and Atmospheric Administration	4,190	e	4,313	f	5,357	g	4,902	g	5,708	g
Department of Defense										
Army Corps of Engineers	7,046	a	9,093	a	16,587	a	5,423	a	4,855	a
Department of Health and Human Services										
U.S. Centers for Disease Control and Prevention	6,082	h	6,181	i	6,670	j	6,447	j	6,342	j
Food and Drug Administration	1,574	h	1,873	i	2,062	j	2,365	j	2,510	j
Department of Homeland Security										
U.S. Coast Guard	8,554	k	8,631	l	9,624	m	10,123	m	10,078	m
Federal Emergency Management Agency	4,572	k	5,515	l	5,971	m	6,194	m	6,527	m
Department of Housing and Urban Development										
Community Planning and Development	7,326	n	10,548	n	14,567	o	8,581	o	8,425	o
Department of Interior										
Bureau of Land Management	1,398	p	1,233	q	1,582	r	1,316	r	1,314	r
Bureau of Indian Affairs	2,409	p	2,455	q	2,987	r	4,762	r	2,706	r
Office of Surface Mining Reclamation and Enforcement	409	p	612	q	587	r	704	r	606	r

continues

Data Table 17 *continued*

	Budget Authority, Dollars in Millions (appropriations reported where marked with *)									
	FY 2007		FY 2008		FY 2009		FY 2010 (est.)		FY 2011 (est.)	
Bureau of Reclamation	1,136	p	1,349		2,115	r	1,210	r	1,232	r
U.S. Fish and Wildlife Service	2,182	p	2,410	q	2,715	r	2,764	r	2,873	r
U.S. Geological Survey	997	p	1,009	q	1,186	r	1,113	r	1,134	r
National Park Service	2,676	p	2,872	q	3,669	r	3,154	r	3,147	r
Department of Justice										
Environment and Natural Resources Division*	95	s	99	t	103	u	110	u	119	u
Department of Labor										
Occupational Safety and Health Administration	487	v	486	w	520	x	559	x	573	x
Department of State										
Oceans, International Environment, and Scientific Affairs Bureau	27	y	18	oo	49	z	179	z	129	z
U.S. Agency for International Development (administrative expenses)*	740	y	776	oo	924	z	1,659	z	1,704	z
Department of Transportation										
Maritime Administration	435	aa	598	bb	665	cc	595	cc	528	cc
St. Lawrence Seaway Development Corporation	16	aa	17	bb	34	cc	33	cc	33	cc
Pipeline and Hazardous Materials Safety Administration	134	aa	153	bb	114	cc	124	cc	141	cc
Executive Office of the President										
Council on Environmental Quality and Office of Environmental Quality	3	dd	3	ee	3	ff	3	ff	3	ff
Office of Management and Budget	77	dd	78	ee	88	ff	93	ff	93	ff
Office of Science and Technology Policy	6	dd	7	ee	5	ff	7	ff	7	ff

Independent Agencies										
Environmental Protection Agency	7,533	a	7,393	a	14,754	a	10,203	a	9,875	a
The Surface Transportation Board	25	ii	25	hh	26	ff	28	ff	25	ff
Tennessee Valley Authority	(428)	gg	112	gg	225	ff	1,111	ff	719	ff
Appalachian Regional Commission	65	gg	73	gg	75	ff	76	ff	76	ff
Federal Maritime Commission	20	gg	22	gg	23	ff	24	ff	25	ff
Congress										
Congressional Budget Office	35	jj	37	kk	46	ff	45	ff	47	ff
Congressional Research Service	101	jj	102	kk	107	ff	112	ff	120	ff
Bilateral Commissions										
(US-Canada) International Joint Commission*	6	ll	7	mm	8	nn	8	nn	8	nn
(US-Mexico) International Boundary and Water Commission*	34	ll	155	mm	296	nn	76	nn	74	nn
Total	70,692		82,798		124,909		99,874		97,131	

DATA TABLE 18

Overseas Dams With Chinese Financiers, Developers, or Builders (as of August 2010)

Description

China is rapidly expanding its involvement in a large number of dams outside its own borders. These dams include projects on rivers shared by China and neighboring countries as well as dams completely outside Chinese watersheds in countries where the Chinese government, financial institutions, or companies have political or financial interests. This table is modified from a more comprehensive table maintained by one of the leading nongovernmental organizations tracking international dam projects: the International Rivers Network (IRN). It includes information on the country, dam project, river, financier, builder, or developer, with a limited update on current status as of mid-2010.

Limitations

Limited, inconsistent information is available for many of these Chinese dam projects. Details on financing, status, ownership, contracts, and more are often kept secret, or change quickly with development plans. These data are compiled by the International Rivers Network from a wide variety of sources and reflect the status of these projects as of late 2009 through mid-2010. Many details may be wrong, or may have changed, but they provide the most comprehensive and integrated list available.

The most up-to-date information on Chinese dam projects can be found at http://www.internationalrivers.org/china, or through Peter Bosshard at IRN.

SOURCES

Modified and used with permission of Peter Bosshard and International Rivers Network, Berkeley, California.

Data Table 18 Overseas Dams With Chinese Financiers, Developers, or Builders (as of August 2010)

Country	Project	River(s)	Financiers	Developer	Builder	Status
Albania	Bushat Hydropower Station	Drin River (in Shkoder)	China Exim ($100 million of buyer's credit)		China International Water and Electric Corp (CWE)	China Exim provided loans in 2001
Albania	Mao Zedong Hydropower Station				Sinohydro Bureau 14	Completed 1971
Algeria	Beniharon Hyodropower Station				Sinohydro Bureau 14	
Algeria	Boukourdane Dam	Boukourdane, Tipiza Province			Sinohydro Bureau 14	Operational since 1992
Algeria	Cuckoosi Dam			Presume GoA	Sinohydro Minjiang Bureau	Under construction
Algeria	Mawuena Dam		Sinohydro Bureau 13 (holding 49% of shares)	Sinohydro Bureau 13 (holding 49% of shares)		
Angola	Gangelas dam		China Exim	GoA	Sinohydro	The first phase of the work ended in 2007 and the second phase is now in its concluding stage
Bangladesh	Peaking Power Plant	Sirajganj		North West Power Generation Company (NWPGC)		Eight companies including five from China submitted bids
Belize	Chalillo Dam	Macal River		Belize Electric Company Limited (BECOL) with Fortis as the parent company	Sinohydro Bureau 11	Operation began in 2007
Belize	Mollejon Hydropower Station	Macal River		Fortis	Sinohydro Bureau 14	Completed 1995
Benin	Adjarala Hydroelectric Dam	Mone River		Communaute Electrique du Bénin	Sinohydro	Contract signed on March 12, 2009; 45 months estimated completion
Botswana	Dikgatlhong Dam	Shashe and Tati Rivers		GoB	Sinohydro	Groundbreaking February 2008; building to have started 9 March 2008 and finish in 2012

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Burma	Hatgyi Dam	Salween River, Kayin State	Sinohydro	Burma Department of Hydropower Implementation (DHPI)/EGAT/ Sinohydro	Burma Department of Hydropower Implementation (DHPI) 15%, the Electricity Generating Authority of Thailand (EGAT) 45%; China's Sinohydro Corporation 40%	On hold. In December 2007, over 50,000 people, including villagers from the proposed dam sites, signed a petition calling on the Chinese government to halt the construction of Chinese dam projects in Burma until international standards of best practice can be met.
Burma	Hopin Dam					
Burma	Htamanthi Dam				India's National Hydropower Co., Ltd; Myanmar's Ministry of Water and Electricity	MoU Signed
Burma	Hutgyi Dam	Than Lwin River	Sinohydro	Dept of Hydropower Planning, Sinohydro, Electricity Generating Authority of Thailand (EGAT) International and International Group of Entrepreneurs	Sinohydro	EGAT and SinoHydro are in the consortium to build this project. The dam was originally expected to begin generating electricity in 2015 or 2016.
Burma	Kapaung Dam					
Burma	Khaunlanphu Dam	N'Mai River	China Power Investment Company			

Burma	Kun Chaung Dam	Phyu			China Heavy Machinery Corporation	
Burma	Kun Dam	Sittang River	Alstom?			
Burma	Kunhing Dam				Hanergy, Goldwater?	
Burma	Kunlong Dam					
Burma	Kyaing Tong (Kengtawng) Dam	Pawn River			CNEEC, Zhejiang Orient Holdings Group Limited	
Burma	Kyauk Naga Dam					
Burma	Kyaukme Dam				Sinohydro Bureau 14	
Burma	Kyee-ohn kyee-wa Dam	Mone River	Dept of Irrigation			
Burma	Laiza Dam	Mali River	China Power Investment Co.			
Burma	Lakin Dam	N'Mai River	China Power Investment Co.			
Burma	Man Tung (Mantawng or Manton) Dam	Nan Ma River (tributary of Salween)		China Hydropower Engineering Consulting Group (HydroChina); Union of Myanmar's Ministry of Electric Power No. 1	China Hydropower Engineering Consulting Group	MOU signed on December 20, 2009.
Burma	Mawlaik Hydropower Project and Kalewa Coal-Fired Thermal Power Plant Project	Chindwin River		China Guodian Corporation, Burma's Electric Power Ministry No 1, and Tun Thwin Mining		MoU signed on May 2010. It is believed that the thermal power plant at Paluzawa would be used to provide electricity for the construction of a much larger hydropower facility farther up the Chindwin in Mawlaik township.
Burma	Mone Dam	Mone River			Sinohydro	

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Burma	Myitsone Dam + 6 others	Mali, Nmai, and Irrawaddy Rivers				In May 2007, twelve respected elders and leaders from townships across Kachin State sent an objection letter to Senior General Than Shwe requesting that the project be canceled. In early April 2010, a serious of explosions occurred. According to the *Democratic Voice of Burma* newspaper, the explosions killed 3 people and injured 20. A government investigation is currently under way into the cause of the blast.
Burma	Nam Hkam Hka				Sinohydro Bureau 14	
Burma	Nam Lwe (Lwi) River dams (6)	Nam Lwe (Lwi) River		Yunnan Power Grid Corporation and the State Development and Investment Corporation (SDIC) Huajing Power Holdings		In February 2010, http://news.sohu.com reported that Chinese firms were planning to develop seven dams in the Wa and Mongla areas: one on the Nam Hka River, a tributary of the Nu-Salween River that flows through the Wa capital, and another six on the Nam Lwi River, a tributary of the Mekong.
Burma	Nam Myao (Nam Myaw)					
Burma	Namtabat Hydropower Project	Salween River, Kayah State			Datang (Yunnan) United Hydropower Developing Co	Details of project unclear. MOU was signed in January 2010 for 31 hydropower projects in Myarnmar involving investment by foreign companies.
Burma	Nampun Hydropower Project	Salween River, Kayah State			Datang (Yunnan) United Hydropower Developing Co	Details of project unclear. MOU was signed in January 2010 for 31 hydropower projects in Myanmar involving investment by foreign companies.

