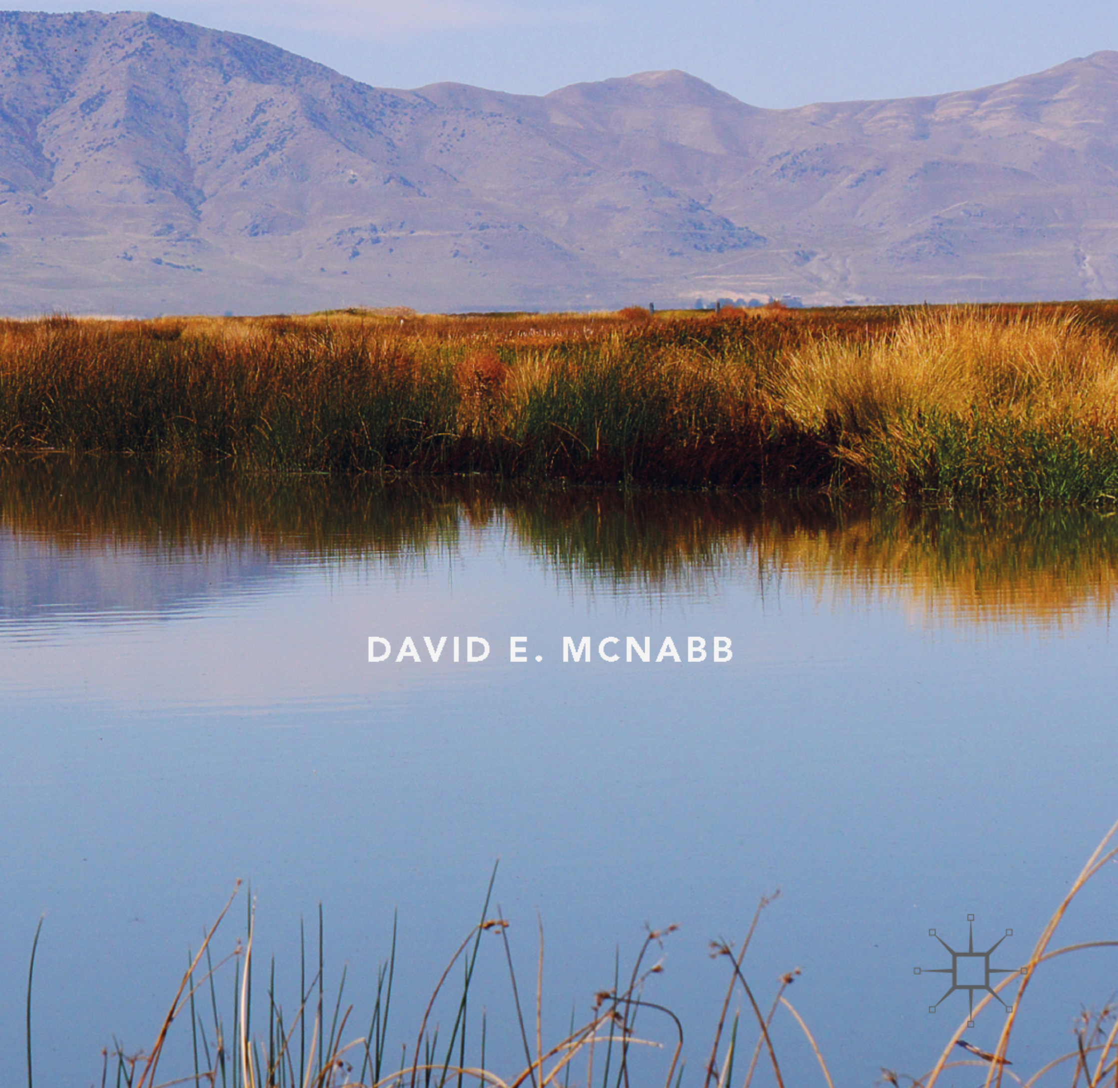
WATER RESOURCE MANAGEMENT

SUSTAINABILITY IN AN ERA OF CLIMATE CHANGE



DAVID E. MCNABB

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Sustainability in an Era of Climate Change

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America's water resources—streams, rivers, wetlands, estuaries, lakes and coasts—are at the heart of our environment, our economy and out history. The quality and quantity of water resources affect all levels of our society from the national to the individual citizen.

A nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of its shortsightedness. The hard lessons of history are clear, written on the deserted sands and ruins of once-proud civilizations.

President Lyndon B. Johnson
Message submitting to Congress the first assessment
of the Nation's water resources, 1968

For the men and women who toil in the Nation's water world.

Preface

This book is about how water managers in the United States are responding to the call for increased effort to achieve sustainable supplies of clean fresh water for the present and future generations. Water managers face many barriers in their efforts to achieve sustainability in the supply of this resource. While water is indeed one of life's most essential commodities, in many parts of the country it is one of, if not the, most stressed resources. Americans traditionally have shown a disregard for the way they treat the finite supply of water. Streams and lakes are still considered by too many to be convenient places to discard waste.

Today, water managers must deal with a multifaceted complex of water-related challenges. Water management has been most concerned with eliminating water pollution. But recent climate trends have shown that our concerns can no longer be just about ensuring the water we drink and use for our showers is safe to drink.

There will always be a need to ensure first the fresh water we drink and use in the production of our food is clean and safe for human consumption. At the same time, however, we find better ways to supply sufficient water needed to generate the electricity we use to power our air conditioning and light our cities and to irrigate the food crops needed for sustenance.

Water resource management is the human activity of planning, developing, processing, storing, distributing, and managing the optimum use of the available water resource—whether it is for a local water utility service area, a watershed, a state, a multistate region, or for a nation, water resource managers must consider the competing demands for current and future availability of water in order to arrive at a solution that assures equitable allocation of available water on a sustainable basis.

Water management is as much about what is mistakenly called wastewater as it is about the water for consumption; what was once considered to be wastewater is increasingly being into recycled into water for reuse in our homes, industries, and farms. This important resource at is now an integral component of water management, just as has the stormwater that refreshes our aquifers even while it often floods huge swaths of land, and pollutes our rivers, lakes, and aquifers. In many coastal areas, advanced technology has made desalinated seawater is now a valued addition to the overall water supply.

The core theme in the book is the need to manage all aspects of these limited sources of supply in an increasingly hostile environment. It seeks to explain how the men and women working in water management are bringing the once separate classes of water together in ways that will be need to achieve sustainability of the resource. Water managers must consider effects of water supplies on the economy, environment, and society in an integrated way. The goal for all of us is to ensure that a reliable supply of clean, safe water is available when and where it is needed by today's generation and those that will follow. We can get by without a lot of things, but we can't get by without water.

What do we mean by water management? According to the World Bank, water resource management is the human activity of planning, developing, processing, storing, distributing, and managing the optimum use of available water resource. The responsibilities of water managers are the same, regardless of whether it is for a local water utility, a watershed, a state, a multistate region, or for a nation, water resource managers must consider the competing demands for current and future availability of water in order to arrive at a solution that assures equitable allocation of available water on a sustainable basis (World Bank 2003).

The US water management story, in a sense, begins with an assessment of the state of the resource in the major basins in the first decades of this century. It goes on to paint a picture of how the industry, its regulators, and its major stakeholders arrived at this critical juncture. It concludes with several chapters on how water managers are moving toward a more holistic, innovative, and collaborative approach to managing the resource so that the elusive goal of a sustainable resource is there for today, tomorrow and for future generations as well. The task is not an easy one. In many ways, the cards are stacked against water managers achieving their goals. Global warming, changing precipitation patterns, population growth, and continuing urbanization place barriers in the way of overcoming these challenges and others.

Acknowledgments

As always, I thank the administration and faculty of the Pacific Lutheran University School of Business for their exceptional assistance and support for the past more than 35 years. I am also very thankful to Ayswaraya Nagarajan for her extensive support in bringing out this book.

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The State of America's Water Resource

> *As a whole the nation has abundant water resources with average annual precipitation of 30 inches for the conterminous United States, average natural runoff of 1,200 billion gallons per day, and large reserves of water underground. However, the Nation is less fortunate in the distribution and timing of the water resources.*
>
> USWRC 1968, First National Assessment of the Nation's Water Resources

The Water Resources Council (WRC), established by the US Water Resources Planning Act of 1965, prepared two national assessments of the state of the water resource, the first was published in 1968 and the second in 1978. The council was made up of Department Secretaries and agency heads that monitored national and regional water supplies, coordinated federal, state, regional, and river basin water programs and administered grant and loan program to states for water resources planning. The assigned functions of the WRC included requirements to "maintain a continuing study and prepare periodically an assessment of the adequacy of the supplies of water necessary to meet the water requirements in each water resources region in the United States . . . [and] to maintain a

D.E. McNabb, *Water Resource Management*,
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continuing study of the relation of regional or river basin plans and programs to the requirements of the larger regions of the Nation" (WRC 1968, xi). The Council was dissolved on October 31, 1982, with most of the recording and management responsibilities returned to the US Geological Survey (USGS) in the Department of the Interior.

Today, the USGS collects water data for 21 water resource regions (hydrologic units) of the United States (Fig. 1.1); 18 of the units are in the conterminous 48 states, with a separate region each for Alaska, Hawaii, and for the Puerto Rico and the American Virgin Islands. Data are collected for such information categories as stream flow, groundwater and surface levels, precipitation, temperature, and water use and quality, among others.

The water industry is facing an increasingly complex and challenging future: suppliers must surmount daily operational challenges associated with pumping, treating, and supplying safe and affordable water supplies

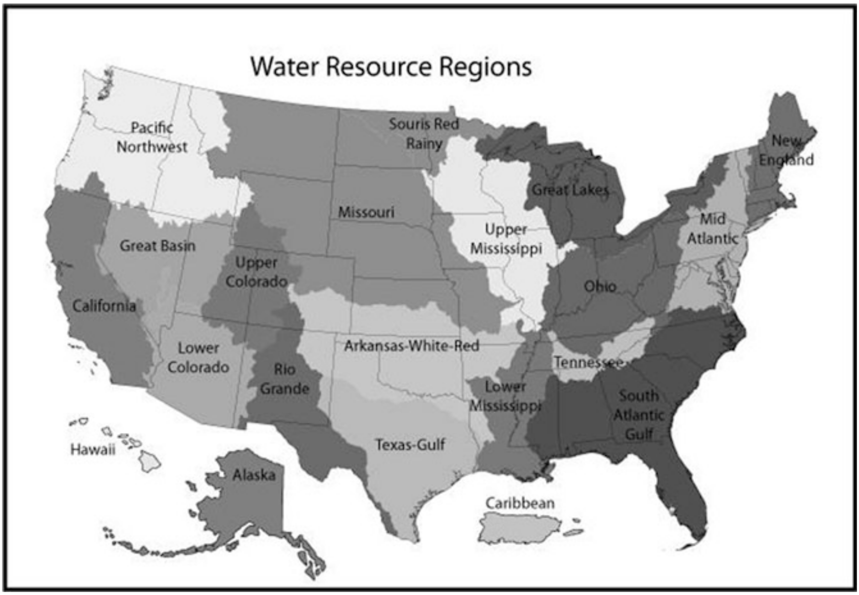

Fig. 1.1 USGS water resource regions (hydrologic units) of the United States
Source: USGS

to a growing population while many are finding their traditional supplies fast disappearing. Planning for sustainability is absolutely necessary for sourcing, treatment, storage, and delivery of freshwater and for the collection, treatment, and the recycling and discharge of wastewater in this exceedingly challenging environment has never been more vital than it is today.

The United States is blessed with a large and reliable supply of freshwater. Only Brazil and Nepal have a greater supply (Table 1.1). Yet, large portions of the United States are finding it increasingly difficult to find reliable sources of potable water to supply their customer base during what has become a period of global climate change. Some communities have to deal with excessive rainstorms with insufficient stormwater collection and discharge facilities, while others must cope with declining supplies while living through longer and longer periods of

Table 1.1 Top ten nations with available water resources and 5-year precipitation averages

	Total available freshwater			Annual precipitation[b]	
Rank	Nation	Cubic kilometers[a]	US Gallons	Inches	Millimeters
1	Brazil	8,233	2,174,928,497,875,386	69.33	1,761
2	Nepal	4,508	1,190,887,606,998,936	59.06	1,500
3	United States[c]	3,069	810,744,025,261,698	28.15	715
4	Canada	2,902	766,627,292,704,284	21.14	537
5	China	2,840	750,248,625,527,280	25.39	645
6	Colombia	2,132	563,214,813,247,944	127.56	3,240
7	Indonesia	2,019	533,363,371,457,598	106.38	2,702
8	Peru	1,913	505361,134,025,946	68.43	1,738
9	Russian Federation	1,911	504,832,789,923,462	15.11	460
10	Congo, Dem. Rep.	1,283	338,932,741,743,486	60.75	1,543

Notes
[a]One cubic kilometer = 264.17 US gallons
[b]Includes rain and snow, 2011–2015 averages
[c]Excludes Alaska and Hawaii
Sources: CIA World Fact Book, World Bank, Conversion Tables

severe drought. The world may still have plenty of water; but, only something like 2.5 percent of all that water is potable water. Moreover, not all of the freshwater is available when and where it is needed. This chapter takes a basin approach to describing the state of the resource within the lower 48 states.

Freshwater in a Salt Water World

The USGS has described the globe as indeed “a watery place,” but adds that nearly all of it is not available as drinking water for human consumption. More important, current misuse of the existing freshwater supplies has resulted in contamination of many of the limited sources of supply of water that is potable while long-term droughts and higher temperatures are drying up many of the traditional resources. Contamination from man-made and natural causes has made many existing freshwater sources no longer fit for human consumption without extensive treatment. A recent example of a combination of human and natural effects groundwater is the damage done to the groundwater supplies in sections of California. That state’s s rich agricultural Central Valley has been particularly hard hit. Drought has reduced the availability of surface water, resulting in over withdrawal of the groundwater aquifer. In addition, water pumped from private and municipal wells in many sections of the Valley has been found to be contaminated by high levels of naturally occurring uranium. Similar problems are surfacing in other areas of the country’s Western states as a result of drought conditions and over-pumping primarily for irrigation.

Close to 96.5 percent of all Earth’s water is in the world’s oceans. The freshwater that is available for human use is stored in the air as water vapor, in rivers and lakes, in icecaps and glaciers, in the ground as soil moisture and underground aquifers. These freshwater resources provided the earth’s 7.3 billion people in 2015 with the water they needed every day to live, and will have to continue to do so for the estimated 11 billion inhabitants alive at the end of this century.

The combined forces of climate change, population growth, and population relocation are, as expected, making it increasingly difficult to serve customers with all the freshwater they need as a price they can afford. Desalination can generate enough water to augment demand in coastal regions, but not for residents hundreds and thousands of miles inland. Clearly, the country's water suppliers must find new resources. One still somewhat controversial source that is becoming increasingly viable is recycled or reclaimed water. One of the country's early programs is the El Paso Water Utilities (EPWU) advanced water purification system. In good water supply years, El Paso gets its water from stored surface water and groundwaters. However, the continuing drought in the Southwest has left the district's reservoirs at 10 percent of their capacity or less. The EPWU has long used reclaimed water for non-potable reuse and for recharging the local aquifer. In 2012, the utility began a feasibility study of the increasing the capacity of advanced wastewater purification for use in aquifer recharging and other potential uses.