Burma	Nao Pha Dam	Salween River		China Hydropower Engineering Consulting Group (HydroChina; Union of Myanmar's Ministry of Electric Power No. 1	China Hydropower Engineering Consulting Group	MOU signed on December 20, 2009.
Burma	Ngaw Chang Hka (four dam cascade)	N'Mai Hka River		Yunnan Power Investment Corporation's (YPIC); Myanmar's Department of Hydropower Implementation	YPIC's International Energy Cooperation and Development Company	On February 26, 2009, Yunnan Power Investment Corporation's (YPIC) International Energy Cooperation and Development Company and Myanmar Ministry of Electric Power No. (1) Department of Hydropower Implementation signed a memorandum of understanding for the joint development of Ngaw Chang Hka Hydropower Project.
Burma	Pashe (may not be exact name)	N'Mai River	China Power Investment Co.			
Burma	Paunglaung Dam	Sittang River		Lower Paunglaung Dam: "construction and investment support from YMEC, Sinohydro Bureau 14, Ningbo Huyong Electric Power Material Co., and Kunming Hydroelectric Investigation Design & Research Institute"	Sinohydro Bureau 14	Lower Paunglaung completed 2005
Burma	Phizaw (may not be exact name)	N'Mai River	China Power Investment Co.			

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Burma	Phyu Dam					
Burma	Shweli 1	Shweli River	see below		Sinohydro Bureau 14	Completed in 2008
Burma	Shweli River 3	Shweli River, upper Shan State, Namkhan	Yunnnan Joint Development Corporation (Yunnan Power Grid Corporation, YMEC, Yunnan Huaneng Lancang River Hydropower Company); China Power Investment Co.		Sinohydro Bureau 14	Additional units in the Shweli River project are being pursued on an irregular basis. The electricity will be exported to China and to factories and mining operations in Burma.
Burma	Shwesayay				India's National Hydropower Co., Ltd; Myanmar's Ministry of Water and Electricity	MoU Signed
Burma	Tarpein 1	Tarpein River (or Taping, Daying)		Datang Group is the Owner of Dapein 1, with investment from China Power International Trade Company and Jiangxi Water Resources Planning and Design Institute	Burma's Ministry of Electric Power No. 1 and a conglomerate of Chinese companies, including China Datang Corporation	Goal to bring first Tarpein unit online by 2010. The nickel mining-smelting complex under construction by the PRC's Non-ferrous Metals Corporation farther down the Irrawaddy is almost certainly one of the beneficaries.

Burma	Yeywa Dam	Dokhtawady River, Manadalay division, Central Burma, Kyaukse	China Exim Bank ($200 million preferential interest rate loan), Citic; China Power Investment Co.	In late 2004, Burma's Ministry of Electric Power signed a contract with a consortium created by the China International Trust and Investment Co. (CITIC) and Sinohydro Corporation for the implementation of the Yeywa Dam.	China Gezhouba Group Co., China National Electric Equipment Co., Hunan Savoo Oversea Water & Electric Engineering Co., China National Heavy Machinery Co. (CHMC), Sinohydro Bureau 1 and COLENCO	MoUs signed; five contracts signed since 2004. Construction began in 2006; completed?
Burma	Ywathit Hydropower Project	Salween River, Kayah State			Datang (Yunnan) United Hydropower Developing Co	Details of project unclear. MOU was signed in January 2010 for 31 hydropower projects in Myanmar involving investment by foreign companies.
Burma	Zaungtu					
Burma	Zawgyi 1				Sinohydro Bureau 14	
Burma	Zawgyi 2					
Burma	Zichuang					
Burma	Kachin	Ngawchanka River		Myanmar International Group of Entrepreneurs Company	China YPIC International Energy Cooperation and Development Company	Agreement signed July 23, 2010
Burma	Shweli 2	Shweli River	see below		Sinohydro Bureau 15	See below
Burma	Weigyi	Salween River				Currently shelved
Burundi	Lumengyi Hydropower Station				Sinohydro Bureau 14	

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Burundi	Mugere Hydropower Station	Mugere River				Completed 1982
Cambodia	Da Dai Hydropower Project	Da Dai River			Gezhouba	Gezhouba won bid in June 2010.
Cambodia	Kamchay Dam	Kamchay River	China Exim Bank--$280 million loan received by Sinohydro	Sinohydro	Sinohydro	1st power plant to come online October 2009; completion was expected 2010.
Cambodia	Kirirom III	Koh Kong Province			China State Grid Xin Yuan International Investment Co. Ltd	Agreement signed between builder and Cambodian Minister of Economics and Finance Keat Chhun, Cambodian Minister of Mines and Energy Suy Sem on February 5, 2008; project to be completed in three years.
Cambodia	Lower Stung Russey Hydropower Dam	Stung Russey Chrum River, located downstream area of Stung Atay Dam			China Yunnan Corporation for International Techno-Economic Cooperation	
Cambodia	Lower Stung Russey Chrum Hydropower Project (Steung Russei Chrum Kraon)	Strung Russey Chrum River	China Exim Bank; INFINITY Insurance in conjunction with People's Insurance Company of China		Hong Kong branch of the state-owned China Huadian Group	Planned to be complete in 2014.
Cambodia	Sambor Hydropower Project	Mekong River, Shan State	China Southern Power Grid Company. A subsidiary of CSG (Guangxi Power Industry Surveying and Design Institute) is doing the feasibility study.			Feasibility study: CSG has yet to conduct a detailed evaluation of the environmental and social impacts of Sambor.

Cambodia	Srepok 3 Hydropower Project	Srepok River, a tributary of the Mekong River in Cambodia's Ratanakiri Province				MoU Signed for feasibility study; will begin preliminary work, including the commissioned feasibility study on design, review of the project feasibility, etc.
Cambodia	Srepok 4 Hydropower Project	Srepok River, a tributary of the Mekong River in Cambodia's Ratanakiri Province				MoU Signed for feasibility study; will begin preliminary work, including the commissioned feasibility study on design, review of the project feasibility, etc.
Cambodia	Stung Atay Dam	Atay River			China Yunnan Corporation for International Techno-Economic Cooperation	The project was approved in Feburary 2007.
Cambodia	Stung Cheay Areng	Stung Cheay Areng	China Southern Power Grid Company			CSG signed an MoU with the Government of Cambodia to study the project's feasibility in October 2006.
Cambodia	Stung Tatay Hydropower Project				China National Heavy Machinery Corporation completing study	China and Cambodia officially signed Memorandum of Understanding on China Southern Power Grid Company Limited's Undertaking Feasibility Research for Sambor (with a planned installation capacity of 3000 MW) and Stungcheayareng (with a planned installation capacity of 26 MW) Hydropower Projects in the Kingdom of Cambodia.
Cameroon	Lagdo Hydropower Station	Benoue River, Niger River Basin			Sinohydro Bureau 14	Completed 1983
Cameroon	Mekin Hydroelectric Project	Dja and Mekin Rivers	China Exim Bank (FCFA 21.9 billion/85% total cost)			Chinese Ambassador to Cameroon, Huang Changquing, signed contract early January 2010.

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Cameroon	Memve'ele Hydropower Station	Ntem River	African Development Bank; Development Bank of Central African States; Dutch Development Bank; Arab Development Bank and Multilateral Investment Guarantee Agency		Sinohydro	Sinohydro has a preliminary agreement to take over the 200 MW Memve'ele hydropower station; project completion estimated for December 2014.
Central African Republic	Baoli 3 Hydropower Project					February 2, 2010, agreement signed
Central African Republic	Mbali Dam				Sinohydro Bureau 14	
Columbia	Ituango Hydroelectric Power Station	Ituango River				February 2010, Sinohydro and other companies shortlisted
Congo, Democratic Republic of	Bandindu Dam					
Congo, Democratic Republic of	Grand Inga (Inga 3)	Congo River	Paid for by the Congo government: $360 million raised through government bonds and own capital; $80 million to China Electric Wire and Cable Import/ Export Corporation		Sinohydro	Work has begun on a link between Mbandaa (capital of the Equateur province) and Inga Dam.
Congo, Democratic Republic of	Zongo II Dam	Inkisi River			Sinohydro	In April 2009, the government signed an MoU with Chinese construction company Sinohydro to build the dam.