People in the United States and most of the water-scarce regions of the world are still far from accepting the direct reuse of reclaimed wastewater directly into municipal freshwater delivery systems. This reluctance to accept recycled water is what is often referred to as the "yuck factor" (Stenekes et al. 2006). Still, water suppliers are finding more and more non-human consumption uses for recycled water. Industry leaders and federal regulators agree that until a global standard for membrane technology that produces the desired water quality is accepted and strict guidelines, the reuse of treated wastewater is not likely to become a sizeable quantity of new supply for the municipal water utilities of the country. Climate change has brought that acceptance much closer than might otherwise have been the case.

Water Statistics

Water use statistics in the United States have been recorded and published by the USGS every five years since 1950. These statistics record how these eight categories of water users consume: fresh and saline water, public supply (domestic, commercial, and municipal supplied by public and private utilities), domestic (self-supplied or by public suppliers) irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power generation). Water withdrawals are measured when water is removed from a source for any use and measured in gallons per day in acre feet (enough water to cover one acre of water one foot deep).

As later chapters will support, water resources and its policies in the United States are both dynamic and diverse. The key product of this is that the United States continues to lack a single, cohesive national water policy. However, the many diverse governance and policy structures at the federal, state, and local levels this may be an impossible task to accomplish (Reimer 2012).

The water and wastewater sectors of the nation are facing an increasingly complex and challenging future, and the very people who should be solving the problems are making them worse.

Planning for sustainability is absolutely necessary for sourcing, treating, storing, and delivering freshwater and for the collection, treatment, and the recycling and discharge of wastewater in this exceedingly challenging environment affected by climate change has never been more vital than it is today.

River Basins and Watersheds[1]

Hydrologists and other water management scientists in the United States evaluate the state of the resources by taking a basin approach. River basins are important from hydrological, economic, and ecological points of view. They absorb and channel most the runoff from snowmelt and rainfall that can ultimately supply fresh drinking water as well as support hydropower, agricultural irrigation, and recreational opportunities. River basins have also formed a critical link between land and sea, providing transportation routes for people, and making it possible for fish to migrate between marine and freshwater systems.

[1] This discussion of the factors that influence selected regions of the US water supply has been adapted from a number of federal weather and natural resource sources, including NOAA, USGS, Bureau of Reclamation, the EPA, and the US Global Change Research Program's National Climate Assessment (NCA), and other cited in-text.

Rivers, streams, and wetlands in a composite basin act as natural filters and sponges, cleansing and storing water for later use. Basins play a role in water purification, water retention, and regulation of floods. These often very large-scale ecosystems include forest and grassland and marshes as well as rivers, lakes with other components.

Hydrologists around the globe employ the integrated river basin approach when analyzing a surface water system for its sustainability for human use and for maintaining a healthy natural environment. This coordinated approach focus on the economic and social benefits derived from the human use of water resources while conserving and, where necessary, restoring freshwater ecosystems. In the United States, the Bureau of Reclamation is largely responsible management of the river basins in the Western United States; in the Eastern half of the country, the USGS provides much of the same service.

The USGS gathers water data from 21 separate regions, including 18 in the 48 contiguous states and one each in Alaska, Hawaii, and the US Caribbean islands (Fig. 1.1). Agencies dealing with the nation's river basins divide the country into a smaller number of distinct regions: 9 in the lower 48 states and one each in Alaska and Hawaii. The following pages use data from both sources to describe the state of the resource in several of the larger basins and watersheds, beginning with the Northwest/Pacific region with its Columbia River and Snake River Basin. This is followed by the California Region and its two great Central Valley watersheds, the Southwest and its Upper and Lower Colorado River Basin (LCRB), considered to be the most important watershed in the Southwestern United States. Also discussed are the Great Plains/Northern Rockies region, the Midwest/Great Lakes region, and the Northeast and Southeast regions.

The Pacific Northeast and the Columbia River Basin

The 1,240-mile long Columbia River Basin extends across the states of Idaho, Montana, Nevada, Oregon, Washington and Wyoming, and parts of southern British Columbia, Canada (Fig. 1.2). The dominant

Fig. 1.2 Map of the Columbia River Basin with location of major dams
Source: USGS

watersheds in this region are built around the two main rivers, the Columbia and the Snake, their tributaries and such other important rivers as the Willamette, Klamath, and Umpqua in Oregon and the Yakima, Chehalis, and the Skagit in Washington. The Columbia River and its tributaries supplies water for municipal suppliers serving eight million people, irrigation water for approximately 7.8 million acres, and hydropower that meets from 60 to 70 percent of the electric power needs of the needs of the Pacific Northwest. While there are something like 400 dams in the region, the most important ones are the 31 major federal dams of the Federal Power System. The Bureau of Reclamation manages more than 50 dams and reservoirs in the Pacific Northwest region, with a combined storage capacity of more than 18 million acre-feet.

The Northwest is often considered an "excessively rainy place," but that is true only for the Pacific coastal regions of the Oregon and Washington, as much as 200 inches of rain per year can be found. Most of the precipitation falls west of the coastal mountain ranges and the Cascade Mountain range, keeping the eastern half of Oregon and Washington in a rain shadow. Most of the precipitation falls between October and March, with summers often quite dry. The mountain snowpack has historically functioned as natural storage for summer water needs. However, the region's warmer climate is resulting in far less snow, particularly at lower and mid-level mountain regions.

The 1964 Columbia River Treaty

Currently, both the United States and Canada play a role in managing the basin's water. The Columbia River Treaty was signed in 1961 and went into effect in 1964. Flooding and a steady water supply for hydropower generation were the two main concerns that led to the treaty. However, use of the water for municipal supplies and for irrigation were not included in the negotiations leading to the treaty. And now, the treaty is close to expiring. Since September 16, 2014, both countries have been able, with 10 years' notice, unilaterally to opt out of the treaty. The United States and Canada entered into the treaty in 1964. At that time, the focus was on flood control and hydroelectric power generation. Because warmer temperatures limited snowpack and summer water supply limits on the horizon in Washington, Oregon and Idaho, a greater concern has become the use of Columbia Basin water to irrigate the region's many farms and ranches. The Columbia River Treaty

(CRT) grew out of the United States' and Canada's mutual interest in controlling and harnessing the Columbia River system.

The CRT has two key components: (1) Canada's pledge to provide more than 15 million acre-feet of reservoir space that can be used for improving the flow of the Columbia River, and to operate that storage to maximize hydroelectric power generation and limit flooding in the United States and Canada and (2) the United States' promise to pay Canada for the benefits. The growing need for irrigation water and the failure of the treaty to take irrigation needs into effect were described thus:

> The original CRT used the word "irrigation" only once, and "consumptive use" twice. The phrase "water supply" does not appear at all. In other words, the CRT, which focused almost solely on hydropower and flood control, gave virtually no thought to consumptive water uses. That the CRT largely ignored out-of-stream water uses, however, is not to say they are unimportant in the Columbia Basin. Far from it, in the United States alone, approximately 7.1 million acres are currently under irrigation in the Basin. As measured at The Dalles, Oregon, 9 percent of the Columbia's flow is diverted for agriculture. Right now, there is considerable demand among irrigators for more (MacDougal and Kearns 2014).

From 2014 forward either the United States or Canada may terminate the CRT with 10 years' notice. And, even if neither nation opts out, important provisions relating to flood control will expire automatically in 2024, and possibly no provisions for other important water uses will be negotiated. The Bureau of Reclamation voiced its concern in 2016 that, due to changes in water supply due to climate change, there is growing concern that the Columbia River system will not be able to meet the future water needs already allotted, let alone allow for increases in withdrawals for irrigation. Key findings released in 2016 by the Pacific Northwest Region Hydromet and included in the Reclamation Bureau's 2016 climate change and water supply study were:

- Pacific Northwest temperatures are predicted to continue increase rapidly over the rest of the century with the greatest changes in the summer months.

- Projected precipitation models suggest the Pacific Northwest will see drier summers and wetter autumns and winters. Precipitation falling as rain instead of snow will increase winter runoff and reduce summer runoff, reducing water availability for irrigation.
- Snowpack accumulations will decline due to warmer temperatures; snowmelt will begin earlier in many subbasins, particularly in low and mid-level elevations. The shift in snowmelt runoff threaten problems with flood control and irrigation supply as more water runs off in late winter and early spring.
- The decreased snowpack may result in decreases in groundwater infiltration, further reducing river flows in summer months.
- The expected longer growing season will result in increased demands for irrigation water.
- Warmer temperatures will increase demand for power for air conditioning when less water is available.

California and the Central Valley River Basins

The state of the water resource in California is monitored by the USGS, with an emphasis on the two major river basins in the California Central Valley, the Sacramento and the San Joaquin Rivers. The EPA, which is responsible for maintaining water quality in all surface and groundwater resources, includes the entire Central Valley in the San Francisco Bay Delta watershed (Fig. 1.3). This river basin covers more than 75,000 square miles and includes the largest estuary on the west coasts of North and South America. It also contains the only inland delta in the world.

The watershed extends nearly 500 miles from the Cascade Range in the north to the Tehachapi Mountains in the south, and is bounded by the Sierra Mountain Range to the east and the Coast Range to the west. Nearly half of the surface water in California starts as rain or snow that falls within this watershed and flows downstream in the two main rivers to the Pacific Ocean at San Francisco. In addition, the watershed provides a primary source of drinking water for 25 million

Fig. 1.3 The San Francisco Bay watershed and three major river basins
Source: EPA

Californians, irrigation for 7,000 square miles of agriculture, and includes important economic resources such as California's water supply infrastructure, ports, deepwater shipping channels, major highway and railroad corridors, and for energy generation. In the Delta, declining water quality and increasing demand for limited water resources is the subject of research and planning to protect this valuable resource for the future; some scientists worry that the efforts to save the Delta are too little and too late. The watershed includes a diversity of freshwater, brackish water, and saltwater aquatic habitats. Several endangered and threatened aquatic species are found here including delta smelt, steelhead, spring run Chinook salmon, winter run Chinook salmon, and others.

Monitoring and reporting of the water supply of the basins is managed by the USGS, together with other federal, state, and local agencies. However, a much large consortium of agencies has organized to study the system and recommend steps to preserve its sustainability. The Sacramento and San Joaquin Basins Study (SSJBS) is a partnership between the U.S. Reclamation Bureau, California Department of Water Resources, California Partnership for the San Joaquin Valley, Stockton East Water District, El Dorado County Water Agency, the Madera County Resources Management Agency, and several other local and regional associations also participate. The scope of the SSJBS takes in the entire Central Valley of California with an area of more than 22,500 square miles from the Tehachapi Range in the South to the Klamath Mountains in the north. The Central Valley Project (CVP) and the California State Water Project (CSWP) are the main water management operations in the Central valley. The CVP includes of 20 dams, 11 power plants, and more than 500 miles of canals. The State-owned and operated CSWP distributes water from Lake Oroville on the feather river to municipal and agricultural water users in the central valley and the central and southern coastal areas.

The largest rivers in the watershed are the 455-mile-long Sacramento that drains the northern half of the state, and the 366-mile-long San Joaquin that drains the central and southern portions of the Valley. Both rivers low into the Sacramento Delta which exits into San Francisco Bay. With the smaller Tulare River basin in the southern Central Valley, the watershed covers come 60,000 square miles. Agriculture, which withdraws an annual average of 5.4 million acre feet of the total water in the watershed, is the major user of water from the three river basins and irrigates about three million acres of land. Hydropower, municipal water supply, recreation, and flood control are other major users. The

Sacramento and San Joaquin River watersheds supply, either directly as surface water or indirectly via groundwater recharge, much of the water used by California cities and farms.

The California Drought

The water years of 2012–2014 (extending through the winter months of 2015) were California's driest three consecutive years in terms of statewide precipitation. The previous drought of statewide scale that occurred in 2007–2009 was the first for which a statewide proclamation of emergency was issued; the three-year 2012–2014 period was the second.

California's most significant historical statewide droughts were the six-year drought of 1929–1934, the two-year drought of 1976–1977, and the six-year event of 1987–1992. Those droughts stand out in the observed record due to their duration or reductions in precipitation. The 1929–1934 event occurred within a decade-plus dry period in the 1920s–1930s, and was one of the most severe dry periods in more than a thousand years of reconstructed Central Valley data. The drought's impacts were small by present-day standards, however, because the state's development at the time was small compared to modern times. The 1976–1977 drought, although brief, was notable for the dryness of the period. The 1987–1992 drought was California's first extended dry period since the 1920s–1930s, and provides the closest comparison for drought impacts under a present-day level of development.

The drought that began in 2012 set other records in addition to that of driest three-year period of statewide precipitation. The drought occurred at a time of record warmth in California, with new climate records set in 2014 for statewide average temperatures. Records for minimum annual precipitation were set in many communities in calendar year 2013. Calendar year 2014 saw record-low water allocations for State Water Project and federal Central Valley Project contractors. Reduced surface water availability triggered increased groundwater pumping, with groundwater levels in many parts of the state dropping 50–100 feet below their previous historical lows. Heavy rains and a substantial Sierra snowpack over the 2016–2017 winter alleviated drought, but California water planners must continue to expect more and longer drought periods.

California's Water Supply

California's proximity to the Pacific Ocean and major mountain ranges from the state's hydroclimate setting. Most of the water vapor that provides the state's precipitation comes from the Pacific Ocean; as moist air moves over mountains such as the Sierra Nevada or Transverse Ranges the air is lifted and cooled, resulting in condensation and rain or snow. Snowpack in the Cascade Range and Sierra Nevada contributes to the runoff in the state's largest rivers and to the groundwater basin recharge that support much of California's urban and agricultural water use.

On average, about 75 percent of the state's average annual precipitation of 23 inches falls between November and March, with 50 percent occurring between December and February. The state experiences high annual variability in precipitation. Much of this variability stems from the role of a relatively small number of storms in making up the state's water budget. An imbalance between surface water supplies and the location of major population centers and agricultural production areas has been central to the history of water development in California, leading to the development of major federal, state, and local water projects.

Imported Colorado River Surface Water

Imported surface supplies make up only a small part of the state's water budget. The Colorado River is by far the largest of the imported surface water sources. The state has consistently received its basic interstate apportionment of 4.4 million acre-feet (MAF) of Colorado River water annually, and up until 2003 was also able to receive additional water from hydrologic surpluses or from the unused apportionments of Nevada and Arizona. The Colorado River has been the most reliable of the three major sources of imported water used by urban Southern California, thanks to storage capacity in the reservoir system; the Colorado River basin reservoir storage capacity is equivalent to about four times the river's average flow. Recent prolonged dry conditions in the Colorado River Basin are the driest period of the historical record in terms of inflow to Lake Powell. Lake Powell inflow was below average in 11 of the past 14 water years through water year 2013, with water year 2014 just under average. The single driest year of record for inflow to Lake Powell was 2002 (the prior dry year record had been set in 1977). The decade of the 2000s (2000–2009, inclusive) was the driest decade in the historical record. During these prolonged dry conditions, total system storage dropped to just below half of capacity.

California Groundwater

Under average hydrologic conditions, close to 40 percent of California's urban and agricultural water needs are supplied by groundwater, an amount that increases in dry years when water users whose surface supplies are reduced increase their reliance on groundwater. The state's 515 designated groundwater basins support the majority of California's groundwater development, although an estimated 90 percent of the groundwater used in California is from only 126 of these 515 groundwater basins. The amount of water stored in California's aquifers is far greater than that stored in the state's surface water reservoirs, although only a fraction of that groundwater can be economically and sustainably extracted for use.