Côte d'Ivoire	Soubre Dam		China Exim Bank		Sinohydro	Sinohydro has been reseaching project feasibility since 2007.
Ecuador	Coca Codo Sinclair	Amazon Basin, Coca River	The Export-Import Bank of China will finance the project through a $1.7 billion 15-year loan. The remaining will be funded by Ecuador.	Sinohydro	Sinohydro	Construction has started.
Ecuador	El Reventador Hydroelectric project	Quijos-Coca River			Chinese construction consortium—CMEC and Sinohydro and China Exim Bank	Agreements signed in June 2004.
Ecuador	Mians Jobones	Amazon Basin	Bank of China; Inter-American Development Bank. CAF (Andean Development Corporation) and the Ecuador government.			Proposed but not yet approved
Ecuador	Ocana	Amazon Basin	Bank of China; Inter-American Development Bank. CAF (Andean Development Corporation) and the Ecuador government.			
Ecuador	Soplandora (or Sopladora)	Amazon Basin	Bank of China; Inter-American Development Bank. CAF (Andean Development Corporation) and the Ecuador government.		Gezhouba	Proposed but not yet approved. Ecuador is expected to reach an agreement with the Export-Import Bank of China for a US$600 million loan for the future Sopladora hydropower plant (HPP).
Ethiopia	Chemoga Yeda	5 rivers, five dams		EEPco	Sinohydro	Financial stage

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Ethiopia	Genale Dawe 3			EEPco	Gezhouba	Construction expected to be completed by 2015
Ethiopia	Gibe III	Omo River	African Development Bank possible; World Bank possible; European Investment Bank possible; Italian Government possible; ICBC Bank (China)		Salini Costruttori	Under construction. In May 2010, Ethiopia and China signed an agreement toward a $495 million loan with 85% coming from Chinese state-owned Industrial and Commercial Bank of China (ICBC) for hydro-mechanical and electro-mechanical project subcontract to be carried out by the Chinese Dongfang Electric Corporation.
Ethiopia	Gibe IV	Omo River	AfDB; possibly Chinese assistance	EEPA	Sinohydro	
Ethiopia	Halele Werabesa Dam	Halele Werabesa River	The project anticipates 85% financing from Chinese funders.		Sinohydro	In July 2009, the Ethiopian Government and Sinohydro signed a MoU for the dam.
Ethiopia	Neshi River Hydroelectric Dam	Neshi River			Enka (Turkey); Salini (Italy); and Gezhoua Group	
Ethiopia	Tekeze Hydroelectric Dam	Nile River	China and African sources; Chinese and Ethiopian joint venture company by Sinoydro (49%); China Gezhouba Water and Power Group Ltd (30%); Sur Construction (21%). China Exim Bank providiing $30 million loan.	Chinese and Ethiopian joint venture company by Sinoydro (49%); China Gezhouba Water and Power Group Ltd (30%); Sur Construction (21%).	Sinohydro; China Gezhouba, China Water Resources and Hydropower Engineering Corporation.	Construction under way (as of August 27, 2007); initial target completion date originally late 2008. Landslides in 2008 caused delay of project coming online until August 2009.
Fiji	Nadarivatu dam				Sinohydro	

Gabon	"Grand" Poubara Power Station	Ogooue River	China Exim Bank to lend $83-84 million concessional loan for the dam	Government of Gabon?	Sinohydro	Deal signed in January 2008
Gabon	Belinga Dam	Kongou Falls, Ivindo National Park, Gabon	China Exim Bank (early line of credit provided byBank of China in 2002)		China National Machinery and Equipment Import and Export Corporation (CMEC)	Part of iron ore reserve mine, along with 560 km of railways and ports. First expected shipment of iron ore to China in 2010.
Gambia	Sambangalou	Gambia River		Gambia River Basin Development Organisation (OMVG) / possibly Sinohydro	Sinohydro?	
Georgia	Khadori Hydroelectric Power Plant	Pankasi River	Sichuan Electic Power Import and Export Company			Completed 2003?
Ghana	Bui Dam	Black River	China Exim Bank loan of $292 million buyer's credit for government of Ghana; China also supplying $270 million of concessional finance; $60 million will come from government of Ghana.	Sinohydro and Ghana joint venture; BOT	Sinohydro	Turnkey contracts signed 2007; China Exim loan provided in September 2007
Ghana		Pra River at Awisam; Central Region		Sinohydro	Sinohydro	MoU signed with Pato Power July 2008; scheduled to be completed in three years
Ghana		Pra River at Sekyere Heman, Western Region			Sinohydro	MoU signed with Pato Power July 2008; scheduled to be completed in three years

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Ghana		Ankobra River at Bunso; Western Region		Sinohydro	Sinohydro	MoU signed with Pato Power July 2008; scheduled to be completed in three years
Ghana		Tano River at Tanoso; Western Region		Sinohydro	Sinohydro	MoU signed with Pato Power July 2008; scheduled to be completed in three years
Guinea	Djiploho		$1 billion from China. Exim dam will supply most of the investment; financing of the dam is tied to $9.2 million in aid in return for mineral development rights of Bauxite reserves; debt relief of $4 million		Sinohydro	Construction 2007-2010/11; contract signed in March 2007; scheduled to be completed by 2011
Guinea	Kaleta	Konkoure River, central Guinea		Public-private partnership between West Africa Power Pool (WAPP) and Sinohydro	Sinohydro	MoU signed early 2008
Guinea	Souapiti Dam	Konkoure River	$1 billion		Hongpeng Sinozonto Mining Investment Co Ltd and Shanxi Luneng Jinbei Aluminum Corporation, which forms the Luneng Sinozonto Aluminium Guinea	In November 2007, the Guinean government confirmed the dissolution of an agreement with China Exim Bank and Chinese companies Chalco and Sinohydro.

Guyana	Amaila Falls Hydroelectric Project	Amaila River	Inter-American Development Bank (IDB) and the China Development Bank	The Government of Guyana and the National Industrial and Commercial Investments Limited (NICIL)		Construction to begin mid-2010
Indonesia	Asahan 1 Hydropower Dam	Asahan River, Pintu Pohan Meranti district	JBIC		Sinohydro bureau No 16	
Indonesia	Jatigede Dam Project	Cimanuk River (West Java, near Bandung City, Sumadeng District)	$250 million loan provided by China (Exim)		Sinohydro	Contract signed with Sinohydro on April 30, 2007; total time line is 65 months.
Iran	Bakhtiari	Bakhtiari River				
Iran	Lorestan Dam	Rudbar River, approximately 100 km to Aligoodarz in Lorestan Province	Iran Hydropower Resources Development		Gezhouba	
Iran	Mollasadra Project	Core River			Gezhouba	Operational in 2007
Iran	Taleghan Dam	Taleghan River	China Exim Bank		Sinohydro	Sinohydro received export credit financing in June 2007; project since completed.
Kazakhstan	Chilik River Hydropower Project	Chilik River		Limited Kazakhstan Natural Gas Technology Company	China Gezhouba Group Company	As of February 12, 2010, the contract had yet to be approved by either government.
Kazakhstan	Moinak Hydropower Project	Charyn River	China Development Bank ($200 million) and Development Bank of Kazakhstan		Sinohydro (turn-key)	Construction began in 2006; Sinohydro received contract in May 2006.
Kenya	Magwagwa Dam	Sondu River		Sinohydro		August 2009 kick off MoU between Kenyan government and Sinohydro

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Kenya	Songoro Hydropower Plant, add-on to 60 MW Sondu Miriu Scheme	Western Kenya	Japan Bank for International Cooperation financing more than 50% of project through 30-year loan; Japanese firm Nippon Koei will consult; Kengen will pay balance.	Kengen	Sinohydro Bureau #13	Sinohydro expected to complete construction work within 36 months starting November 2008
Kyrgyzstan	Kambaratin Hydropower Project	Naryn River	Deal pending			Deal pending
Kyrgyzstan	Sarydzhaz Cascade	Sarydjaz River, Tianshan range (drains to China/xinjiang)	Deal pending			Deal pending
Lao PDR	Nam Beng	Beng River				MOU signed in 2006
Lao PDR	Nam Feuang	Feuang				MOU signed in April 2007; ongoing feasibility study
Lao PDR	Nam Khan 2		Sinohydro	Sinohydro	Sinohydro	MOU signed October 13, 2006
Lao PDR	Nam Khan 3		Sinohydro	Sinohydro	Sinohydro	MOU signed October 13, 2006
Lao PDR	Nam Leuk	Vientiane	US$130million was largely financed by ADB and Japanese government.			Began operation in 2000
Lao PDR	Nam Lik 1,2	Nam Lik			China International Water and Electric Corperation (80%); Laos 20%	A PPA and Concession agreement was signed in April 2007; Construction started December 2007 (40% complete); expected COD 2010.