Future Availability Estimates

The average temperature in California throughout the watershed has increased by about 2°F since 1900. The pace of that increase has accelerated since 1970 and is expected to increase even more rapidly in the future. Future precipitation is expected to remain similar to the recent past, but will occur more as rain and less as snow. This is likely to decrease natural recharging of the groundwater resource, further stressing groundwater supplies and quality. Runoffs off expected to increase and to shift from spring to occur more during late fall and winter. Reductions in supply from evaporation during warmer summers are expected to be much greater from reservoirs. As flows change, greater withdrawals from surface water in the Basin occur and water quality is expected suffer even more so in the Delta, where salinity is projected to increase by 20 percent over the rest of this century.

The Southwest and the Colorado River Basin

The water supply of the American Southwest is the nation's most endangered. Most of the region depends upon the Colorado River for human consumption and agricultural use. The Colorado River Basin covers about 246,000 square miles, including parts of the seven "basin states" of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming (Fig. 1.4). The 1,450-mile long river eventually flows into Mexico's Gulf of California. The basin supplies water to at least six major United States cities: Albuquerque, Denver, Las Vegas, Los Angeles, Phoenix, Salt Lake City, and San Diego.

The Colorado River is considered to be most heavily regulated river in the world. The basin's supply is ruled by a complex body of decrees, rights, court decisions, international treaties, and laws that is together referred to as the *Law of the River*. The keystone of the Law is the 1922 Colorado River Compact, an interstate agreement among the seven basin states with general water allotments. The 1922 Compact divided the Colorado River Basin into the Upper Basin and the Lower Basin, with Lees Ferry, just downstream of Glen Canyon Dam, the dividing point (USBR 2012). The Upper Basin includes those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lees Ferry. The Lower Basin includes parts of the states of Arizona, California, Nevada, New Mexico, and Utah where waters naturally drain into the Colorado River system below Lees Ferry. The Colorado River Compact allocated to each of the two basins the use of 7,500,000 acre-feet of water per year from the Colorado River system in perpetuity, did not apportion water to any state. Six years later, the Boulder Canyon Project Act of 1928 named the US Secretary of the Interior as lower basin water master, with responsibility for distributing all Colorado

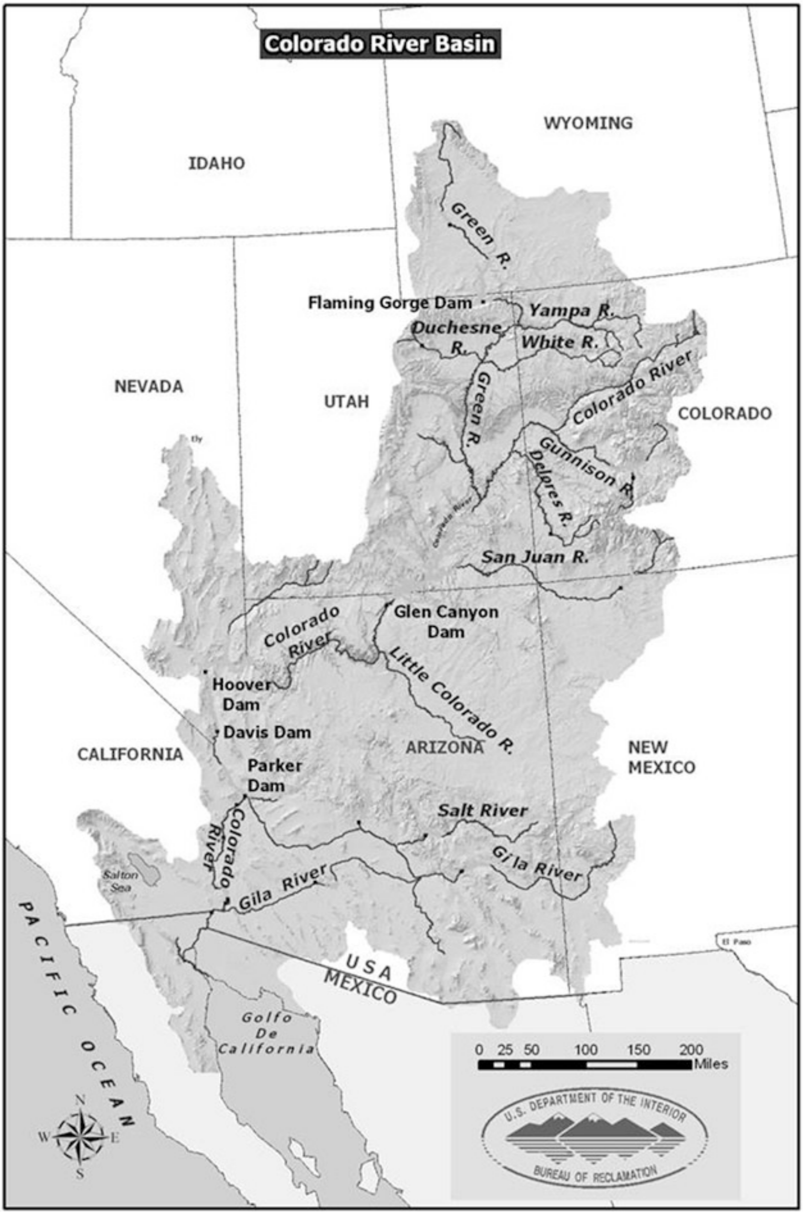

Fig. 1.4 The Colorado River Basin from Wyoming to Mexico

Source: US Dept. of the Inferior, Bureau of Reclamation

River water below Hoover Dam. From that date on, major water users of Colorado River water had to contract with the Secretary of Interior for annual deliveries.

The first formal state allocations had to wait until 1948, when the Upper Basin States established the Upper Colorado River Basin compact. That agreement permitted Arizona to use 50,000 acre-feet of water annually from the Upper Colorado River system. The remaining water was allocated to the Upper Basin States in these percentages: Colorado, 51.75 percent; New Mexico, 11.25 percent; Utah, 23 percent; and Wyoming, 14 percent. The Lower Basin states were unable to come to agreement on how to allocate the Lower Basin river water. Tired of waiting, Arizona then filed suit in the US Supreme Court to make the determination. In October of 1964 the Supreme Court awarded the first 7,500,000 acre feet in the Colorado River mainstem: California was entitled to 4,400,000 acre feet, Arizona 2,800,000 acre feet, and Nevada, 300,000 acre feet. Current allocations are shown in Table 1.2.

The International Boundary Water Commission between the United States and Mexico in 1944 guaranteed Mexico 1.5 million acre feet of Colorado River water as its share. A 1973 agreement guaranteed the

Table 1.2 Colorado River Water apportionments by state, in acre feet and percent of the total

Upper basin	Percent (%)	Million acre feet/year
Arizona	0.3	0.05
Colorado	23.4	3.86
New Mexico	5.1	0.84
Utah	10.4	1.71
Wyoming	6.3	1.04
Upper basin total	45.5	7.50
Lower basin		
Arizona	7.0	2.80
California	26.7	4.40
Nevada	1.8	0.30
Lower Basin Total	45.5	7.50
Seven state total	91.0	15.00
Mexico	9.0	1.50
Total for entire basin	100	16.50

Source: US Bureau of Reclamation

quality of the Colorado River water Mexico was to receive. A point of contention today is that those allotments were established during the end of what was the wettest 10-year-long period in a hundred years of recorded precipitation when the annual average supply from all sources was18.8 million acre feet. The negotiators, allowing for variation, used as a base an annual flow of 16.5 million acre feet and established 15.0 million acre feet as the amount for allocating shares, while flows from 2001 to 2009 averaged closer to 12.1 million acre feet.

The river supplies water to nearly 40 million people, irrigates close to 4.5 million acres of farmland in the United States and Mexico, and supplies hydropower plants that generate more than 10 billion kilowatt-hours annually. Water from the river also provides for recreation use and environmental benefits that include supporting a wide diversity of fish and wildlife and their habitats and preserving flow and water-dependent ecological systems. Major problems facing the basin are meeting the water needs of rapidly increasing population, decreasing stream flows, and the uncertain effects of a changing climate.

The USGS (2013a) coordinated its most recent Colorado River Basin Focus Area Study with the Bureau of Reclamation's Basin Study Program (both agencies are part of the US Department of the Interior). The study began in January 2010 and was completed in December 2012. It defined current and future imbalances in water supply and demand in the Colorado River Basin and the adjacent areas of the Basin States that receive Colorado River water for approximately the next 50 years, and developed and analyzed adaptation and mitigation strategies to resolve those through the year 2060. The options were separated into four main categories based on their approach for resolving the imbalance: increased supply, reduced demand, modify operations, and governance and implementation. The Reclamation study also examined strategies to resolve those imbalances under a range of conditions that could occur during the study period. The USGS portion of the study focused on the following three elements: (1) estimates of current water use and historical trends in water use into the future; (2) regional and field scale assessments of evapotranspiration and the dynamic variation in snowpack water content (including volume and timing of snow-water releases); and (3) estimations of groundwater discharge to streams and rivers. Although groundwater contributions to streams in the Colorado River Basin is a relatively poorly understood component of the regional water budget, preliminary estimates by the USGS ranged between 20 and 60 percent of the surface-water flow in the upper Basin was dependent upon groundwater.

The Upper Colorado River Basin

The Upper Colorado River Basin (UCOL) is divided into two distinct regions into an upper and a lower basin. The upper basin covers approximately about 17,800 square miles, beginning where the Colorado River originates in the mountains of central Colorado and continues about 230 miles southwest into Utah (Fig. 1.5). The major tributaries of the Upper Basis are the Green, San Juan, Escalante, Gunnison, and Dolores rivers. This section of the total river basin is itself divided into two regions: the Southern Rocky Mountains and the Colorado Plateau. The north–south dashed line in the map in Fig. 1.5 marks the divide. Because of differences in altitude of about 10,000 feet from east to west, the climate ranges from alpine conditions to semiarid/arid conditions in the southwest. Precipitation ranges from 40 inches or more per year in the eastern part of the basin to less than ten inches per year at low elevations in the western part of the basin.

Irrigation accounts for 97 percent of the water use in the UCOL (Spahr et al. 2000). Ninety-nine percent of the water withdrawn is derived from surface-water sources. Groundwater only accounts for one percent of water use and is an important resource in remote and rural areas where the water is used primarily for domestic purposes. Water diverted eastward from the UCOL is used by many municipalities in the eastern plains of Colorado. This diverted water from the UCOL has accounted for about 35 percent of the water supply for the city of Denver and about 65 percent of the water supply for Colorado Springs. In addition, the Colorado Big Thompson project, using water diverted from the UCOL, provides complete or partial supply for more than 30 cities and towns in northern Colorado. Individual state

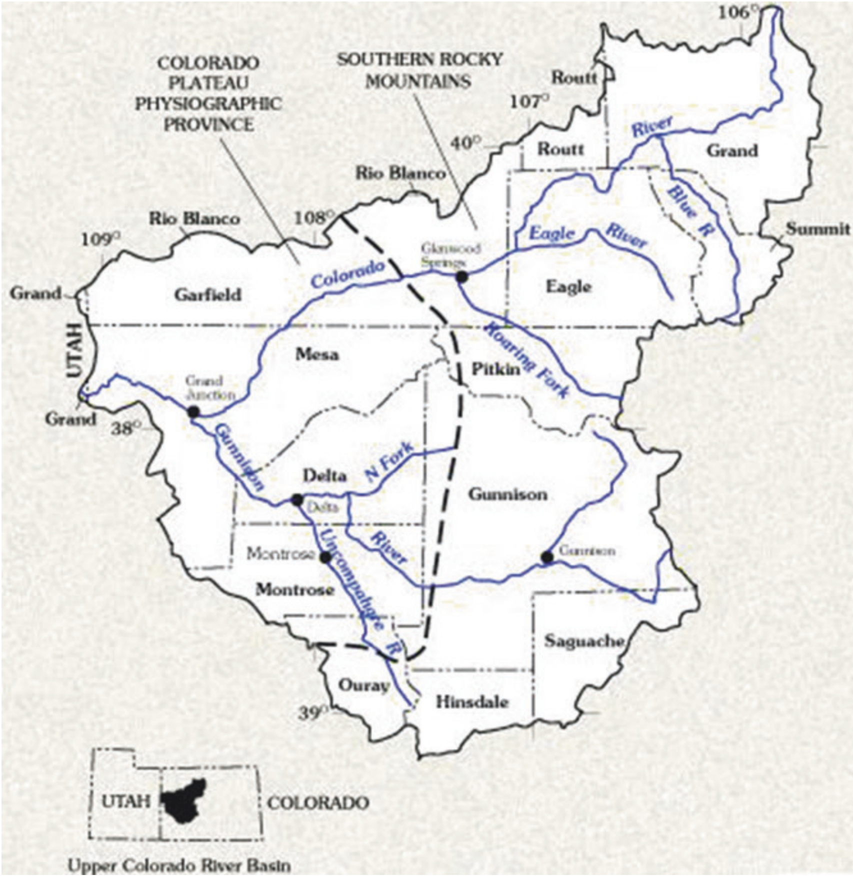

Fig. 1.5 USGS map of the Upper Colorado River Basin
Source: USGS (2013). http://co.water.usgs.gov/nawqa/ucol/

allotments of Colorado River Water in millions of acre feet (maf) per year are show in Table 1.1. Total allotted for all state and Mexico users is 16.5 million acre feet, although the average annual withdrawals have seldom exceeded 15 maf, not because states are taking less than they have been allotted, but under the existing drought conditions, the system cannot provide the full allotted amounts. A 2012 study of the supply and demand of the entire river system identified drought-related lower stream flows of the Upper Basin tributaries were the maid cause for shortages in the Upper Colorado. Because not all the users allocated Upper Basin were as yet withdrawing all of their allocations, upper Basin growth is expected to exacerbate the shortages in the near future.

The Lower Colorado River Basin

The LCRB is that portion of the river below Lee's Ferry, just below Glen Canyon Dam. Lake Mead behind Hoover Dam is the main storage location for the Lower basin. Almost all of Arizona, Southern California, Nevada, and Mexico are included in this portion of the Basin. The most important tributaries are the Paria, Virgin, Little Colorado, Bill Williams, and Gila rivers. The water supply of Lower Basin is also the most threatened supply source of the substantially over-allocated system.

USGS and the USBR have made extensive studies of the supply and demand factors in both the Upper and Lower basins. The USBR 2012 study contained results of a variety of future states of basin water and supply and demand with projections to 2060. The projections were the result of four different models, with results according to various degrees of probability, for a total of 48 different scenarios (4 supply levels, 6 demand levels, and 2 post-2026 lake Power and Lake Mead operation assumptions). The Lake Mead and Lower Basin projections reached as a result of the analysis included the following:

- Lakes Powel and Mead elevations both show a wide range of future levels. At Lake Mead under all scenarios except one, elevations from the 2012 level range from an increase of 5 feet to a decrease of 75 feet by 2060. The one not in that range projects all lake levels to decline by 90–140 feet.
- Projections of Lower Basin shortages reflect the increasing differences between supply and demand. Shortages increase from 550 thousand acre feet (Kaf) in 2012 to a range of 1.8 maf by 2060 at the 50th percentile. The 2012 and future increasing shortages are primarily

driven by the remaining allocated demands above the lower-level allocations. Meeting unused allocations because of continued growth in the Upper Basin can only be met by surplus conditions (such as greater precipitation or other supply sources such as desalination, reuse, and conservation)

State of the Great Plans Watersheds

The Great Plains, the region west of the Mississippi and east of the Rocky Mountains, west of the Mississippi River and East of the Rocky Mountains extends across the central United States from Canada to Texas. Although once believed to be an endlessly flat terrain of high isolated grasslands, the region is more geographically diverse than it was thought to be. It includes rocky hills, mountains, rivers, lakes, and thousands of acres of irrigated cropland. In its northern regions is also the site of America's latest oil and gas boom—made available by the process of fracturing deep underground deposits by injecting water and chemicals. The region is drained by two major river watersheds: the Missouri and the Upper Mississippi, along with two smaller rivers, the Republican and Platte Rivers, and their hundreds of tributaries. The Great Plains reaches north into the Canadian provinces of Alberta and Saskatchewan, where the Saskatchewan River is the major basin, and extends as far south as northern Texas.