Lao PDR	Nam Mang 1	Nam Mang River (Thaphabath district)		Saytha Construction Company, Sichuan, China-based Dongfang Electric Corporation and Hong Kong-based C (Far East) Industrial Ltd	Saytha Construction Company, Sichuan, China-based Dongfang Electric Corporation and Hong Kong-based C (Far East) Industrial Ltd	Project went to planning phase after agreement was signed between Chinese and Lao companies in May 2010.
Lao PDR	Nam Mang 3	Mang River (Vientiane Province)	China Exim Bank (80% financed)		China International Water and Electric Corp (CWE) now owned by Electricite du Lao)	Commissioned in 2004
Lao PDR	Nam Ngum 5	Ngum River (Upstream of Nam Ngum I)	Exim bank will fund if MIGA provides reinsurance; $200 million total; Bank of China ($140 million loan); Sinohydro ($54 million); Electricite du Laos ($6 million)	Sinohydro has 85% stake	Sinohydro	Agreement signed in April 2007; generating to begin by 2011.
Lao PDR	Nam Ou 2	Ou River	JV between Sinohydro and Lao Government who will have a 25% share	Sinohydro	Sinohydro	Agreement signed October 2007; construction originally scheduled to begin 2009.
Lao PDR	Nam Ou 5	Ou River	Laos (15%); Sinohydro (85%)	Sinohydro	Sinohydro Bureau #15	Contract signed with Sinohydro on August 31, 2008; construction to take 44 months.
Lao PDR	Nam Ou 8	Ou River	Laos (15%); Sinohydro (85%)	Sinohydro	Sinohydro	Start construction in 2009; anticipate full operation in 2015
Lao PDR	Nam Tha	Tha River			China Southern Power Grid Corporation	MOU signed August 28, 2006; feasibility study completed by CSG

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Lao PDR	Nam Tha 1	Tha River			China Southern Power Grid Corporation	MoU for feasibility study signed in 2006 and study submitted in September 2007; CA under negotiation; construction of access road and transmission line has reportedly begun. China Southern Power Grid agreed to build a national power grid and Nam Tha 1 on June 22, 2010.
Lao PDR	Pak Beng Mekong Dam 5th Dam	Mekong (Luang Prabang, Xanakhan District)				MoU signed December 2007 between Da Tang International Power Generation Co Ltd and Deputy Minister of Planning and Investment; feasibility study will take 30 months.
Lao PDR	Paklay dam (4th Dam)	Mekong mainstream	China Exim has provided a US $270 million loan at 6% loan to build the dam, although the company has sought a 2% rate. The loan is being negotiated between the Lao PDR gov & China Exim.	Sinohydro and CEIEC	Sinohydro	MOU signed June 11, 2007
Lao PDR	Sanakham	Mekong mainstream	China Datang Corporation, China Datang Overseas Investment Co., Ltd.?			The General Institute of Hydropower and Water Resources Planning and Design held in Beijing the Review Panel Meeting for pre-feasibility study of the Sanakham Hydropower Project, which was commissioned by the Datang Overseas Project Management Office and conducted by the HydroChina Northwest Engineering Corporation.
Lao PDR	Xepone 3		China National Machinery & Equipment Import & Export Corporation (CMEC)			MOU signed in April 2008

Lao PDR	Xeset 2	Set River	Estimated cost US$135 million, largely financed by China EXIM		Norinco Construction Company of China; Northwest Hydro Consulting Engineers (CMECC)	Under construction (60% complete) and brought into operation September 2009.
Madagascar	Expansion Project		Arab Bank PLC		Sinohydro	Construction of third generator of 34,000kV still in development.
Malaysia	Bakun Dam	Balui River, Sarawak	China Exim	Sinohydro and Malaysia JV	Sinohydro Bureau 14 with local Malaysian Firms	Anticipated completion is now July 2011
Malaysia	Baleh HP	Rejang River, Sarawak				Pre-feasibility October 2007
Malaysia	Baram HP	Sarawak				Pre-feasibility October 2007
Malaysia	Batang Ai Extension	Sarawak				Detailed study commenced October 2007
Malaysia	Belaga HP	Batang Rajang River, Sarawak				Pre-feasibility October 2007
Malaysia	Belepeh HP	Sarawak				Pre-feasibility October 2007
Malaysia	Bengoh Water Supply Project				Sinohydro	
Malaysia	Eluk Bahang Water Supply Project					
Malaysia	Hulu Terengganu			Tenaga Nasional Berhad	Loh & Loh Corporation Berhad, Sinohydro	Loh & Loh Corporation said that its subsidiary Loh & Loh Constructions had a 60% interest in the joint venture, with Sinohydro holding the balance.
Malaysia	Lawas HP	Sarawak				
Malaysia	Limbang HP	Sarawak				Feasibility study commenced October 2007
Malaysia	Linau HP	Sarawak				
Malaysia	Metjawah HP	Sarawak				
Malaysia	Mindulu Dam	Shalouyue State, Mindulu Town	Sinohydro			Completed 2004

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Malaysia	Murum HP	Rejang River, Sarawak	CTGPC (China Three Gorges Project Corp)		Sarawak Electrical Supply Corporation (SESCO)	MoU signed; construction to start 2008; anticipated completion in 2011
Malaysia	Teluk Bahang Water Supply Project					
Malaysia	Tutoh HP	Sarawak				
Malaysia	Ulu Air HP	Sarawak				
Mali	Felou HP	Senegal	World Bank $75 million & European Develop. Bank $11 million	Organization pour la Mise en Valeur du Fleuve senegal (OMVS)	Sinohydro	Contract signed by Sinohydro in May 2009; expected to take 38 months
Mongolia	Tesiya Hydropower Project			Mongolia		Construction to have been completed in 2007 but there may have been funding issues
Morrocco	Al-Hoceima	Rhis River				
Morrocco	Chefchaouen	Laou River				
Morrocco	Ifrane?	Melloulou River				
Morrocco			China Exim Bank loan of $6.03 million unsecured			Loan 2002
Mozambique	Boa Maria Dam	Pungue River				
Mozambique	Moamba Major Project	Incomati River	China Exim	Sinohydro		China Exim has agreed to finance study.
Mozambique	Mphanda Nkuwa Dam	Zambezi River (70 km downstream of existing Cahora Bassa Dam)	China Exim Bank; Standard Bank; Camargo Correa (Brazilian company); Eskom (South African utility); Knight-Piesold (UK)		Brazilian construction company Camargo Corrêa awarded the contract for construction and operation of the Mphanda Nkuwa dam, in Mozambique.	Construction will begin in 2009; anticipated completion in 2013

Mozambique	Tete Dam	Zambezi River	China Exim Bank			China Exim Bank agreed to fund in 2006
Nepal	Chaku Khola Hydropower Project				China Henan International Cooperation Group Co.Ltd.	Started September 2001
Nepal	Chameliya Hydropower Project	Chameliya River	Nepal has requested loans from Korea, OPEC for transmission lines		China Gezhouba Water and Power Group Ltd	Construction started in 2006-2007.
Nepal	Indrawati-3 Hydropower Project				Pingxiang Mining Industry Group Company Ltd.	Started November 1999
Nepal	Mashandi (Upper Marsiangri?) Hydropower Station				Sinohydro Bureau 14 (90% stake)	
Nepal	Middle Bhotekoshi Hydropower Project	Bhotekoshi River			China Gezhouba Water and Power Group Ltd	Started February 1997
Nepal	Middle Marsyangdi Hydroelectric Project				CWE	Started June 2001
Nepal	Modi Khola Hydropower Project					Completed
Nepal	Puwa Khola (Ilamu) Hydropower Dam	Mai Khola	Sinohydro ($12 million investment)	Sinohydro		
Nepal	Shikta Project	Rapti River in Banke district	Government of Nepal	Government of Nepal	Sinohydro Bureau 11, Sinohydro-Lumbini (Nepal) JV	Started 2006
Nepal	Sunkoshi		China (government)		Chinese	
Nepal	Upper Bhotekoshi Hydropower Project	Bhotekoshi River	Privately financed by shareholders Himal International Power Company, Panda and Harza; the latter two are American companies.		China Gezhouba Water and Power Grou Ltd	Completed mid-1990s

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Nepal	Upper Tamakoshi Hydro Poroject		Employees´ Provident Fund	Upper Tamakoshi Hydro Company	Sinohydro won a 1.21 billion yuan contract from the Nepal Electricity Authority.	Agreement signed August 2010.
Nepal	Upper Trishuli 3 'A' and "B"	Trishuli River	China Exim Bank will fund Trishuli A; B will be paid for with domestic funds			The project is expected to start generating electricity from 2011-12. "Tri A" will be completed and start production around 2011, and "Tri B" around 2012.
Nepal	West Seti Dam	West Seti River	China will finance some of the project: early reports said China Exim ($400 million); Industrial and Commercial Bank ($300 million) and Bank of China ($200 million); SMEC (Australian developer of project since 1994) will sell 15% shares to IL&FS (Indian company), Asian Development Bank (ADB), government of Nepal, China National Machinery and Equipment Import and Export Corp. (CMEC), and 14% to the Nepalese financial institutions		CMEC (14% stake); West Seti Hydro Ltd. (WSHL); SMEC Development (P). Ltd. (Snowy Mountains Engineering Co, Australia), and ADB. Work projected to take 5.5 years.	This project has been proposed for over a decade and is still in flux. As of May 2011, the original developers have withdrawn but China continues to express interest.

Niger	Kandadji	Niger		Sinohydro		
Nigeria	Kandaji	Niger River			China Geo-engineering Corporation	
Nigeria	Mambila Hydropower Dam + Others	Benue River	China Exim Bank loan to Nigeria US$2.1 billion; $1 billion to finance the Mambila hydropower dam		China Geo-engineering Corporation	
Nigeria	Zamfara Dam		China-Import/Export Bank and will be guaranteed by Sofitel Capital Corporation and Intercontinental Bank Plc, who will maintain the project for seven years.		China Geo-engineering Corporation	Scheduled to start providing power to the national grid in the first quarter of 2011
Nigeria	Zungeru Dam	Kaduna River	China Exim Bank	Sinohydro (providing some funding?)	ICFC International Consultancy Company of Austria, Sinohydro	
Oman	Muscat Water Project					
Pakistan	Allai Khwar Hydropower Station	Allai Khwar (trib to Indus)	WAPDA			Anticipated completion in 2008
Pakistan	Bunji Dam	Astore District		Water and Power Development Authority (WAPDA)	China's Three Gorges Project Corporation	MoU signed in August 2009
Pakistan	Darwat Dam	Jamshoro district		WAPDA	Sinohydro	A memorandum of understanding (MoU) for construction of Darwat Dam in Jamshoro district has been signed with the Sinohydro Corporation.