Mississippi River

The Mississippi River flows for 2,320 miles from Lake Itasca, Minnesota, down to the Gulf of Mexico (Fig. 1.6). For most of its northern half, the river serves as the eastern border of the Great Plains region. The Environmental Protection Agency states that more than 50 cities depend on the Mississippi for their daily water supply, while groups like the Upper Mississippi River Conservation Committee and the Upper Mississippi River Basin Committee say that millions of

Fig. 1.6 Map of the Mississippi River Basin
Source: USGS

people in the river's basin use it as a daily water source. Agriculturally, the region also depends on the river as a water source: The river-supplied Mississippi basin supplies more than 90 percent of the country's agricultural exports. The river includes several major tributaries, such as the Missouri, Arkansas, and Ohio rivers.

Missouri River

The Missouri River (Fig. 1.7) is the longest river in North America. It flows more than 2,340 miles through the states of Montana, North and South Dakota, Nebraska, Iowa, and Missouri, where it joins the

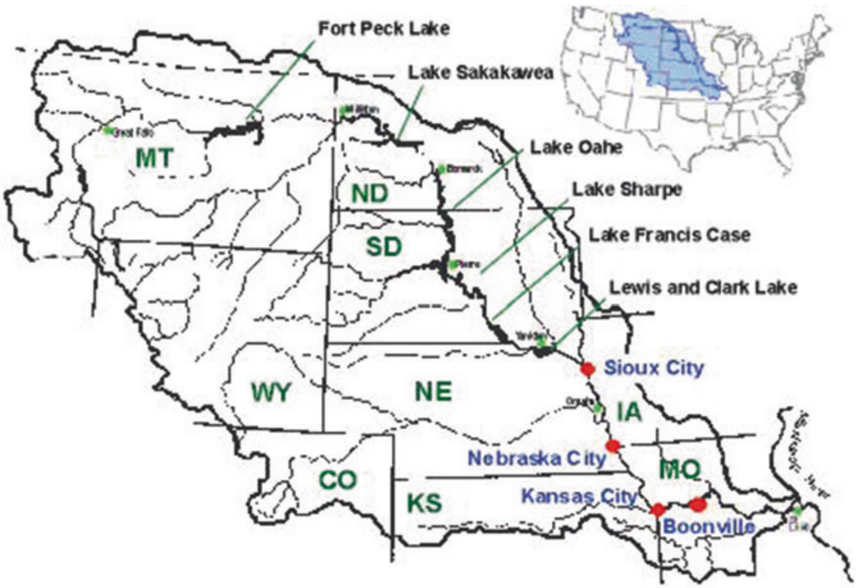

Fig. 1.7 Map of the Missouri River Basin showing major reservoirs
Source: USGS

Mississippi River. The Missouri itself is formed by three smaller rivers in Montana: the Gallatin, Madison, and Jefferson rivers. It joins the Mississippi River near St. Louis, Missouri. About 10 million people live in its river basin. The Missouri River flows through or by several major cities, including Omaha, Nebraska and Kansas City and St. Louis, Missouri. The importance to the river to the region is signaled by the seven major reservoirs providing flood control and water supply for agriculture and municipal uses.

Two smaller River Basins

The Republican River, surrounded by slopes and ridges, begins in southwest Nebraska and flows 200 miles east to Kansas and eventually into Milford Lake. The river is relatively slow flowing and regularly reduced by the stretches of dry weather and local irrigation practices that utilize the water source.

The Platte River, about 310 miles long, flows through the north Nebraska city of North Platte, then turns southeast. It eventually empties into the Missouri River, about 20 miles from Omaha. The river has long been extremely shallow for most of its length. The Platte River remains an important source of water for local agricultural irritation, as more than 12 dams help regulate the river's water flow. Overland migration west over the Oregon Trail after the Civil War followed the course of the Platte to the South Pass in the Rocky Mountains.

The Saskatchewan River

The Saskatchewan River winds through the northern Great Plains region that stretches into Canada. It is Canada's fourth largest river and the largest river system in both Albert and Saskatchewan. The river flows for more than 1,240 miles from Canada's Rocky Mountains to eventually reach Lake Winnipeg. Drought conditions in Alberta have forced the Alberta Energy Regulator (AER) to restrict water withdrawals from the Saskatchewan River system. The restrictions to current holders of 2015–2016 temporary diversion licenses (TDLs). The AER also began encouraging oil and gas operators to voluntarily reduce their consumption in areas with no mandatory restrictions but where stream flows were lower than normal. Water withdrawals from the river system are used in oil fracturing processes.

Alberta Environment and Parks department also issued a low flow advisory in June of 2015 for the Upper Athabasca River basin. The advisory notified water users in the region that current temporary TDLs were suspended and no new applications would be accepted. The AER has applied this restriction to oil and gas operators in the Saskatchewan Basin. Restrictions on TDLs for watercourses (e.g., rivers, creeks) were also put in place for other river basins in Alberta. No applications for temporary withdrawal licenses were being accepted for any water course in the North Saskatchewan River basin; TDFL application is process were suspended until further notice. The AER is working with Alberta Environment and Parks department to monitor water flow in all Alberta's rivers.

Ogallala Groundwater and Surfacewater

Groundwater contained in the Ogallala or Great Plains aquifer is water left by the several periods of glacial coverage over the upper portion of the central North American continent. This water supply extends under eight states from South Dakota to Texas. If it were above ground, its 174,000-square-mile surface area would be nearly double all the water in the five Great Lakes. About one-fifth of all US cattle, corn, cotton, and wheat depend on water from the Ogallala. It is one of the Nation's critical natural resources.

However, the aquifer is in trouble; more is being taken out than is replenishing the resource. In a word, is not being recharged; it will have to wait for another ice age for that to happen. About 30 percent of the aquifer's water has already been pumped out of the ground. An additional 39 percent is expected to be gone in the next 50 years. Replenishing it would take a thousand years or more. It is particularly problematic in its southern sections.

The aquifer that lies under all or parts of eight central plains states is named after the Ogallala band of the Dakota Sioux Indian tribe that once roamed over that part of Nebraska and Wyoming. It is watered at the surface by the South and the North Platte Platt Rivers. Stored surface water in these and other High Plains rivers is used to augment well withdrawals. Both the North and South Platte rivers, for example, are extensively dammed. What was to be the world's second largest earth filled structure, Kingsley Dam, was completed in June of 1941. The dam stores floodwaters of the catchment basin of the North Platte to form Lake McConnaughy. The North Platte and South Platte Rivers join to create the Platte River in western Nebraska near the city of North Platte. The Platte River then flows to the Missouri River, which joins the Mississippi River to flow to the Gulf of Mexico.

The Resource in the Midwest and Great Lakes Regions

The US Midwest and the Great Lakes Region are sometimes considered to be elements of the same great region of the United States. However, others consider them to be separate areas; they are treated as one here. The combined section discussed here includes 12 states and has a population of approximately 68 million people (about 21 percent of the 2015 estimated national total of 321.6 million). The Midwest region is home to expansive agricultural regions, forests in the north, the Great Lakes, substantial industrial activity, and major urban areas, including eight of the nation's 50 most populous cities. The Great Lakes region has experienced shifts in population, socioeconomic changes, air and water pollution, and landscape changes. Portions of the region have long been referred to as America's *Rust Belt*, as segments of the once large base of heavy industry has either moved to other locations or simply no long exists.

The Midwest Region

Americans disagree on which states belong in the Midwest and which belong in the Great Lakes region, but tend to agree that these six make up the core of the Midwest: North and South Dakota, Nebraska, Iowa, Kansas, and Missouri. Precipitation in the Midwest is greatest in the east, tapering off the farther one moves to the west. Precipitation occurs about once every seven days in the western part of the region and once every three days in the southeastern part of the region. The ten rainiest days can contribute as much as 40 percent of total precipitation in a given year. Generally, annual precipitation increased during the twentieth century by up to 20 percent in some locations, with much of the increase driven by intensification of the when rainfall is heaviest., This tendency towards more intense precipitation events along with warmer temperatures is projected to continue in the future.

Snowfall varies across the region, comprising less than 10 percent of total precipitation in the south, to more than half in the north, with as much as two inches of water available in the snowpack at the beginning of spring melt in the northern reaches of the river basins. When this amount of snowmelt is combined with heavy rainfall, the resulting flooding can be widespread and catastrophic. The 2008 flooding in the Midwest caused 24 deaths, $15 billion in losses via reduced agricultural yields, and closure of key transportation routes. Water infrastructure for flood control, navigation, and other purposes is susceptible to climate change impacts and other forces because the designs are based upon historical patterns of precipitation and stream flow, which are no longer appropriate guides. Weather records in the region reveal declines in the frequency of high snowfall years over much of the Midwest, but an increase in lake effect snowfall in the Great Lakes portion of the country.

Large-scale flooding occurs more or less regularly in the Midwest, largely due to extreme precipitation, often occurring when snowmelt is not a contributing factor. Examples include the August 2007 Rush Creek and the Root River floods in Minnesota and with multiple rivers in southern Minnesota in September of 2010. These warm-season events are projected to increase in number and extent.

Changing land use and the expansion of urban areas are reducing water infiltration into the soil and increasing surface runoff. These changes exacerbate impacts caused by increased precipitation intensity. Many major Midwest cities are served by combined storm and sewage drainage systems. As surface area has been increasingly converted to impervious surfaces (such as asphalt) and extreme precipitation events have intensified, combined sewer overflow has degraded water quality, a phenomenon expected to continue to worsen with increased urbanization and climate change. The EPA estimates there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually. The Great Lakes, which provide drinking water to more than 40 million people and are home to more than 500 beaches, have been subject to recent sewage overflows. For example, stormwater across the city of Milwaukee recently showed high human fecal waste levels at all 45 outflow locations, indicating widespread sewage contamination. One study estimated that increased storm events will lead to an increase of up to 120 percent in combined sewer overflows into Lake Michigan by 2100 under a very high emissions scenario leading to additional human health issues and beach closures. Municipalities may be forced to invest in new infrastructure to protect human health and water quality in the Great Lakes, and local communities could face tourism losses from fouled near-shore regions.

While there was no apparent change in drought duration in the Midwest region as a whole over the past century, the average number of days without precipitation is projected to increase in the future. This could lead to agricultural drought and suppressed crop yields. This would also increase thermoelectric power plant cooling water temperatures and decrease cooling efficiency and plant capacity because of the need to avoid discharging excessively warm water.

The Resource in the Great Lakes Region

The water resource in this section of the country is dominated by the extremely large amounts of surface water stored in the Great Lakes. However, US and Canadian river basins and groundwater are also important to the overall supply. These six are the states considered to be in the Great Lakes region: Minnesota, Wisconsin, Michigan, Illinois, Indiana, and Ohio. The Ohio River watershed drains much of the region and is the most significant river in the six-state region.

The Ohio River Basin

The Ohio River Basin is a region of 204,000 square miles covering parts of 14 states and including a population of nearly 25 million people, many in such major cities as Pittsburgh, Columbus, Cincinnati, Louisville, Indianapolis, and Nashville. The Ohio River flows 981 miles from Pittsburgh, Pennsylvania to Cairo, Illinois, where it joins with the Mississippi. The entire river basin is shown in Fig. 1.8.

Water-related problems in the Ohio River Basin include dealing with the effluent from municipal wastewater treatment plants, combined sewage and stormwater overflows, urban stormwater, acid (coal) mine

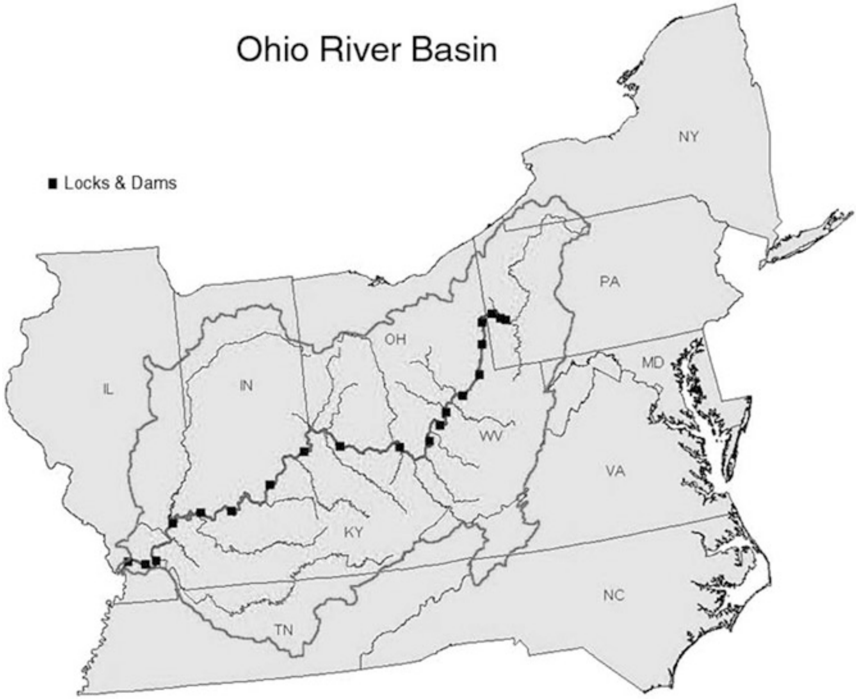

Fig. 1.8 Map of the Ohio River Basin
Source: Ohio River Basin Consortium

drainage, agricultural and forest lands runoff, sedimentation, toxic industrial pollutants, problems from oil and gas recovery brines, reservoir sedimentation, groundwater pollution, drinking water contamination, emerging pathogens, and exotic aquatic species. The region has been cited as a major contributor of acid precipitation for areas to the northeast and has a number of hazardous waste disposal sites.

Groundwater in the Great Lakes Region

The water supply of the Great Lakes region is made up not only of the lakes themselves, but also of the network of rivers and their tributaries and the groundwater on which the lakes depend.

Groundwater is a major natural resource in the Great Lakes Region that helps link the Great Lakes together with their watershed. The Lakes constitute the largest concentration of unfrozen fresh surface water in the western hemisphere. Because the quantity of water in the lakes is so large, groundwater in the Great Lakes Basin is often overlooked when evaluating the hydrology of the region. Groundwater, however, is more important to the hydrology of the Great Lakes and to the health of ecosystems in the watershed than is generally recognized (USGS 2013b).

USGS scientists estimate that the amount of groundwater stored in the Great Lakes Region is approximately equal to all the surface water stored in Lake Michigan. This groundwater is released slowly to provide a reliable minimum level of water flow in regional streams, lakes, and wetlands. However, pumping groundwater from the Great Lakes aquifers has a significant impact on this replenishment.

Most of the large public water supplies in the region are obtained from the lakes themselves, but groundwater is the source of drinking water for about 8.2 million people within the watershed. Much of the surface water remains polluted from decades of industrial and toxic waste, while agricultural runoff and rising water temperatures have resulted in toxic algae blooms in some lakes.

Although most residents of Chicago use water from Lake Michigan, many people in the Chicago suburbs residing outside of the lake use groundwater as a source of supply. As the suburban areas near the watershed boundary expand, more and more people will depend on groundwater to supply household water needs. Small manufacturing companies in suburban locations also are increasing their groundwater use. In addition to water quantity issues in the Great Lakes Region, water quality is also a concern. As development increases, activities that could threaten the quality of groundwater also increase. Human health needs to be safeguarded, as does the health of many other organisms that rely on clean water. Thus, the major groundwater resource issues in the Great Lakes Region revolve around: (1) the quantity of groundwater, (2) the interaction of groundwater and surface water, (3) changes in groundwater quality as development expands, and (4) ecosystem health in relation to quantity and quality of water. In summary, groundwater is an essential part of the Great Lakes Region water-supply system. It is a critical resource for maintaining human health and healthy ecosystems.

Effects of Groundwater Withdrawals

Irrigation is the largest use of water in the Great Lakes watershed, and groundwater sources contribute about half of the water used for irrigation. In areas where surface water sources are not readily available, it is likely that groundwater will be the water source if new irrigation systems are installed.

The effects of groundwater withdrawals from Great lakes region aquifers have been quantified at only a few locations. Chicago, Milwaukee and Toledo, Ohio areas are among the several locations where extensive groundwater studies have been published. The effects of groundwater pumping in the Chicago-Milwaukee metropolitan area where, in 1980, about 300 Mgal/d was withdrawn from a very productive sandstone aquifer system. Prior to large-scale withdrawal of groundwater, recharge and discharge for the aquifer were in balance at about 350 Mgal/d. When wells were first drilled into the sandstone aquifer along Lake Michigan, the initial ground-water level at Milwaukee was reported to be 186 feet above the surface of Lake Michigan; in Chicago, it was reported to be 130 feet above the lake surface. By 1980, large-scale pumping had caused the water levels in wells to decline as much as 375 feet in Milwaukee and 900 feet in Chicago. At some locations, the quality of groundwater was altered when water levels were drawn below the layer that confines the aquifer. By 1994, groundwater withdrawals in Chicago for public supply decreased to about 67 million gallons per day (Mgal/d) and total ground-water withdrawals decreased to about 200 Mgal/d. These withdrawals were concentrated west and southwest of the earlier pumping centers. As a result, ground-water levels in some parts of the Chicago area have risen by as much as 250 feet, although levels continued to decline in the southwestern Chicago and the Milwaukee metropolitan areas.

The Toledo, Ohio metropolitan area obtains groundwater from wells near Lake Erie. Pumping has lowered water levels in wells as much as 35 feet below the average level of Lake Erie. In addition, pumping has drawn water from Lake Erie into the groundwater system and intercepted water that would have discharged from the groundwater system to Lake Erie (USGS 2013). Although water-level data indicated that these interactions were taking place, the amounts of water being induced from the lake and intercepted by the pumping have not been quantified.

Although small in comparison to the amount of water in storage in the Great Lakes, groundwater directly and indirectly contributes about 80 percent of the water flowing from the watershed into Lake Michigan. On the basis of these data, it is evident that groundwater is an important component of the Great Lakes Region.

State of the Resource in the Eastern United States

The eastern United States consists of two very different regions, the Northeast and the Southeast. In the northernmost of the 12 states in the Northeast, heavy snow and ice conditions characterize much of the winter months. In the southeast heavy rainstorms and floods are common. Global warming will have very different effects upon the water resources of the two regions. As a result, the water supplies of region follow different themes.

In 2015, there were 10 weather and climate disaster events with losses exceeding $1 billion each across the United States. The number was nearly three times what has been normal for the country. Half of disasters were in the eastern United States, three were in the south-central section of the country; and two were in California. Overall, these events resulted in the deaths of 155 people and had significant economic effects on the areas impacted. The 1980–2015 annual average is 5.2 extreme weather events (CPI-adjusted); the annual average for the most recent 5 years (2011–2015) was 10.8 extreme weather events.

The State of the Resource in the Northeast

Heat waves, heavy downpours, and sea level rise pose growing challenges to many areas of the 12 states that constitute the Northeast: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. Despite its reputation for a generous supply of participation, the region has also suffered from periodic droughts; the Northeast's most severe drought in the last hundred and thirty years occurred between 1961 and 1966, when the region suffered a precipitation deficit of over 50 inches (Gellis 1985).

Although much of the Northeast is covered by forest, the region also has large areas of grass and open croplands, coastal zones, beaches and dunes, and wetlands, and several of the Nation's largest metropolitan areas and the Nation's capital. In addition to being force to an increasing number of severe weather events, rising sea levels are threatening much more of the coastal areas, including the important wetlands. The region has also been known for its rich marine and freshwater fisheries, much of which is being impacted by the loss of tidal marshlands. The region's natural areas that contribute important ecosystem services to the groundwater supplies and contribute and protect surface water supplies, buffer shorelines, and sequester carbon in soils and vegetation are being lost to population growth.

Precipitation in the Northeast

Average annual precipitation varies by about 20 inches throughout the Northeast with the highest amounts coming in some coastal and mountainous regions. During winter, storms bring bitter cold and snow and ice, especially in the northern area. For example, Mt. Washington in northern New Hampshire, the highest peak in the northeastern United States at 6,288 feet, holds the record for the highest recorded wind speed in the lower 48 states. On the afternoon of April 12, 1934, the Mt. Washington Observatory recorded a wind speed of 231 miles per hour (mph) at the summit, the world record for most of the twentieth century, and still a record for measured wind speeds not involved with a tropical typhoon or a cyclone[1]. Winds on April 1, 2016, were 63 mph with gusts to 74 mph.

Summers are warm and humid, especially to the south. The Northeast is often affected by extreme events such as ice storms, floods, droughts, heat waves, hurricanes, and major storms in the Atlantic Ocean off the northeast coast, referred to as *nor'easters*. The Northeast has experienced a greater increase in extreme precipitation than any other region in the United States; between 1958 and 2010, the Northeast saw more than a 70 percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1 percent of all daily precipitation events).

Between 1895 and 2011, temperatures in the Northeast increased by almost 2°F and precipitation increased by approximately five inches, or more than 10 percent. Coastal flooding has increased as a result of a rise in sea level of approximately one foot since 1900. Winter and spring precipitation is projected to increase; projections for the end of this century range from about 5 to 20 percent increases in winter precipitation. Projected changes in summer and fall, and for the entire year, are generally small at the end of the century compared to natural variations. The frequency of heavy downpours is projected to continue to increase as the century. Seasonal drought risk is also projected to increase in summer and fall as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt. Global sea levels are projected to rise one to four feet by 2100.

State of the Resource in the Southeast

The Southeast and Caribbean region is home to more than 80 million people and draws millions of visitors every year. The region has two of the most populous metropolitan areas in the country (Miami and Atlanta) and four of the ten fastest growing metropolitan areas. Two that are vulnerable to sea level rise and storm surge are in Florida (Palm Coast and Cape Coral-Fort Myers) and one is in South Carolina (the Myrtle Beach area). Management of river flow has deprived the coastal wetlands of the freshwater and sediment that are needed to allow the lands to exist and grow. Dredging of canals through marshes for oil and gas exploration and pipelines has led to erosion and intense saltwater intrusion. This has resulted in additional wetland loss.

Groundwater Damage from Saltwater Intrusion

Many of the Southeast's coastal areas are sinking while the sea level is becoming higher. The result is extensive saltwater intrusion into important groundwater aquifers. This problem is projected to continue over the rest of the century, further reducing the availability of freshwater for the increasing population and for local irrigation. For example, agricultural areas around Miami-Dade County, Florida and southern Louisiana with shallow groundwater tables are at risk of increased inundation and future loss of cropland from a projected 27-inch rise in sea level. Climate change is expected to increase harmful surface water algal blooms and several disease-causing agents in inland and coastal waters, which were not previously problems in the region. For instance, higher sea surface temperatures are associated with higher rates of ciguatera fish poisoning, one of the most common hazards from algal blooms in the region.

Decreasing Water Availability

Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and unique ecosystems. The Southeast has the existing power plant capacity to produce 32 percent of the nation's electricity. Water used for steam and cooling in thermoelectric generation is nearly 30 percent of the total, water used in the southeast—more than in any other region. Net energy demand is projected to increase, largely due to higher temperatures and increased use of air conditioning. This will potentially stress electricity generating capacity, distribution infrastructure, and energy costs.

Water resources in parts the Southeast have generally been abundant and sufficient to support large populations in urban areas, rural communities, unique ecosystems, and economies based on agriculture, energy, and tourism. However, the region also experiences extensive droughts, such as the 2007 drought in Atlanta, Georgia, that created water conflicts among three states. In northwestern Puerto Rico, water was rationed for more than 200,000 people during the winter and spring of 1997–1998 because of low reservoir levels. Droughts are one of the most frequent climate hazards in the Caribbean, resulting in economic losses. In order to extend the availability of existing groundwater resources, Florida is one of the four states most active in employing recycled water wherever possible.

Water supply and demand in the Southeast and Caribbean are influenced by many changing factors, including climate, population, and land use., With projected increases in population, the conversion of rural areas, forestlands, and wetlands into residential, commercial, industrial, and agricultural zones is expected to intensify. The continued development of urbanized areas will increase water demand, and threaten environmentally sensitive wetlands bordering urban areas. Higher sea levels will increase saltwater intrusion into freshwater supplies from rivers, streams, and groundwater sources near the coast. With increasing demand for food and rising food prices, irrigated agriculture will expand in some states. Also, population expansion in the region is expected to increase domestic water demand. Such increases in water demand by the energy, agricultural, and urban sectors will increase the competition for water, particularly in situations where environmental water needs conflict with other uses.

Summary

Large portions of the United States and many foreign countries are facing the greatest challenge of all: securing reliable sources of potable water to serve their growing populations during an age of dramatically shifting climate. The world may plenty of water, but not all of that water is available when and where it is needed. The globe may indeed be "a watery place." However, not all of it is directly available and usable for human consumption. More important, current misuse of the existing freshwater supplies is resulting in greater contamination of many sources of supply. Contamination from man-made and natural causes has made taken existing supplies unfit for human consumption. A recent example of a combination of human and natural effects groundwater is the damage done to the groundwater supplies caused by a long drought and over-pumping of wells for irrigation purposes taking place in California's rich agricultural Central Valley. Water pumped from private and municipal wells has been found to be contaminated by high levels of uranium (Box 1.1). Similar problems are surfacing in other areas of the country's Western states as a result of drought conditions and over-pumping for irrigation.

Box 1.1 California farm-area water contaminated with uranium

There is danger in the drinking water in large sections of California's rich Central Valley. Growing levels of uranium is showing up in the well water, according to a 2015 report in the San Jose *Mercury News*. Uranium is a naturally occurring but unexpected byproduct of irrigation, of drought, and of the overpumping of natural underground water reserves. An investigation in California's central farm valleys by the Associated found that authorities were doing little to inform the public at large of the growing risk; long-term exposure to uranium can damage kidneys and raise cancer risks, say scientists.

In California's Central Valley one in 10 public water systems have raw drinking water with uranium levels that exceed federal and state safety standards, according to the U.S. Geological Survey. Many schools, hospitals and other public agencies in the Valley draw all their water from their own wells. And that water often exceeds the minimum levels of uranium. Treatment to remove the danger is extremely expensive. As a result, some Central California farm-region schools buy bottled water in place of drinking fountains, which are off limits because of uranium and other contaminants.

The city of Modesto, with a half-million residents, spent more than $500,000 to start blending water from one its contaminated well to dilute the uranium to safe levels. The city has capped a half-dozen other wells found to have excess levels of uranium.

"The USGS calculates that the average level of uranium in public-supply wells of the eastern San Joaquin Valley increased 17 percent from 1990 to the mid-2000s. The number of public-supply wells with unsafe levels of uranium, meantime, climbed from 7 percent to 10 percent over the same period there."

Source: Scott Smith, *Mercury News*, December 8, 2015

The combined forces of climate change, population growth, and population relocation are, as expected, making it increasingly difficult to serve customers with all the freshwater they need as a price they can afford. Desalination can generate enough water to augment demand in coastal regions, but not hundreds and thousands of miles inland. But, find new sources they must. One still controversial source that is becoming increasingly viable is recycled water. One of the country's early programs is EPWU advanced water purification system. In good water supply years, El Paso gets its water from stored surface water and groundwaters. However, the continuing drought in the Southwest has left the district's reservoirs at 10 percent of their capacity or less. The EPWU has long used reclaimed water for non-potable reuse and for recharging the local aquifer. In 2012, the utility began a feasibility study of the increasing the capacity of advanced wastewater purification for use in aquifer recharging and other potential uses.

The country is still far from accepting the direct reuse of reclaimed wastewater into municipal freshwater delivery systems. Until a global standard for membrane technology that produces the desired water quality is accepted and strict guidelines, the treatment and reuse of wastewater is not likely to become a sizeable quantity of new supply in the municipal water utilities of the country.

Water suppliers in the United States and elsewhere in the world are facing massive challenges, many of which are attributable to the climate change already under way. These changes are having an impact upon the natural weather forces that include long-term droughts and stronger intense storm conditions. There is little doubt that these adverse changes to the world's weather patterns are going to continue. Arid areas such as the Western United States have become more arid and population growth is already taxing the limited water supplies available in many regions. In states such as Arizona and California freshwater resources are already under strain, and no end is in sight. Similar drought conditions are spreading to regions that have long enjoyed seemingly unlimited underground supplies of freshwater. Among the many challenges facing large and small water utilities today and which need to be addressed are the problem of decaying infrastructure, declining water resources, increases in water use, severe drought conditions in some areas and destructive rain storms in others, increasingly rigorous national, regional and local environmental policies and the need to protect the security and stability of supply, distribution systems, and records.

Additional Reading

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2

Internal Pressures on the Resource

Water use statistics in the United States have been recorded and published by the US Geological Survey (USGS 2015) every five years since 1950 for fresh and saline water withdrawals by eight categories of water users: public supply (domestic, commercial, and municipal supplied by public and private utilities), domestic (self-supplied or by public suppliers), irrigated agriculture, livestock raising and processing, aquaculture, industrial, mining, and thermoelectric power generation. Water withdrawals are measured when water is removed from a source for any use and measured in gallons per day or acre feet. A 60-year history of total water used in the United States is shown in Table 2.1. A steady increase in withdrawals occurred from the 154 billion gallons per day (bgal/d) in 1950 to 435 bgal/d in 1980, after which time water withdrawals averaged 394.5 bgal/d. Withdrawals reached a low of 354 bgal/d in 2010. The amounts of water used by major categories of use are shown in Fig. 2.1; percentages are shown in Table 2.2.