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Pakistan	Diamer Basha Dam	Indus River	China (Water and Power Ministry told *Daily Times* that China would provide bulk but not all of the funding). World Bank refused to provide aid for project in 2008-2009.		7,000 skilled laborers who have worked on Three Gorges Dams are promised.	Work originally to start in 2009; limited construction began in February 2011.
Pakistan	Dubowa Power Station	River unknown; located in the North-West Province	Sinohydro	WAPDA	Sinohydro	Completed
Pakistan	Gomal Zam Dam	Gomal River	Sinohydro	Frontier Works Association/ WAPDA	Sinohydro	Construction in progress; to be completed by 2010 but still not done by May 2011
Pakistan	Jinnah Hydropower Station	Indus River	WAPDA		Dongfang	Contract signed with CMECC 2003; anticipated completion in 2010 but now delayed until mid- to late-2011.
Pakistan	Keyal Khwar Hydropower Project		KfW loan for feasibility study		Dongfang Electric Corporation	
Pakistan	Khan Khwar Power Station	Khan Khwar River (tributary to Indian River)	Arab Abu Dhabi Foundation	Wapda	Sinohydro	Anticipated completion in 2008; actual generation began December 2010
Pakistan	Kohala Hydropower Project		Sinohydro interested		CWE?	
Pakistan	Mangla Dam Extension	Jhelum River between Punjab and Kashmir	China and Pakistan		China International Water and Electric Corporation (38% of contract)	

Pakistan	Neelum-Jhelum Dam	Azad Jammu & Kashmir, Muzaffarabad District; Neelum River	WAPDA		Gezhouba Company; Pakistan will also seek reinsurance from China.	Contract signed between Gezhouba & CMEC & Water and Power Development Authority of Pakistan
Papua New Guinea	Yang Power Station				China National Electric Equipment Corporation	
Philippines	Baligatan Hydropower Station	Magat River				Completed 1987
Philippines	Diduyon Hydropower Project	Diduyon River	Chinese bank, unspecified	Philippine Green Energy Management Company Limited?	CGGC International Limited, a controlling subsidiary of China Gezhouba Group Company Limited	In January 2010, China Gezhouba Group Company Limited signed a $600 million contract with Philippine Green Energy Management Company Limited.
Philippines	San Rogue		Govt of Philippines and China Exim Bank loan of $27 million			
Philippines	Laiban Dam			Abacus Consolidated Resources and Holdings Inc. or San Miguel Corp	Sinohydro	July 2010 tenders to Metropolitan Waterworks and Sewerage System; Sinohydro and local company submit an unsolicited proposal for joint venture project.
Republic of Congo	Buangza Hydropower Station	Niari River		SNE (GoC)	Sinohydro Bureau 14	
Republic of Congo	Imboulou	Lefini River, tributary to Nile	China Exim Bank	SNE (GoC)?	CMEC and Fichtner (German company)	
Republic of Congo	Moukoukou Dam (repairs)		China Exim Bank		CMEC	
Republic of Congo	Sangha region (dam name unknown)			Sinohydro		Sinohydro is due to start construction of the dam in June 2011, which should provide hydroelectric power for the northern region of the country.
Serbia	Djerdap (Iron Gates) 3	Danube	"two Chinese companies" unidentified in article	GOS/ Energoprojekect		Modernization is still in progress.

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Sri Lanka	Broadlands Hydropower Project	Kelani River			China National Electric Equipment Corporation	Announced sucessful tender in 2010
Sudan	Kajbar Dam	Nile River	China (75%) and the Sudan			
Sudan	Merowe Dam	Nile River	China Exim Bank, Arab funders	GoS	Sinohydro, China International Water & Electric Corp. and China National Water Resources and Hydropower Engineering Corporation share the main civil-engineering contract.	Construction in progress
Sudan	Roseires Dam (heightening)	Blue Nile River	Arab Fund for Economic Development, Islamic Development Bank, Kuwaiti Fund for Economic Development, OPEC Fund, Abu Dhabi Fund for Development, and the Kuwait Fund for Arab Economic Development (KFAED) will extend Sudan a 58-million Kuwaiti Dinar (USD 212 million) loan for raising the Roseires Dam.	GoS	Sinohydro and China Water and Electric Corp (CWE)	Contract signed April 28, 2008

Sudan	Upper Atbara Hydro Junction Project	Atbara River	Sudanese government	Sudan's Dams Implementation Unit, China International Water & Electric Corporation (parent company, the China Three Gorges Corporation)	China International Water & Electric Corporation	Contract signed April 7, 2010
Syria	Tishrin Hydropower Project	Euphrates River	Arab Fund		Northwest Hydropower Consulting Engineers, CHEEC	Project tendered to CWH in 1993
Tajikstan	Nourobod-2 Hydroelectric Power Plant	Khingob River			Sinohydro?	Preliminary MOU signed 2008
Tajikstan	Zarafshon (formerly Yovon or Yavan) Hydroelectric Power Station	Zarafshon(or Zarafshan) River, Northern Tajikistan; for power to Panjakent District	CDB loan of $200 million for three years for development of three projects; China Exim Bank also expected to provide loan.	Sinohydro (BOT)	Sinohydro	Signed MOU in November 2006 on joint development of water power stations; Sinohydro signed agreement with Government of Takijistan in January 2007.
Tanzania	Kilombero Hydropower Project	Kingengenas and Shughuli Falls	China Africa Development Fund (CADF)	Rufiji Basin Development Authority (RUBADA) and	China National Heavy Machinery Co-operation	A Memorandum of Understanding (MoU) was signed on June 27, 2010, between the Rufiji Basin Development Authority (RUBADA) and the China National Heavy Machinery Co-operation. The project, in Kilombero, Morogoro region, is estimated to be ready in one year.
Thailand	Chon Buri Power Station			EGAT	EGAT	March 12, 2008: Sinohydro signed contract; to take 27 months
Thailand	Khlong ThaPower Station	irrigation		EGAT	Sinohydro	
Thailand	Royal Pak Phanang Water Gate	Pak Phanang River		EGAT	Sinohydro Bureau 14	

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Thailand	Naresuan Hydropower Station	Phitsanulok	JV between Italian / Thai ITD & Sinohydro	EGAT	Sinohydro	
Togo (and Benin)	Adjarala Dam	Mono River	China Exim Bank			
Tunisia	Meila Dam	Meilahe River			Sinohydro Bureau 15	Contract signed in September 2008 for construction; Sinohydro Bureau 15 says construction will take 42 months.
Turkey	Adiguzel Hydropower Station	B. Menderes, near Denizli				Completed 1993?
Turkey	Karacaoren Hydropower Station	Karacaoren River				Completed 2003; or 1993?
Uganda	Ayago North and South Hydropower Dams	Nile River, Murchison Falls in Nebbi district	China Development Bank		CITIC and Gezhouba	Feasibility study under way
Uganda	Bujagali dam		one ref to chinese involvement		Chinese company may have lost bid May 2008.	
Uzbekistan	Ahangar hydro plant	Tashkent Region	China Exim Bank		CNEEC	Agreement signed April 2006
Uzbekistan	Andijan hydro plant	Andijan region	China Exim Bank ($14.9 mill)		CNEEC	Agreement signed April 2006
Vietnam	Cua Dat Hydroelectric Dam	Chu River, Thanh Hoa Province	Sinosure providing buyer and commercial credits for BNP Paribas Bank's loan of $18.1 million to the Vietnam Construction Export and Import Corporation.		China National Heavy Machinery Corporation; Dong Fang Electrical Machinery Company	Anticipated that the first turbine will begin operating in December 2008; second in Feburary 2009. Actual operations begun in late May 2010 after period of testing.
Vietnam	Nammu Hydropower Station		Nam Mu hydropower joint stock company		Yunnan Machinery Export Import Import Company and Song Da (Vietnam)	Completed 2006?

Vietnam	PhuocHoa Gate Dam	Be River	ADB		Sinohydro	Contracted awarded to Sinohydro December 2007
Vietnam	Song Bung 4	Vu Gia - Thu Bon river system	ADB loan $196 million		Sinohydro	Work started for the Song Bung 4 hydropower plant in NamGiang district of the central province of Quang Nam.
Vietnam	Tuyenquang Hydropower Project	Gam River	EVN			Commissioned in 2008
Vietnam	Xiaozhong (aka Lao Cai) Hydropower Station	Xiao Zhong River	CSG/EVN		CSG/EVN (Vietnam and China Power Investment Co., Ltd. was established in November 14, 2006, by the Southern Power Grid Company, a wholly owned subsidiary of Yunnan Power Grid Company and Vietnam in the first 49:51 of the power companies to set up than the shares)	Partnership formed in 2006; first turbines to come online by March 2010.
Zambia	Batoka Gorge	Zambezi River	Zimbabwe		Three Chinese companies	
Zambia	Condo Gorge		possibly China Exim Bank and China Development Bank	possibly Sinohydro	Three Chinese companies	
Zambia	Itezhi-Tezhi hydropower project					
Zambia	Kafue Lower Gorge Power Station	Kafue River	Copperbelt Energy Corp in partnership with Mopani Copper Mines and others; possibly IFC or China Exim (up to 85%); China Development Bank (CDB)?	ZESCO	Sinohydro	China Development Bank (CDB) offered on May 11, 2010, to provide one billion dollars (787 million euros) for Kafue Lower Gorge and proposed Sinohydro to develop the project. Power purchase agreement to be signed by April 2011.