The results of the 2010 survey were published in 2014. Withdrawal percentages of the estimated average daily withdrawals of surface and subsurface (ground) fresh and saline water in 2010 for each category are shown in Table 2.2. The estimated total daily water use for all states averaged of

D.E. McNabb, *Water Resource Management*,
DOI 10.1007/978-3-319-54816-6_2

Table 2.1 Total water withdrawals in the United States, 1950–2010

	Total water withdrawals (data are in billion gallons per day)												
	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Fresh	174	227	240	270	318	342	363	336	335	337	349	349	306
Saline	10	19	31	44	54	70	71.9	60.3	68.3	60.8	63.5	60.9	48.3
Total	184	246	271	314	372	412	435	396	403	394	416	410	354

Source: USGS 2015

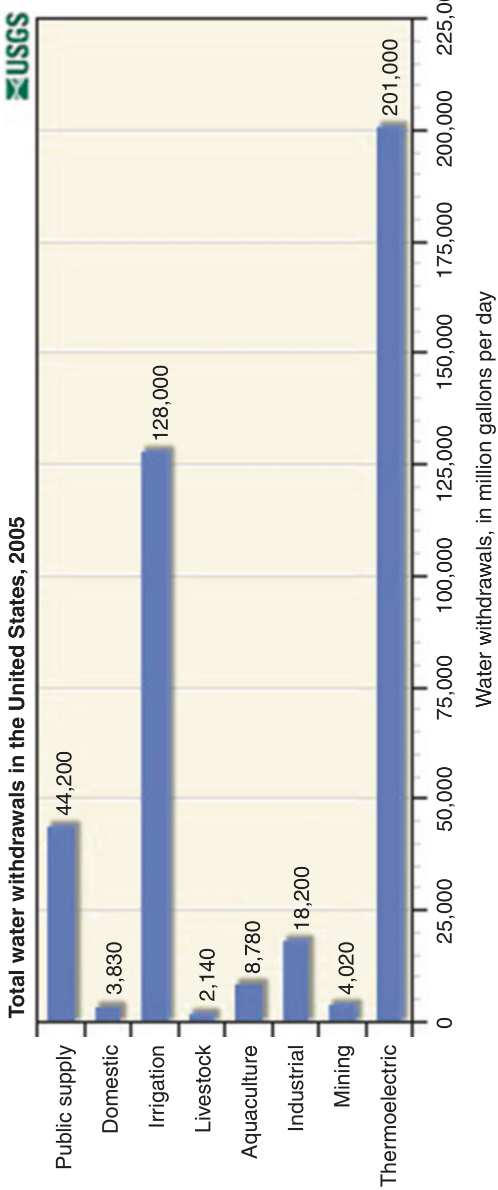

Fig. 2.1 Source and use of surface water and groundwater in the United States, 2010 (in millions of gallon per day)

Source: US Geological Survey (2015)

Table 2.2 Water use in the United States by sector in 2010 (percent)

Water use sector	Percent of total use
Thermoelectric power generation	45
Agriculture irrigation and livestock	34
Public supply (parts, government, etc.)	12
Industrial	4
Aquaculture	3
Mining (including fracking)	1
Domestic (general household use)	1
Total	100

Source: USGS *Estimated Water Use in the United States in 2010* (2015)

88 gallons per person per day. While this rate of water use is significant, the important qualifier to remember is that the 2010 estimates were the lowest since 1970. Freshwater use withdrawals consisted of 306 bgal/d or 86 percent of the total; saline water (any water with more than 1,000 million parts per milligram of any dissolved solids) withdrawals were estimated to be 48.3 bgal/d or 14 percent of the total. Fresh surface water withdrawals were nearly 15 percent lower than in 2005; fresh groundwater withdrawals were close to 4 percent less than 2005. Saline surface withdrawals were 24 percent below 2005; saline groundwater withdrawals were also lower, but at an undetermined rate saline surface water is almost exclusively (97 percent of the total) used for cooling thermoelectric generator plants, although a measurable amount is also used in petroleum mining.

Public and Domestic Supply Water Use

Public supply describes water withdrawn by public and private water suppliers that provide water to at least 25 people or have a minimum of 15 connections. In 2014, there were approximately 155,693 public water systems subject to regulations administered by the Environmental Protection Agency (EPA) in the United States. This was down from the nearly 170,000 systems reported in the 2010 census. Of these totals, there were close to 54,000 community water system in 2010 and 52,110 in 2014.

Community water systems provide water to at least 25 people at their primary residences, with water supplied to roughly the same population all year. Another 103,583 systems are either one of two types of non-community systems: transient non-community systems that provide water to at least 25 or more people at least 60 days a year, but not to the same people and not on a regular basis, or non-transient systems that provide water for the same 25 or more people at least six months of the year. Close to 15 percent of US residents get their water from their own wells, although this number is declining as the country continues to urbanize. Figure 2.2 shows the domestic use of water and percentage population growth expected by 2030.

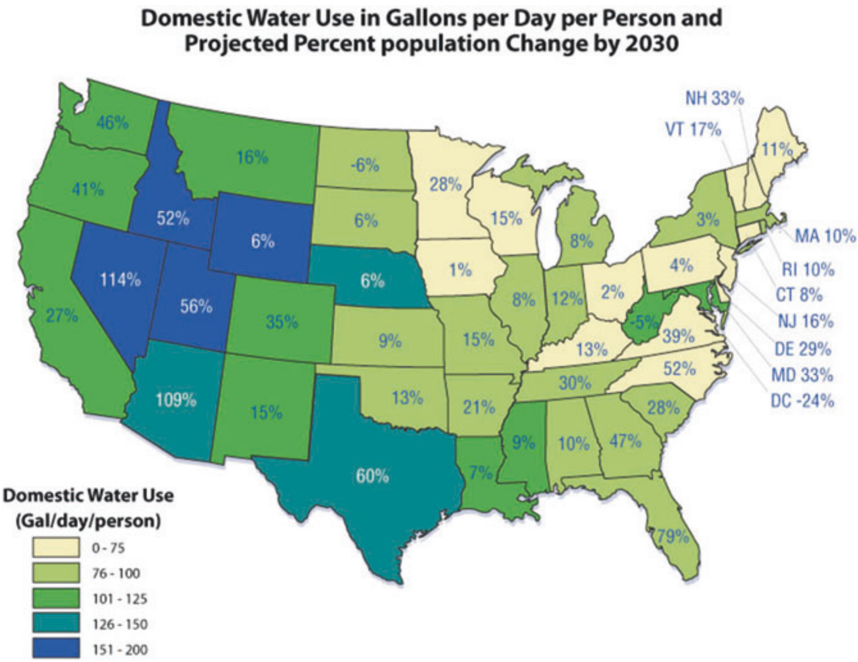

Fig. 2.2 Average water use per person and projected percent population change

Sources: Water use data by USGS (2005); population growth estimates by US Census Bureau; published by EPA (2016)

The USGS has estimated that in 2010 close to 42,000 million gallons (47,100 thousand acre feet) were withdrawn for public supply, for approximately 14 percent of the total freshwater withdrawals that year. (The total is 22 percent of all freshwater withdrawals when water for thermoelectric generation is not included.) In some states, public supply water sources include desalinated seawater or brackish groundwater that has been treated to reduce dissolved solids. San Diego, California, opened that state's largest seawater desalination plant in December of 2015. The reverse osmosis design plant in Carlsbad, north of San Diego, will process up to 50 million gallons of freshwater a day, which is from 8 to 10 percent of the San Diego County's total supply. Another 15 desalinization plants are planned for construction in California, suffering a continuing series of severe drought. Additional plants are also planned in Mexico. Water from the just-opened plant costs about twice as much as water purchased from the Metropolitan Water District of Southern California, the largest water wholesaler in the region; this supplier is fast approaching its maximum available surface water resources. San Diego is also looking at recycling wastewater for augmenting existing supplies of tap water (Fikes 2015).

The nation's public water system sector consists of two main segments: the utilities that distribute water to where it is needed and the general services segment that provides water and wastewater-related services to utilities and consumers. This chapter addresses the utilities segment. The majority of systems in this segment are owned and operated by local governments or special districts, accounting for approximately 84 percent of all community water systems and 98 percent of all community wastewater systems. The utility systems are heavily regulated, both for safety and sanitation and for environmental impact.

Nearly all public supply water withdrawals are delivered to domestic, commercial, and industrial users. Part of the total is used by cities and counties for public services, including use for schools, public pools, parks, golf courses, firefighting, and municipal structures, while because of leaks and infrastructure failures and down times for repairs, some is simply unaccounted for. Most people in the United States receive their water from public suppliers—commonly a water district or a municipal public utility. In 2010, public suppliers provided consumers more than 23,000 million gallons of freshwater a day; approximately 87 percent of domestic water is provided by public utilities.

Domestic (Privately Supplied) Water Use

Domestic water use is closely associated with public use, except it refers to privately supplied water that is used exclusively for indoor and outdoor water use in single-family and multi-unit residences. Typical indoor uses are bathing, drinking, food preparation, washing clothes, and flushing toilets. Typical outdoor uses are watering lawns and gardens, washing personal vehicles, driveways and sidewalks, maintaining swimming pools and ponds, and other landscape used in a domestic situation. Approximately 13 percent of the population, roughly 44.5 million people, is still self-supplied, either from private wells, cisterns, or surface water sources.

Table 2.3 compares water delivery percentages for domestic self-supplied water use and deliveries by public suppliers from 1955 to 2005. While population has almost doubled over this period, the percentage of domestic self-supplied has been reduced by more than half.

Non-domestic Users of Water

Non-domestic users of water include water used for steam-powered and gas turbine generation and for cooling of coal, natural gas, and nuclear power generation.

Thermoelectric Power Generation Water Use

Thermoelectric generation plants were the largest users of water in 2010, closely followed by water used for agriculture. Importantly, usage totals for both sectors were lower than their 2005 consumption rates. With

Table 2.3 Comparison of public-supplied and domestic self-supplied water deliveries

	1955–2010 water delivery comparisons by population											
	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Population (million)	164.0	179.3	193.8	205.9	216.4	229.6	242.4	252.3	267.1	285.3	300.7	313.0
Public supply (%)	70	76	79	80	81	81	83	83	84	84	86	86
Domestic self supply (%)	30	24	21	20	19	19	17	17	16	16	14	14

Source: USGS (2015)

Table 2.4 Water withdrawals for thermoelectric generation in the United States, 2010

	Withdrawals in million gallons per day by source and type				
	Ground water		Surface water		All types
State	Fresh	Saline[1]	Fresh	Saline[1]	Total
Texas	38.8	0	10,400	661	11,100
Illinois	5.65	0	10,700	0	10,700
Florida	43.5	6.54	570	8,570	9,190
N. Carolina	0.37	0	7,660	1,360	9,020
Michigan	4.12	0	8,510	0	8,520
Alabama	0	0	8,250	0	8,250
New York	2.39	0	2,750	4,850	7,600
Ohio	23.0	0	7,190	0	7,220
California	33.1	48.4	32.2	6,490	6,600
Missouri	16.9	0	5,890	0	5,910
All 50 states total[2]	587	134	116,000	43,800	161,000

Notes
[1]includes brackish and seawater
[2]includes Puerto Rico and the US Virgin Islands
Source: USGS data

public supply withdrawals in 2010, these three users accounted for 90 percent of the total withdrawals. Electricity generation withdrawals were 20 percent below 2005 and irrigation withdrawals were 9 percent below 2005. More than 50 percent of the total withdrawals in 2010 occurred in just 12 states, led by California's 11 percent of the total withdrawals and 10 percent of the freshwater withdrawals. Texas 7 percent of the total withdrawals, and together with Oklahoma, accounted for about 70 percent of the total saline groundwater withdrawals; most of this was used in mining. The largest surface water withdrawals occurred in California; California, Arkansas, Texas, and Nebraska were the four largest fresh groundwater withdrawers, together accounting for 42 percent of the national total (Table 2.4).

Production of electrical power by thermoelectric steam generators is also one of the largest uses of water in all parts of the world; it is also a large contributor to greenhouse gases formed from burning carbon-based fuels. Thermoelectric power plants produce some 90 percent of the electricity in the United States. Water used in generating thermoelectric power is used in steam-driven turbine generators. Surface water has been the source for more than 99 percent of total thermoelectric power withdrawals. The decade-long drought in the Southwest and above normal summer heat levels has resulted in heavy use of groundwater to supplement declining surface water sources. In coastal areas, the use of saline water instead of freshwater expands the overall available water supply (Averyt et al. 2011), In 2005, thermoelectric power withdrawals accounted for 49 percent of total US water use, 41 percent of total freshwater withdrawals for all categories, and 53 percent of fresh surface water withdrawals. Water amounts used by thermoelectric power plants in 2005 are included in Box 2.1.

Box 2.1 Thermoelectric power generation uses huge amounts of water

A report prepared in 2011 for the Energy and Water in a Warming World Initiative the Union of Concern Scientists included the following conclusions about power plants and water use:

> "Power plants are thirsty. Every day in 2008, on average, water-cooled thermoelectric power plants in the United States withdrew 60 billion to 170 billion gallons (180,000 to 530,000 acre feet) of freshwater from rivers, lakes, streams, and aquifers, and consumed 2.8 billion to 5.0 billion gallons of that water. Our nation's large coal fleet alone was responsible for 67 percent of those withdrawals, and 65 percent of that consumption.
>
> Where that water comes from is important. In the Southwest, where surface water is relatively scarce, power plants withdrew an average of 125–190 million gallons of groundwater daily, tapping many a1quaifers already suffering from overdraft. By contrast, power plants east of the Mississippi relied overwhelmingly on surface water."

Source: Averyt et al. (2011, 12)

Thermoelectric power plants use a variety of fuels to boil water to make the steam used to drive the generators. The most common fuel burned to generate heat has been coal, although nuclear fuel-powered generating plants produce close to 20 percent of the electricity. As older coal-fired plants reached the end of their productive live over the last decade, a growing number of generating plants have been converted to natural gas. The steam used to drive turbines must be cooled so heat is condensed and the water withdrawn can be reused or discharged back into the source. Figure 2.3 shows steam evaporating from thermoelectric power plant cooling towers.

This steam generation and cooling process is the major use for water. Three methods are used for cooling water before its reuse or discharge: (1) a once-through system in which the water is used once before cooling and discharge; (2) a recirculation cooling process in which the water is used more than once before returned to the source, or is retained in closed systems; and (3) a dry cooling system in which air is blown across steam-carrying pipe.

Fig. 2.3 Aerial photo of Beaver Valley Power Station in Pennsylvania, showing evaporation loss from the large cooling towers

Source: US Geological Survey, 2015; US Nuclear Regulatory Commission photo

Once-through systems withdraw the largest amounts of water from the surface sources usually used. Dry-cooled systems, most of which use natural gas fuel, use almost no water. Of the three, the once-through system requires the least amount of energy, least costly to construct, but uses the most water. Hybrid systems use some combination of the three cooling methods by dry-cooling systems when the outside air is too hot for efficient cooling.

According to the USGS (2015), a significant amount of water is lost due to evaporation during the cooling process, with more lost in plants that use on-site cooling ponds. In closed-loop cooling systems, the total volume of water withdrawals can be reduced by nearly 95 percent compared to the water required for once-through cooling. The conventional type of wet cooling system uses towers that are designed to remove heat by pumping hot water to the top of the tower and then allowing it to fall down while contacting the air which comes in from the bottom and/or sides of the tower. As the air passes through the water, it exchanges some of the heat and evaporates some of the water. In cooling towers, as much as 50 percent or more of water is lost through evaporation. The air-cooled water is collected at the bottom of the tower and is then pumped back to the condenser for reuse. Cooling towers have been increasingly used because they require much less water and land than once-through cooling systems. Release of water into the atmosphere in the form of steam can be seen in almost all nuclear power thermoelectric power plants.

Agricultural Water Use

Agricultural water is water that is used to grow grains, fruits and nuts, fresh produce, sustain and process livestock, and provide clean water for fish farms. The use of agricultural water makes it possible to grow and process many vegetables and animal products that are main part of our diet. Agricultural water is withdrawn for irrigation, and for mixing and applying pesticide and fertilizer applications and for many other farm uses. According to the USGS, water used for irrigation accounts for nearly 65 percent of the world's freshwater withdrawals other than thermoelectric power.