continues

Data Table 18 *Continued*

Country	Project	River(s)	Financiers	Developer	Builder	Status
Zambia	Kalungushi Hydropower Project				China National Electric Equipment Corporation	
Zambia	Kariba North Bank Hydropower Station (extension)	Zambezi River	China Exim Bank providing 85% ($430 million); remainder provided by Development Bank of Southern Africa	ZESCO	Sinohydro	Contract signed in late November 2007; construction to commence in early 2008. China EXIM provided funds to double the capacity. Expected to be finished by 2012.
Zambia	Lumangwe Falls	Kalungwishi River		ZESCO; unnamed Chinese firm		Development of the project is expected to begin in 2010.
Zambia	Lusiwasi Extension (rehabilitation)	Lusiwasi River		ZESCO	China National Electric Equipment Corporation	Letters of intent signed by CNEEC and ZESCO Power Corporation on the Lusiwasi and Lunzua hydropower projects, with a total value of $189.9 million.
Zimbabwe	Gwayi-Shangani Dam	Zambezi River			unnamed Chinese company	
Zimbabwe	Kariba South Bank Expansion	Zambezi River	China's Export and Import bank will provide a $250-million loan. The Infrastructure Development Bank of Zimbabwe is expected to raise $150 million.	Zimbabwe Electricity Supply Authority, Sinohydro	Sinohydro	

DATA TABLE 19

Per-Capita Bottled Water Consumption by Top Countries, 1999-2010 (Liters per Person per Year)

Description

Per-capita bottled water consumption is reported by the top 20 consuming countries for the years from 1997 to 2010, with data gaps. Data through 2007 and for 2010 come from the Beverage Marketing Corporation (BMC). Units are in liters per person per year. The greatest per-capita consumption occurs in the United Arab Emirates, Mexico, and Italy—all at over 200 liters per person per year. Data from 2009 for a subset of European Union (EU) countries are also provided, courtesy of the European Federation of Bottled Waters and Canadean, as noted below. These data often agree, but sometimes disagree substantially, with the BMC data. Care should be taken in comparing them.

Limitations

Data earlier than 1997 are not currently or consistently available. No distinction among types of bottled water is provided, and such definitions may vary from country to country. As noted above, data through 2007 and for 2010 are provided by the BMC; the 2009 data for EU countries come from Canadean, through the European Federation of Bottled Waters. These two data sets are similar but have some notable differences, such as for Belgium, France, and Germany.

SOURCE

Data provided by the BMC are used with permission. Canadean data come from http://efbw.eu/bwf.php?classement=07.

Data Table 19 Per-Capita Bottled Water Consumption by Top Countries, 1999–2010 (liters per person per year)

Countries	1999	2000	2001	2002	2003	2004	2005 (BMC)	2007 (BMC)	2009 (Canadean)	2010 (BMC)
Mexico	117	124	130	143	157	169	179	205		243
Italy	155	160	164	167	179	184	191	202	189	187
United Arab Emirates	110	114	119	133	145	164	181	260		153
Belgium-Luxembourg	122	118	118	124	133	148	160	150	120	148
Germany	101	102	103	105	121	125	128	126	165	134
France	118	126	131	141	148	142	139	136	112	132
Spain	102	105	109	112	127	137	146	120	124	124
Lebanon	68	77	85	94	96	102	107	111		121
Thailand	67	70	73	76	77	77	77	89		114
Hungary	30	39	46	51	62	66	70	108	109	111
Switzerland	90	90	90	92	96	100	104	107		108
United States	64	67	74	82	85	91	99	111		107
Slovenia	48	56	64	71	78	80	81	95	56	107
Croatia	42	47	52	56	62	69	78	92		101
Cyprus	67	72	76	81	86	92	98	91		98
Qatar							81			95
Saudi Arabia	76	80	85	90	88	88	93	91		95
China/Hong Kong							69			95
Czech Republic	62	68	74	80	84	87	90	93	77	92
Austria	75	75	78	79	86	82	81	95	95	91
Israel	23	29	38	47	56	61		88		
Portugal	70	72	73	76	78	80	83	85		

Source: http://efbw.eu/bwf.php?classement=07 (European Federation of Bottled Waters) and the Beverage Marketing Corporation.

Water Units, Data Conversions, and Constants

Water experts, managers, scientists, and educators work with a bewildering array of different units and data. These vary with the field of work: engineers may use different water units than hydrologists; urban water agencies may use different units than reservoir operators; academics may use different units than water managers. But they also vary with regions: water agencies in England may use different units than water agencies in France or Africa; hydrologists in the eastern United States often use different units than hydrologists in the western United States. And they vary over time: today's water agency in California may sell water by the acre-foot, but its predecessor a century ago may have sold miner's inches or some other now arcane measure.

These differences are of more than academic interest. Unless a common "language" is used, or a dictionary of translations is available, errors can be made or misunderstandings can ensue. In some disciplines, unit errors can be more than embarrassing; they can be expensive, or deadly. In September 1999, the $125 million Mars Climate Orbiter spacecraft was sent crashing into the face of Mars instead of into its proper safe orbit above the surface because one of the computer programs controlling a portion of the navigational analysis used English units incompatible with the metric units used in all the other systems. The failure to translate English units into metric units was described in the findings of the preliminary investigation as the principal cause of mission failure.

This table is a comprehensive list of water units, data conversions, and constants related to water volumes, flows, pressures, and much more. Most of these units and conversions were compiled by Kent Anderson and initially published in P. H. Gleick, 1993, *Water in Crisis: A Guide to the World's Fresh Water Resources*, Oxford University Press, New York.

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4_13,

Water Units, Data Conversions, and Constants

Prefix (Metric)	Abbreviation	Multiple	Prefix (Metric)	Abbreviation	Multiple
deka-	da	10	deci-	d	0.1
hecto-	h	100	centi-	c	0.01
kilo-	k	1000	milli-	m	0.001
mega-	M	10^6	micro-	μ	10^{-6}
giga-	G	10^9	nano-	n	10^{-9}
tera-	T	10^{12}	pico-	P	10^{-12}
peta-	P	10^{15}	femto-	f	10^{-15}
exa-	E	10^{18}	atto-	a	10^{-18}

LENGTH (L)

1 micron (μ)	= 1×10^{-3} mm	**10 hectometers**	= 1 kilometer
	= 1×10^{-6} m	**1 mil**	= 0.0254 mm
	= 3.3937×10^{-5} in		= 1×10^{-3} in
1 millimeter (mm)	= 0.1 cm	**1 inch (in)**	= 25.4 mm
	= 1×10^{-3}m		= 2.54 cm
	= 0.03937 in		= 0.08333 ft
1 centimeter (cm)	= 10 mm		= 0.0278 yd
	= 0.01 m	**1 foot (ft)**	= 30.48 cm
	= 1×10^{-5} km		= 0.3048 m
	= 0.3937 in		= 3.048×10^{-4} km
	= 0.03281 ft		= 12 in
	= 0.01094 yd		= 0.3333 yd
1 meter (m)	= 1000 mm		= 1.89×10^{-4} mi
	= 100 cm	**1 yard (yd)**	= 91.44 cm
	= 1×10^{-3} km		= 0.9144 m
	= 39.37 in		= 9.144×10^{-4} km
	= 3.281 ft		= 36 in
	= 1.094 yd		= 3 ft
	= 6.21×10^{-4} mi		= 5.68×10^{-4} mi
1 kilometer (km)	= 1×10^5cm	**1 mile (mi)**	= 1609.3 m
	= 1000 m		= 1.609 km
	= 3280.8 ft		= 5280 ft
	= 1093.6 yd		= 1760 yd
	= 0.621 mi	**1 fathom (nautical)**	= 6 ft
10 millimeters	= 1 centimeter	**1 league (nautical)**	= 5.556 km
10 centimeters	= 1 decimeter		= 3 nautical miles
10 decimeters (dm)	= 1 meter	**1 league (land)**	= 4.828 km
			= 5280 yd
10 meters	= 1 dekameter		= 3 mi
10 dekameters (dam)	= 1 hectometer	**1 international nautical mile**	= 1.852 km
			= 6076.1 ft
			= 1.151 mi

Water Units, Data Conversions, and Constants *(continued)*

AREA (L^2)

1 square centimeter (cm^2)	$= 1 \times 10^{-4} m^2$
	$= 0.1550\ in^2$
	$= 1.076 \times 10^{-3}\ ft^2$
	$= 1.\ 196 \times 10^{-4}\ yd^2$
1 square meter (m^2)	$= 1 \times 10^{-4}$ hectare
	$= 1 \times 10^{-6}\ km^2$
	= 1 centare (French)
	= 0.01 are
	$= 1550.0\ in^2$
	$= 10.76\ ft^2$
	$= 1.196\ yd^2$
	$= 2.471 \times 10^{-4}$ acre
1 are	$= 100\ m^2$
1 hectare (ha)	$= 1 \times 10^4\ m^2$
	= 100 are
	$= 0.01\ km^2$
	$= 1.076 \times 10^5\ ft^2$
	$= 1.\ 196 \times 10^4\ yd^2$
	= 2.471 acres
	$= 3.861 \times 10^{-3}\ mi^2$
1 square kilometer (km^2)	$= 1 \times 10^6\ m^2$
	= 100 hectares
	$= 1.076 \times 10^7\ ft^2$
	$= 1.\ 196 \times 10^6\ yd^2$
	= 247.1 acres
	$= 0.3861\ mi^2$
1 square inch (in^2)	$= 6.452\ cm^2$
	$= 6.452 \times 10^{-4}\ m^2$
	$= 6.944 \times 10^{-3}\ ft^2$
	$= 7.716 \times 10^{-4}\ yd^2$
1 square foot (ft^2)	$= 929.0\ cm^2$
	$= 0.0929\ m^2$
	$= 144\ in^2$
	$= 0.1111\ yd^2$
	$= 2.296 \times 10^{-5}$ acre
	$= 3.587 \times 10^{-8}\ mi^2$
1 square yard (yd^2)	$= 0.8361\ m^2$
	$= 8.361 \times 10^{-5}$ hectare
	$= 1296\ in^2$
	$= 9\ ft^2$
	$= 2.066 \times 10^{-4}$ acres
	$= 3.228 \times 10^{-7}\ mi^2$
1 acre	$= 4046.9\ m^2$
	= 0.40469 ha
	$= 4.0469 \times 10^{-3}\ km^2$
	$= 43{,}560\ ft^2$
	$= 4840\ yd^2$
	$= 1.5625 \times 10^{-3}\ mi^2$
1 square mile (mi^2)	$= 2.590 \times 10^6\ m^2$
	= 259.0 hectares
	$= 2.590\ km^2$
	$= 2.788 \times 10^7\ ft^2$
	$= 3.098 \times 10^6\ yd^2$
	= 640 acres
	= 1 section (of land)
1 feddan (Egyptian)	$= 4200\ m^2$
	= 0.42 ha
	= 1.038 acres