The US Department of Agriculture has computed the amount of land used for each of six major designated regions in the 48 continuous United States, as well as for Alaska and Hawaii as a separate unit. The data are provided for each state and for a varying number of states grouped into ten common regions. The data for 2007 in thousands of acres for each of the regions are shown in Table 2.5 (the data do not indicate whether the land is actually in use or currently inactive). The region with the largest acreage in cropland was the Northern Plains with 97,699,000 acres, followed closely by the Corn Belt states with 97,018,000 acres. The two regions with the smallest area devoted to cropland were the Southeast with 12,483,000 acres and the Northeast with 12,967,000 acres. The Mountain states had the largest area in pasture and range land (303,397,000 acres); The Mississippi Delta states had the smallest area in pasture with 7,209,000 acres; The Mountain states also had the greatest acreage devoted to forest land with 121,478,000 acres; the northern Plains had the smallest acreage in forest land at 5,677,000 acres.

Water quality is often severely affected by agricultural use (CDC 2009). Pollution occurs as a result of poor planning of food processing plant sites, animal farms and feedlots, barnyards, and stormwater. Poor water quality can affect the quality of food crops and lead to illness in those who consume them. For example, the water may contain the bacteria that cause human disease. Irrigating crops with contaminated water can then lead to contaminated food products which lead to illness when eaten. In December 2006, fast food restaurants in 4 Northeastern states emerged as a common link among 71 sickened people across 5 states, 52 of whom were ultimately confirmed by the Centers for Disease Control to have tested positive the same *E. coli* strain. An *E. coli* website reported that at least 33 people, many of them college students, became ill with *E. coli* O145, a toxic strain of the *Escherichia coli* bacterium which can cause serious illnesses, in April and May of 2010. The illnesses were clustered around colleges and universities in Michigan, Ohio, New York, and in Tennessee. On May 5, 2010, a food supplier recalled packaged romaine lettuce due to *E. coli* O145 contamination. Three patients developed a type of kidney failure, although no deaths were reported. In 2015, an *E. coli* episode in a chain of ethnic food

Table 2.5 Major uses of land in 48 United States by region, 2007 (thousands of acres)

Region	Cropland	Pasture and range	Forest use land	Special use areas	Urban areas	Misc other	Total land
Northeast	12,967	4,627	66,774	11,214	12,537	3,272	111,390
Lake states	40,559	7,486	50,759	10,130	4,218	8,911	122,063
Corn Belt	97,018	16,390	34,264	9,411	8,102	5,394	164,579
Northern Plains	97,688	74,827	5,677	8,170	1,063	6,845	194,271
Appalachian	22,654	10,551	70,819	8,869	6,677	4,160	123,730
Southeast	12,483	10,288	75,150	9,698	6,815	6,815	123,320
Delta states	18,230	7,209	52,317	4,500	2,284	6,683	91224
Southern Plains	46,955	120,442	24,779	7,951	5,382	5,989	211,497
Mountain	43,244	303,397	121,478	32,537	3,779	13,454	547,890
Pacific	22,110	57,040	74,021	36,821	7,239	6,610	203,840
48 states Total	407,908	612,257	576,037	169,300	60,167	68,133	1,893,803

Source: USDA economic research service. Distributions may not add to totals due to rounding restaurants caused the temporary closure of restaurants in the California, Oregon, and Washington state. More than 40 cases were traced to the chain. Food researchers reported the outbreak was likely caused by contaminated food products.

Sources of Agricultural Water

Agriculture is a major user of ground and surface water in the United States, accounting for approximately 80 percent of the water for consumption, and more than 90 percent is many arid and semi-arid Western states. Agricultural water comes from a variety of sources. Sources of agricultural water include surface water from rivers, streams, irrigation ditches, open canals, and impounded water such as ponds, reservoirs, and lakes; groundwater from private and community-owned wells; and rainwater that is locally collected water such as cisterns and rain barrels.

Municipal water systems such as city and rural water may also be used for agricultural purposes but generally is not reported as agricultural water withdrawals. Irrigation is critical to agriculture in the United States: nearly 55 percent of the value of all crops sold comes from irrigated farms accounting for only 30 percent of all harvested cropland. The United States is the world's third largest user of water for irrigation (Table 2.6), let only by China and India.

Table 2.6 Agricultural irrigation freshwater withdrawals, 2010

Source and use	Use in millions of gallons/day	Percent of the total
Surface water		
Irrigation	80,000	31
Other agriculture use	182,000	69
Groundwater		
Irrigation	56,900	68
Other agriculture use	26,400	32
Total		
Irrigation	137,000	40
Other agriculture use	208,000	60

Source: CDC, USGS data (Use totals do not equal 100%)

Agriculture accounts for over 80 percent of water withdrawn from surface water or groundwater sources for *consumptive use*. This means that the water has been lost through evaporation, plant transpiration, incorporation in products or crops, or consumption by humans or livestock. Surface and groundwater withdrawals from the 2000 census of agriculture are shown in Table 2.6. The USGS water use estimates generally refer to *withdrawals* as the quantity of water withdrawn from a water source, whereas the USDA reports on farm *applied* water use, referring to estimates of the quantity of water applied to the field for a particular crop with an on-farm irrigation application system.

Annual crop consumptive-use estimates refer to the quantity of water actually *consumed* (taken up) by the crop plant over its various crop-growth stages for crop retention and evapotranspiration. Withdrawal estimates generally reflect diversion system conveyance losses (such as ditches and canals), while estimates of field water applied do not. Consumptive-use estimates may or may not account for associated system efficiency losses (e.g., evaporation, deep percolation, and runoff) and salt-leaching requirements for a given crop, location, and irrigation system. Which estimate to use and how to use it are important in clarifying discussions of water use and policy (USDA 2013).

Irrigated farming is the major contributor to water use in the 17 Western United States, where irrigated farms accounted for 60 percent of all crop sales in 2008, and 75 percent of all US irrigated cropland acres. Farms in the Western states use a wide variety of irrigation systems, about 36 percent of irrigated acres are irrigated with gravity-based systems such as gated-pipe furrow systems or flooding entire fields, while 67 percent are irrigated with pressure-sprinkler systems such as center-pivot sprinkler or drip/trickle systems. Some acres are irrigated with both system types. To improve irrigation efficiency, federal and state agencies and local water management districts have provided financial and technical assistance to producers to improve water delivery on farms (such as the lining of open-ditch irrigation systems) and/or promote more efficient application technologies (such as low-pressure-sprinkler irrigation systems). About 18 percent of irrigated farms in the West participated in these programs during 2003–2008 (USDA 2013).

Water Used for Aquaculture

Aquaculture, the practice of fish or shellfish farming, includes the breeding, rearing, and harvesting of plants and animals in all types of water environments including ponds, rivers, lakes, and the ocean. It includes the farming of all kinds of freshwater and marine species of fish, shellfish, and plants. Products include food fish, sport fish, bait fish, ornamental fish, crustaceans, mollusks, algae, sea vegetables, and fish eggs (NOAAFisheries 2016).

The process includes the production of seafood from hatchery fish and shellfish which are grown to market size in ponds, tanks, cages, or raceways. "Stock restoration" is a form of aquaculture in which hatchery fish and shellfish are released into the wild to rebuild wild populations or coastal habitats such as oyster reefs and clam beds. Aquaculture also includes the growing plant species used in a range of food, pharmaceutical, nutritional, and biotechnology products. The activity takes place in both fresh and salt water (Table 2.7).

Freshwater aquaculture produces species that are native to rivers, lakes, and streams. US freshwater aquaculture is dominated by catfish but also produces trout, tilapia, and bass. Freshwater aquaculture takes place primarily in ponds and in on-land, man-made systems such as recirculating aquaculture systems. Freshwater aquaculture occurs in ponds, flow through raceways, cages, net pens, and closed-circulation tanks. Total

Table 2.7 Aquaculture water withdrawals in top five states and US totals, 2010

	Withdrawals in million gallons per day by Source		
State	Ground water	Surface water	Totals
Idaho	65.6	2,690.0	2,750
North Carolina	11.5	1,450.0	1,470
California	171.0	802.0	973
Oregon	33.4	679.0	712
Virginia	9.4	286.0	295
All 50 states totals[1]	1,820.0	7,610.0	9,420.0

Notes
[1]Includes 0.41 Mgal/day in Puerto Rico
Source: USGS data

freshwater withdrawals for aquaculture during 2010 were 9,420 million gallons per day (Mgal/day) or 10,000 acre-feet per year. Surface water is the dominant source; much of this water is used in raceways and is returned to the source after use. Source quantities and the top five states where aquaculture occurs are shown in Table 2.7.

NOAA and its Office of Aquaculture focus on marine aquaculture, although research and advancement in technology can be more broadly applied. US marine aquaculture primarily produces oysters, clams, mussels, shrimp, and salmon as well as lesser amounts of cod, moi, yellowtail, barramundi, seabass, and seabream. Because these operations do not use freshwater, no further discussion will be included here.

Industrial Users of Water

The manufacturing and processing industries that produce metals, wood and paper products, chemicals, gasoline, and oils are major users of water (USGS 2015). Probably every manufactured product uses water during some part of the production process. Industrial water use includes water used for such purposes as fabricating, processing, washing, diluting, cooling, or transporting a product; incorporating water into a product; or for sanitation needs within the manufacturing facility. Some industries that use large amounts of water produce such commodities as food, paper, chemicals, refined petroleum, or primary metals. Approximately 88 percent of industries using water for manufacturing or processing supply their own water. The data on industrial used supplied by local agencies or utilities are included in the domestic data; industrial water withdrawals with self-supplied water for 2005 and 2014 estimate are shown in Table 2.8. Industrial water use has declined from 18,200 Mgal/day in 2005 to an estimated 15,950 Mgal/day in 2014.

Industrial use of both fresh and saline (or brackish) water account for about 4 percent of total withdrawals, or about 9 percent of total withdrawals when thermoelectric generation water use is excluded. Surface water was the source for 83 percent in 2005 of total industrial withdrawals and less than 78 percent in 2014. Industrial use of groundwater accounted for about 17 percent of withdrawals in 2005 and less than

Table 2.8 Industrial self-supplied water withdrawals by source and type, 2005 and 2014

	2005			2014		
	Fresh water	Saline water	Total	Fresh water	Saline water	Total
Surface water	13,900	1,150	15,000	12,100	900	13,000
Ground water	3,070	40	3,110	2,900	50	2,950
Totals	17,000	1,190	18,200	15,000	950	15,950

Source: USGS (2015)

6 percent in 2014. In both periods, nearly all of the surface water withdrawals and of the groundwater withdrawals for industrial use were freshwater. For 2005, total industrial withdrawals were 8 percent less than during 2000.

Water Used in Mining

This category of water users includes quarrying, milling (crushing, screening, washing, and flotation of mined materials), re-injecting extracted water for secondary oil and natural gas recovery, and other operations associated with mining activities. All mining withdrawals were considered self-supplied.

Mining has a long history in North America. Even before the first European settlers set foot on this continent and mined coal to heat their homes, the native population was using coal to bake the clay they mined by hand for storage vessels. In modern times, mining corporations use water during the process of mining, processing, grading, and transporting of ores, oil and gas, sand and gravel and similar resources secured by mining. Mining has also played an important part in the development of what are known as "soft rock;" industrial minerals such as clay, talc, and coal. The use of water is used at one or more stage in the mining and processing of these materials. The United States now produces a wide variety of mined commodities from gold to coal to "exotic" minerals used in

Table 2.9 Mining water withdrawals, by source and type, for the United States in 2005

Source	Mining water withdrawals (in million gallons per day)					
	Freshwater	Percent	Saline water	Percent	Total	Percent
Surface water	1,300	56.3	190	11.1	1,490	37.1
Ground water	1,020	43.7	1,520	88.9	2,540	63.2
Total	2,310	100	1,710	100	4,020	100

Source: USGS (2015)

everything from pharmaceuticals to jewelry to high-tech products. All these products would not be possible without the use of water in mining (USGS 2014; Mavis 2003).

During 2005, an estimated 4,020 Mgal/day was withdrawn for mining purposes. Mining withdrawals were about 1 percent of total withdrawals and about 2 percent of total withdrawals for all categories excluding thermoelectric power. Groundwater was the source for 63 percent of total withdrawals for mining. Nearly 90 percent of the surface water withdrawals were freshwater. The source and type of water used in mining activities is shown in Table 2.9.

Ten states account for two-thirds of all the water withdrawals for mining in 2005. Three of these ten, Texas (16%), Minnesota (11%), and California (8%), accounted for 34 percent of the total withdrawals for mining. Other large users of water for mining activities included Wyoming (6%), Alaska, Florida, and Oklahoma (5% each); Louisiana, Ohio, and Utah (4% each). Sand and gravel operations in Indiana and iron ore mining in Michigan and Minnesota accounted for the largest fresh surface water withdrawals. Mineral salt extraction from the Great Salt Lake in Utah accounted for the largest saline surface water withdrawals for mining in the United States. Florida, Ohio, Nevada, Arizona, and Pennsylvania accounted for 52 percent of fresh groundwater withdrawals. Gas and oil operations in Texas, California, Oklahoma, Wyoming, and Louisiana were responsible for the large saline groundwater withdrawals in those States, where saline water is a byproduct of mining operations (USGS 2014).

Summary

According to the USGS, in 2010, about 355,000 Mgal/day or 397,000 thousand acre-feet per year, of water was withdrawn for use in the United States. Freshwater made up 86 percent of the total, with saline water used in thermoelectric power generation making up the remaining 14 percent. Surface water from rivers, streams, and lake made up78 percent of the total. Thermoelectric power generation accounted for 51 percent of the total fresh surface water withdrawals and irrigation accounted for 29 percent. The largest surface water withdrawals occurred in California, where irrigation accounted for 76 percent of total fresh surface water withdrawals. Large quantities of fresh surface water were also withdrawn for thermoelectric power generation in Illinois, Texas, Michigan, and Alabama. Large saline surface water withdrawals for thermoelectric power occurred in Florida, California, Maryland, and New York; these four states accounted for 57 percent of the national total saline surface water withdrawals. Thermoelectric water is converted to steam with heat for turning turbines, and is generated by burning coal or from nuclear power, and is also used for cooling.

Agricultural irrigation accounted for 65 percent of the total fresh groundwater withdrawals in 2010. California, Arkansas, Texas, and Nebraska were the biggest users of water for irrigation. Fresh groundwater irrigation withdrawals in these four states together accounted for 42 percent of the national total fresh groundwater withdrawals. Irrigation used more than three times more fresh groundwater than public supply, which was the next largest use of groundwater in the Nation.

During this same year, more than 50 percent of all water withdrawals in the United States took place in just 12 States: California, Texas, Idaho, Florida, Illinois, North Carolina, Arkansas, Colorado, Michigan, New York, Alabama, and Ohio. California alone accounted for 11 percent of the total for all categories and 10 percent of total freshwater withdrawals for all categories nationwide. Texas accounted for about 7 percent of total withdrawals for all categories, predominantly for thermoelectric power, irrigation, and public supply. Florida had the largest saline surface water withdrawals, 18 percent of the total, and used primarily for thermoelectric power generation. Oklahoma and Texas accounted for about 70 percent of the total saline groundwater withdrawals in the United States, mostly for petroleum and natural gas mining.