(continues)

Water Units, Data Conversions, and Constants *(continued)*

VOLUME (L^3)

1 cubic centimeter (cm^3)	$= 1 \times 10^{-3}$ liter
	$= 1 \times 10^{-6}$ m^3
	= 0.06102 in^3
	$= 2.642 \times 10^{-4}$ gal
	$= 3.531 \times 10^{-3}$ ft^3
1 liter (l)	= 1000 cm^3
	$= 1 \times 10^{-3}$ m^3
	= 61.02 in^3
	= 0.2642 gal
	= 0.03531 ft^3
1 cubic meter (m^3)	$= 1 \times 10^{6}$ cm^3
	= 1000 liter
	$= 1 \times 10^{-9}$ km^3
	= 264.2 gal
	= 35.31 ft^3
	= 6.29 bbl
	= 1.3078 yd^3
	$= 8.107 \times 10^{-4}$ acre-ft
1 cubic decameter (dam^3)	= 1000 m^3
	$= 1 \times 10^{6}$ liter
	$= 1 \times 10^{-6}$ km^3
	$= 2.642 \times 10^{5}$ gal
	$= 3.531 \times 10^{4}$ ft^3
	$= 1.3078 \times 10^{3}$ yd^3
	= 0.8107 acre-ft
1 cubic hectometer (ha^3)	$= 1 \times 10^{6}$ m^3
	$= 1 \times 10^{3}$ dam^3
	$= 1 \times 10^{9}$ liter
	$= 2.642 \times 10^{8}$ gal
	$= 3.531 \times 10^{7}$ ft^3
	$= 1.3078 \times 10^{6}$ yd^3
	= 810.7 acre-ft
1 cubic kilometer (km^3)	$= 1 \times 10^{12}$ liter
	$= 1 \times 10^{9}$ m^3
	$= 1 \times 10^{6}$ dam^3
	= 1000 ha^3
	$= 8.107 \times 10^{5}$ acre-ft
	= 0.24 mi^3
1 cubic inch (in^3)	= 16.39 cm^3
	= 0.01639 liter
	$= 4.329 \times 10^{-3}$ gal
	$= 5.787 \times 10^{-4}$ ft^2
1 gallon (gal)	= 3.785 liters
	$= 3.785 \times 10^{-3}$ m^3
	= 231 in^3
	= 0.1337 ft^3
	$= 4.951 \times 10^{-3}$ yd^3
1 cubic foot (ft^3)	$= 2.832 \times 10^{4}$ cm^3
	= 28.32 liters
	= 0.02832 m^3
	= 1728 in^3
	= 7.481 gal
	= 0.03704 yd^3
1 cubic yard (yd^3)	= 0.7646 m^3
	$= 6.198 \times 10^{-4}$ acre-ft
	= 46656 in^3
	= 27 ft^3
1 acre-foot (acre-ft or AF)	= 1233.48 m^3
	$= 3.259 \times 10^{5}$ gal
	= 43560 ft^3
1 Imperial gallon	= 4.546 liters
	= 277.4 in^3
	= 1.201 gal
	= 0.16055 ft^3
1 cfs-day	= 1.98 acre-feet
	= 0.0372 in-mi^2
1 inch-mi^2	$= 1.738 \times 10^{7}$ gal
	$= 2.323 \times 10^{6}$ ft^3
	= 53.3 acre-ft
	= 26.9 cfs-days
1 barrel (of oil) (bbl)	= 159 liter
	= 0.159 m^3
	= 42 gal
	= 5.6 ft^3
1 million gallons	= 3.069 acre-ft
1 pint (pt)	= 0.473 liter
	= 28.875 in^3
	= 0.5 qt
	= 16 fluid ounces
	= 32 tablespoons
	= 96 teaspoons
1 quart (qt)	= 0.946 liter
	= 57.75 in^3
	= 2 pt
	= 0.25 gal
1 morgen-foot (S. Africa)	= 2610.7 m^3
1 board-foot	= 2359.8 cm^3
	= 144 in^3
	= 0.0833 ft^3
1 cord	= 128 ft^3
	= 0.453 m^3

Water Units, Data Conversions, and Constants *(continued)*

VOLUME/AREA (L^3/L^2)			
1 inch of rain	= 5.610 gal/yd^2	**1 box of rain**	= 3,154.0 lesh
	= 2.715×10^4 gal/acre		
MASS (M)			
1 gram (g or gm)	= 0.001 kg	**1 ounce (oz)**	= 28.35 g
	= 15.43 gr		= 437.5 gr
	= 0.03527 oz		= 0.0625 lb
	= 2.205×10^{-3} lb	**1 pound (lb)**	= 453.6 g
1 kilogram (kg)	= 1000 g		= 0.45359237 kg
	= 0.001 tonne		= 7000 gr
	= 35.27 oz		= 16 oz
	= 2.205 lb	**1 short ton (ton)**	= 907.2 kg
1 hectogram (hg)	= 100 gm		= 0.9072 tonne
	= 0.1 kg		= 2000 lb
1 metric ton (tonne or te or MT)	= 1000 kg	**1 long ton**	= 1016.0 kg
	= 2204.6 lb		= 1.016 tonne
	= 1. 102 ton	**1 long ton**	= 2240 lb
	= 0.9842 long ton		= 1.12 ton
1 dalton (atomic mass unit)	= 1.6604×10^{-24} g	**1 stone (British)**	= 6.35 kg
			= 14 lb
1 grain (gr)	= 2.286×10^{-3} oz		
	= 1.429×10^{-4} lb		
TIME (T)			
1 second (s or sec)	= 0.01667 min	**1 day (d)**	= 24 hr
	= 2.7778×10^{-4} hr		= 86400 s
1 minute (min)	= 60 s	**1 year (yr or y)**	= 365 d
	= 0.01667 hr		= 8760 hr
1 hour (hr or h)	= 60 min		= 3.15×10^7 s
	= 3600 s		
DENSITY (M/L^3)			
1 kilogram per cubic meter (kg/m^3)	= 10^{-3} g/cm^3	**1 metric ton per cubic meter (te/m^3)**	= 1.0 specific gravity
	= 0.062 lb/ft^3		= density of H_2O at 4°C
1 gram per cubic centimeter (g/cm^3)	= 1000 kg/m^3		= 8.35 lb/gal
	= 62.43 lb/ft^3	**1 pound per cubic foot (lb/ft^3)**	= 16.02 kg/m^3

(continues)

Water Units, Data Conversions, and Constants *(continued)*

VELOCITY (L/T)

1 meter per	= 3.6 km/hr	**1 foot per second**	= 0.68 mph
second (m/s)	= 2.237 mph	**(ft/s)**	= 0.3048 m/s
	= 3.28 ft/s	**velocity of light in**	= 2.9979×10^8 m/s
1 kilometer per	= 0.62 mph	**vacuum (c)**	= 186,000 mi/s
hour (km/h	= 0.278 m/s	**1 knot**	= 1.852 km/h
or kph)			= 1 nautical
1 mile per hour	= 1.609 km/h		mile/hour
(mph or mi/h)	= 0.45 m/s		= 1.151 mph
	= 1.47 ft/s		= 1.688 ft/s

VELOCITY OF SOUND IN WATER AND SEAWATER
(assuming atmospheric pressure and sea water salinity of 35,000 ppm)

Temp, °C	Pure water, (meters/sec)	Sea water, (meters/sec)
0	1,400	1,445
10	1,445	1,485
20	1,480	1,520
30	1,505	1,545

FLOW RATE (L^3/T)

1 liter per second	= 0.001 m^3/sec	**1 cubic decameters**	= 11.57 1/sec
(1/sec)	= 86.4 m^3/day	**per day (dam³/day)**	= 1.157×10^{-2}
	= 15.9 gpm		m^3/sec
	= 0.0228 mgd		= 1000 m^3/day
	= 0.0353 cfs		= 1.83×10^6 gpm
	= 0.0700 AF/day		= 0.264 mgd
1 cubic meter per	= 1000 1/sec		= 0.409 cfs
second (m³/sec)	= 8.64×10^4 m^3/day		= 0.811 AF/day
	= 1.59×10^4 gpm	**1 gallon per minute**	= 0.0631 1/sec
	= 22.8 mgd	**(gpm)**	= 6.31×10^{-5}
	= 35.3 cfs		m^3/sec
	= 70.0 AF/day		= 1.44×10^{-3} mgd
1 cubic meter per	= 0.01157 1/sec		= 2.23×10^{-3} cfs
day (m³/day)	= 1.157×10^{-5}		= 4.42×10^{-3}
	m^3/sec		AF/day
	= 0.183 gpm	**1 million gallons**	= 43.8 1/sec
	= 2.64×10^{-4} mgd	**per day (mgd)**	= 0.0438 m^3/sec
	= 4.09×10^{-4} cfs		= 3785 m^3/day
	= 8.11×10^{-4}		= 694 gpm
	AF/day		= 1.55 cfs
			= 3.07 AF/day

Water Units, Data Conversions, and Constants *(continued)*

FLOW RATE (L^3/T) (continued)

1 cubic foot per second (cfs)	= 28.3 1/sec = 0.0283 m^3/ sec = 2447 m^3/day = 449 gpm = 0.646 mgd = 1.98 AF/day
1 acre-foot per day (AF/day)	= 14.3 1/sec = 0.0143 m^3/sec = 1233.48 m^3/day = 226 gpm = 0.326 mgd = 0.504 cfs
1 miner's inch	= 0.025 cfs (in Arizona, California, Montana, and Oregon: flow of water through 1 in^2 aperture under 6-inch head)
1 miner's inch	= 0.02 cfs (in Idaho, Kansas, Nebraska, New Mexico, North Dakota, South Dakota, and Utah) = 0.026 cfs (in Colorado) = 0.028 cfs (in British Columbia)
1 weir	= 0.02 garcia
1 quinaria (ancient Rome)	= 0.47–0.48 1/sec

ACCELERATION (L/T^2)

standard acceleration of gravity	= 9.8 m/s^2 = 32 ft/s^2

FORCE (ML/T^2 = Mass × Acceleration)

1 newton (N)	= kg-m/s^2 = 10^5 dynes = 0.1020 kg force = 0.2248 lb force
1 dyne	= g·cm/s^2 = 10^{-5} N
1 pound force	= lb mass × acceleration of gravity = 4.448 N

(continues)

Water Units, Data Conversions, and Constants *(continued)*

PRESSURE (M/L^2 = Force/Area)	
1 pascal (Pa)	= N/m^2
1 bar	= 1×10^5 Pa
	= 1×10^6 dyne/cm^2
	= 1019.7 g/cm^2
	= 10.197 te/m^2
	= 0.9869 atmosphere
	= 14.50 lb/in^2
	= 1000 millibars
1 atmosphere (atm)	= standard pressure
	= 760 mm of mercury at 0°C
	= 1013.25 millibars
	= 1033 g/cm^2
	= 1.033 kg/cm^2
	= 14.7 lb/in^2
	= 2116 1b/ft^2
	= 33.95 feet of water at 62°F
	= 29.92 inches of mercury at 32°F
1 kilogram per sq. centimeter (kg/cm^2)	= 14.22 lb/in^2
1 inch of water at 62°F	= 0.0361 lb/in^2
	= 5.196 lb/ft^3
	= 0.0735 inch of mercury at 62°F
1 foot of water at 62°F	= 0.433 lb/in^2
	= 62.36 lb/ft^2
	= 0.833 inch of mercury at 62°F
	= 2.950×10^{-2} atmosphere
1 pound per sq. inch (psi or lb/in^2)	= 2.309 feet of water at 62°F
	= 2.036 inches of mercury at 32°F
	= 0.06804 atmosphere
	= 0.07031 kg/cm^2
1 inch of mercury at 32°F	= 0.4192 lb/in^2
	= 1.133 feet of water at 32°F

TEMPERATURE	
degrees Celsius or Centigrade (°C)	= (°F–32) × 5/9
	= K–273.16
Kelvins (K)	= 273.16 + °C
	= 273.16 + ((°F- 32) × 5/9)
degrees Fahrenheit (°F)	= 32 + (°C x 1.8)
	= 32 + ((°K–273.16) × 1.8)

Water Units, Data Conversions, and Constants *(continued)*

ENERGY(ML^2/T^2 = Force × Distance)

1 joule (J)	= 10^7 ergs	**1 kilowatt-hour**	= 3.6×10^6 J
	= N·m	**(kWh)**	= 3412 Btu
	= W·s		= 859.1 kcal
	= kg·m²/s²	**l quad**	= 10^{15} Btu
	= 0.239 calories		= 1.055×10^{18}J
	= 9.48×10^{-4} Btu		= 293×10^9 kWh
1 calorie (cal)	= 4.184 J		= 0.001 Q
	= 3.97×10^{-3} Btu		= 33.45 GWy
	(raises 1 g H_2O l°C)	**1 Q**	= 1000 quads
			≈ 10^{21} J
1 British thermal unit (Btu)	= 1055 J	**1 foot-pound (ft-lb)**	= 1.356 J
	= 252 cal (raises		= 0.324 cal
	1 lb H_2O l°F)	**1 therm**	= 10^5 Btu
	= 2.93×10^{-4} kWh	**1 electron-volt (eV)**	= 1.602×10^{-19} J
1 erg	= 10^{-7} J	**1 kiloton of TNT**	= 4.2×10^{12} J
	= g·cm²/s²	**1 10^6 te oil equiv.**	= 7.33×10^6 bbl oil
	= dyne·cm	**(Mtoe)**	= 45×10^{15} J
1 kilocalorie (kcal)	= 1000 cal		= 0.0425 quad
	= 1 Calorie (food)		

POWER (ML^2/T^3 = rate of flow of energy)

1 watt (W)	= J/s	**1 horsepower**	= 0.178 kcal/s
	= 3600 J/hr	**(H.P. or hp)**	= 6535 kWh/yr
	= 3.412 Btu/hr		= 33,000 ft-lb/min
1 TW	= 10^{12}W		= 550 ft-lb/sec
	= 31.5×10^{18} J		= 8760 H.P.-hr/yr
	= 30 quad/yr	**H.P. input**	= 1.34 × kW input to motor
1 kilowatt (kW)	= 1000W		= horsepower input to motor
	= 1.341 horsepower		
	= 0.239 kcal/s		
	= 3412 Btu/hr	**Water H.P.**	= H.P. required to lift water at a definite rate to a given distance assuming 100% efficiency
10^6 bbl (oil) /day (Mb/d)	≈ 2 quads/yr		
	≈ 70 GW		
1 quad/yr	= 33.45 GW		
	≈ 0.5 Mb/d		
1 horsepower	= 745.7W		
(H.R or hp)	= 0.7457 kW		= gpm × total head (in feet)/3960

(continues)

Water Units, Data Conversions, and Constants *(continued)*

EXPRESSIONS OF HARDNESS[a]

1 grain per gallon	= 1 grain $CaCO_3$ per U.S. gallon	**1 French degree**	= 1 part $CaCO_3$ per 100,000 parts water
1 part per million	= 1 part $CaCO_3$ per 1,000,000 parts water	**1 German degree**	= 1 part CaO per 100,000 parts water
1 English, or Clark, degree	= 1 grain $CaCO_3$ per Imperial gallon		

CONVERSIONS OF HARDNESS

1 grain per U.S. gallon	= 17.1 ppm, as $CaCO_3$	**1 French degree**	= 10 ppm, as $CaCO_3$
1 English degree	= 14.3 ppm, as $CaCO_3$	**1 German degree**	= 17.9 ppm, as $CaCO_3$

WEIGHT OF WATER

1 cubic inch	= 0.0361 lb	**1 imperial gallon**	= 10.0 lb
1 cubic foot	= 62.4 lb	**1 cubic meter**	= 1 tonne
1 gallon	= 8.34 lb		

DENSITY OF WATER[a]

Temperature		Density
°C	°F	gm/cm^3
0	32	0.99987
1.667	35	0.99996
4.000	39.2	1.00000
4.444	40	0.99999
10.000	50	0.99975
15.556	60	0.99907
21.111	70	0.99802
26.667	80	0.99669
32.222	90	0.99510
37.778	100	0.99318
48.889	120	0.98870
60.000	140	0.98338
71.111	160	0.97729
82.222	180	0.97056
93.333	200	0.96333
100.000	212	0.95865

Note: Density of Sea Water: approximately 1.025 gm/cm^3 at 15°C.

[a]*Source:* van der Leeden, F., Troise, F. L., and Todd, D. K., 1990. *The Water Encyclopedia*, 2d edition. Lewis Publishers, Inc., Chelsea, Michigan.

Comprehensive Table of Contents

Volume 1
The World's Water 1998-1999: The Biennial Report on Freshwater Resources

P.H. Gleick (ed.), *The World's Water Volume 7: The Biennial Report on Freshwater Resources*, The World's Water, DOI 10.5822/978-1-61091-048-4,

Volume 2

The World's Water 2000-2001: The Biennial Report on Freshwater Resources

Volume 3

The World's Water 2002-2003: The Biennial Report on Freshwater Resources

DATA SECTION 237

Water Units, Data Conversions, and Constants 318

Index 329

Volume 4

The World's Water 2004-2005: The Biennial Report on Freshwater Resources

Volume 5
The World's Water 2006-2007: The Biennial Report on Freshwater Resources

DATA SECTION

Volume 6
The World's Water 2008-2009: The Biennial Report on Freshwater Resources

DATA SECTION

WATER UNITS, DATA CONVERSIONS, AND CONSTANTS 343

COMPREHENSIVE TABLE OF CONTENTS 353

Volume 7

The World's Water Volume 7: The Biennial Report on Freshwater Resources

DATA SECTION

Comprehensive Table of Contents

KEY (book volume in boldface numerals)
1: The World's Water 1998-1999: The Biennial Report on Freshwater Resources
2: The World's Water 2000-2001: The Biennial Report on Freshwater Resources
3: The World's Water 2002-2003: The Biennial Report on Freshwater Resources
4: The World's Water 2004-2005: The Biennial Report on Freshwater Resources
5: The World's Water 2006-2007: The Biennial Report on Freshwater Resources
6: The World's Water 2008-2009: The Biennial Report on Freshwater Resources
7: The World's Water Volume 7: The Biennial Report on Freshwater Resources