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3

External Pressures on the Resource: Climate Change

> *Increasing human demands for water and unsustainable rates of water withdrawals are likely to worsen water shortages in the United States as well as the rest of the world. Pollution of existing freshwater supplies exacerbates water constraints and shortages, even while water management advances are improving water quality and availability.*
>
> Global Environmental Management Initiative (GEMI), 2016

Much has been written over the past several decades to warn readers that the Nation's water supplies are limited and we must stop wasting what we have. Water is simply our most precious resource. We are also reminded that people, animals, and plants cannot live without water in one form or another. We are warned regularly that the way we live is resulting in climate warming, regional drought, and an increasing incidence of extreme weather events. My goal in writing this and the next chapter was to tell people more about how the mega-trends occurring as a result of human activity are forcing a change in the way we think about this critical resource. Where and how Americans chose to live, along with warmer climate, are influencing changes in the weather cycle

D.E. McNabb, *Water Resource Management*,
DOI 10.1007/978-3-319-54816-6_3

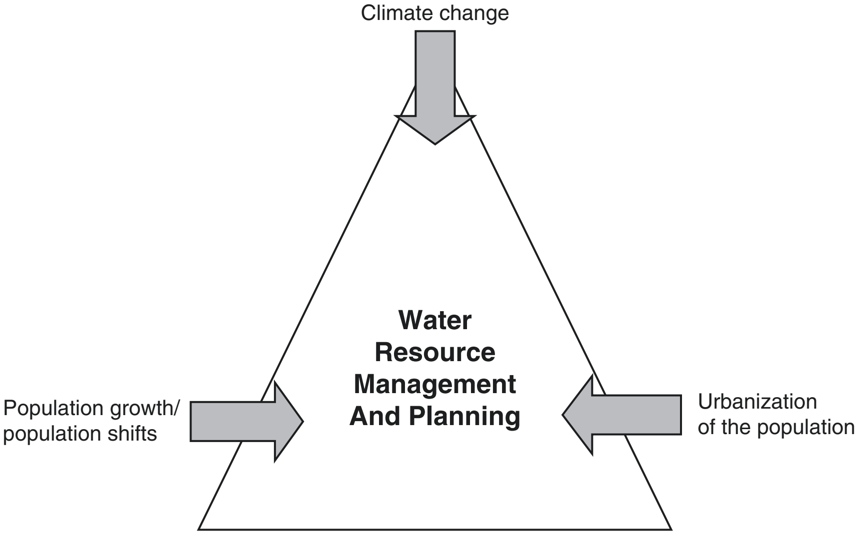

Fig. 3.1 External pressures affecting water resource management

and rates of precipitation, further stressing the water resource in many locations.

Three mega-trends are forcing a change in the way we manage our water resource are: (1) climate change is changing precipitation patterns and increasing the number and severity of extreme weather events; (2) the accelerating pace of population growth and its demographic shift; and (3) the continuing urbanization of the nation. Figure 3.1 illustrates that these three forces are key components in water resource management planning. This chapter examines the impact they have on the resource.

The Impact of Climate Change on the Resource

Despite the slow pace of a small and decreasing body of non-believers willing to admit the veracity of the evidence, the larger scientific community accepts the available data and agrees that the world is undergoing a period of rapid climate change and global warming that is happening is having a severe effect on much of the nation's water supply (Arnell and Lloyd-Hughes 2014). For example, the Environmental Protection Agency (EPA) warned of the problem facing America in a 2016 report on the predicted impact of climate change on the Nation's water resource: "Climate change is changing our assumptions about water resources. As climate change warms the atmosphere, altering the hydrologic cycle, changes to the amount, timing, form, and intensity of precipitation will continue. Other expected changes include the flow of water in watersheds, as well as the quality of aquatic and marine environments. These impacts are likely to affect the programs designed to protect water quality, public health, and safety" (EPA 2016a).

There is no doubt about climate change in the minds of the many scientists whose work was presented in the 2009 *Global Climate Change Impacts in the United States* report to Congress. "Observations show that warming of the climate is unequivocal," they wrote. Their decades of research led them to conclude "that climate change has already altered, and will continue to alter, the water cycle, affecting where, when and how much water is available for all uses. Floods and droughts are likely to become more common and more intense as regional and seasonal precipitation patterns change;: and that "climate change will place additional burdens on already stressed water systems" (Karl, Melillo and Peterson 2009).

The severity of the threat to water is not just a North American concern; it is a global problem as on industry report indicated: "Climate change is greatly affecting weather patterns and the world's ecosystem and, in particular, posing serious challenges to the world's water supply, causing poor water quality and scarcity and putting significant stress on our water infrastructure. Climate change is having a profound effect on how communities can reliably access clean water" (Duffy 2013, 1). This unprecedentedly rapid shift in the temperature of the planet is affecting the Nation's water resources in three significant ways:

1. The traditional precipitation distribution patterns and quantities are changing. Some parts of the country are experiencing longer and

more severe droughts, while others are seeing higher rainfall levels and more extreme weather events, resulting in more and more damaging floods.
2. Warmer air and ocean temperatures are melting and polar region sea and land ice, resulting in rising ocean levels. Rising sea levels endanger habitat and infrastructure in coastal regions and intrusion into supplies of freshwater.
3. Changing weather patterns are exacerbating the trend already underway in the reduction in the quality of freshwater supplies. Extreme rainfall events wash surface contaminants into existing water supply resources, while drought in other parts of the country depletes surface and groundwater supplies, concentrating contaminants in remaining resources.

Impact of Climate Change

Managing water in the midst of a potentially catastrophic climate change has become a major concern across the United States. In many parts of the country, the concern is how to achieve sustainability of water supplies as rainfall and snowpack patterns alter dramatically. In other areas, the problem in being able to deal with heightened surface water pollution from agricultural and/or urbanized area runoff during floods. A report on the state of the climate in 2014 by scientists at the American Meteorological Society indicates that the warming trend due to greenhouse gasses in the atmosphere is having a significant impact on the water supplies of the much of the United States (Box 3.1).

Box 3.1 Summary of the state of the climate in 2014 and 2015

Most of the essential climate variables monitored each year by the American Meteorological Society continued to follow their long-term trends in 2014 and 2015, with several setting new records. Carbon dioxide, methane, and nitrous oxide—the major greenhouse gases released into Earth's atmosphere—again all reached record high average atmospheric concentrations for the year. In 2015, the dominant greenhouse gases released into Earth's atmosphere all continued to reach new high levels: at Mauna Loa, Hawaii, the annual CO_2 concentration increased by a record 3.1 ppm, exceeding 400 ppm for the first time on record. The 2015 global CO_2 average neared this threshold, at 399.4 ppm.

Accompanying the record-high greenhouse gas concentrations 2014 was nominally the highest annual global surface temperature in at least 135 years of modern record keeping. However, due to the combination of El Niño and a long-term upward trend, in 2015 Earth observed record warmth for the second consecutive year. The 2015 annual global surface temperature surpassed the 2014 record by more than 0.1°C.

Averaged sea surface temperatures continue to increase. In the winter of 2013/14, upper ocean heat content was record high for the year, reflecting the continued increase of thermal energy in the oceans which absorb over 90 percent of Earth's excess heat from greenhouse gases. Sea surface temperature for 2015 was again record high globally; however, the North Atlantic southeast of Greenland remained colder than average and colder than 2014. Global annual ocean heat content and mean sea level also reached new record highs. The global mean sea level in 2014 was also record high and 67 mm (2.64 inches) greater than the 1993, when satellite measurements began.

Across the Northern Hemisphere, 2015 late-spring snow cover extent continued to decline, with June being the second lowest in the 49-year satellite record, with the Greenland Ice Sheet experienced melting over more than 50 percent of its surface for the first time since the record melt of 2012. An above-normal rainy season in 2015 led to major floods in the United States; in May, the country recorded its all-time wettest month in its 121-year national record.

Source: Blunden and Arndt (2015, 2016)

The problem is exacerbated by population shifts from northern and northeastern states to the very states in the South and West where water supplies are already under stress. The EPA's projection of domestic water use and regional population change identified Idaho, Nevada, Utah, and Colorado as states with the highest rates of domestic water use per person, 151–200 gallons per person per day, followed by Arizona and Texas and Nebraska with water use from 126 to 150 gallons per person per day. Five of the six states with the third highest daily water use per person (101–125 gallons per day) are in the West: Washington, Oregon, California, Colorado, and New Mexico; West Virginia is the only eastern state in this group.

Changing Precipitation Patterns

The EPA'S 2014 Climate Change Adaptation Plan identified ten agency priorities to be implemented for new water and other environmental projects across the nation that are designed to ensure "adaptive capacity" (readiness and resiliency) in preparation for the expected impact of climate change.

According to the US Center for Disease Control and Prevention (CDC) 2010 report, *When Every Drop Counts: Protecting Public Health During Drought Conditions*, the nation's water resources are facing a number of supply sustainability challenges resulting from the effects of climate change. Among these challenges is the need for the water industry to be prepared to deal with severe drought conditions occurring over an extended period. Another is to be prepared to cope with the increasing number and severity of extreme weather events that result in sustained heavy precipitation runoff and floods.

Effects of Drought

The effects of drought include the drying up of surface reservoirs, reduced stream flows, and the over withdrawing of groundwater aquifers. In some places in the country, the underground water reservoirs that took thousands of years to accumulate are being exhausted in decades. Water tables in some regions of the country have dropped as much as 300 feet or more.

Drought and other changing weather patterns are not new to the world, including the United States. Significant drought events have affected the United States throughout history. Droughts that can last from a single season to multiple decades and can impact from a few hundred to millions of square miles. Studies of paleoclimatic indicators such as lake bottom sediments, glacier ice deposits, and tree ring patterns reveal that cycles of drought have affected North America for the last 10,000 years (National Oceanic and Atmospheric Survey [NOAA] 2003).

Even more is known about droughts occurring during the more recent years of the twentieth century. Perhaps the most notable and well-known US drought event during the last century was the Southwestern states Dust Bowl drought of the 1930s. During those eight years of severe drought, states located on the Great Plains had to live under huge clouds of dust and sand that often blocked out the sun as far as the East Coast for days at a time. In an average year over the past century, hundreds of farms in Texas and Oklahoma essentially disappeared as settlers packed their few belongings and fled West.

In the first 15 years of the twenty-first century, something like 14 percent of the United States has been affected by severe or extreme drought (it was as high as 65 percent during the Dust Bowl), and recently has been as great as 35 percent for some regions. The historical climate record shows that past droughts in North America have lasted decades, and many were far more severe than has experienced over the past century.

Effects of Extreme Weather Events

While the arid and semi-arid West and Southwest are having to cope with drought, much of the middle and Eastern regions of the country are having the opposite problems: more and more severe flooding from extreme weather events. The Eastern United States consists of two very different regions, the Northeast and the Southeast. In the northernmost of the 12 states in the Northeast, heavy snow and ice conditions have traditionally characterized winter months. In the Southeast, heavy rainstorms and floods are increasingly common events. Global warming is having very different effects upon the water resources of the two regions. As a result, the water management activities in the section of the country must address different challenges.

In 2015, there were ten weather and climate disaster events with losses exceeding $1 billion each across the United States. The number was nearly three times what has been normal for the country. Half of disasters were in the eastern United States, three were in the south-central section of the country; and two were in California. These events included a major drought, two floods, five severe storm events, a devastating wildfire, and a

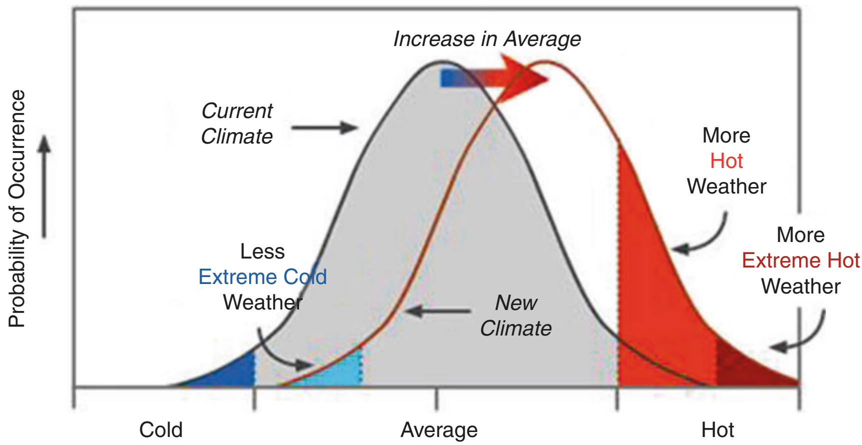

Fig. 3.2 Connection between climate warming and extreme hot weather
Source: EPA (2016d)

winter storm event. Overall, these events resulted in the deaths of 155 people and had significant economic effects on the areas impacted. The 1980–2015 annual average is 5.2 extreme weather events (CPI-adjusted); the annual average for the most recent 5 years (2011–2015) was 10.8 extreme weather events. The connection between climate change and extreme hot weather in the United States is shown in Fig. 3.2.

Dangers of Rising Sea Levels

Sea levels along the US coast are expected to rise as a result of global warming anywhere from 1 to 4 feet or higher by 2100. There is little disagreement on this concept, although estimates of how much they will rise vary. Over the last decade of the twentieth century, as the temperature of the sea has continued to increase, sea levels appear to have risen by from one-half inch to one inch per hear. Most of this rise has been attributed to thermal expansion of the ocean as it warms (Church 2001). The pace of the increase has risen due to melting of glaciers and melting of the polar ice caps and Greenland ice sheet. According to one futurist, many scientists think that instead of rising at the earlier predicted 2°C by

2100, an increase of 6°C or more over the same period is possible (Manien 2012). The current prediction of sea level rise by 2100 is 20 inches. However, melting of the West Antarctic ice sheet would see sea levels rise as much as 16 feet; and should the entire Greenland ice cap melt, sea levels are predicted to rise even more.

Effects of Seal Level Rise to US Coast Areas

The Southeastern United States and Caribbean region is home to more than 80 million people and draws millions of visitors every year. The region has two of the most populous metropolitan areas in the country (Miami and Atlanta) and four of the ten fastest-growing metropolitan areas. Two that are vulnerable to sea level rise and storm surge are in Florida (Palm Coast and Cape Coral-Fort Myers), and one is in South Carolina (the Myrtle Beach area). Management of river flow has deprived the coastal wetlands of the freshwater and sediment that are needed to allow the lands to exist and grow. Dredging of canals through marshes for oil and gas exploration and pipelines has led to erosion and intense saltwater intrusion. This has resulted in additional wetland loss.

Groundwater Damage from Saltwater Intrusion

Saltwater intrusion is projected to continue to reduce the availability of fresh surface and groundwater for irrigation, thereby limiting crop production in some areas. For example, agricultural areas around Miami-Dade County, Florida, and southern Louisiana with shallow groundwater tables are at risk of increased inundation and future loss of cropland from a projected 27-inch rise in sea level. Climate change is expected to increase harmful surface water algal blooms and several disease-causing agents in inland and coastal waters, which were not previously problems in the region. For instance, higher sea surface temperatures are associated with higher rates of ciguatera fish poisoning, one of the most common hazards from algal blooms in the region. Box 3.2 includes notice by the US Center for Disease Control and Prevention (CDC) describes the effects of this algae-related poisoning on humans.

Box 3.2 Rising sea-level warming and algae-related fish poisoning warning

The US Center for Disease Control and Prevention published this warning regarding the harmful effects of consuming fish exposed to algae-related toxins:

> Ciguatera fish poisoning (or ciguatera) is an illness caused by eating fish that contain toxins produced by a marine microalgae called *Gambier discus toxicus*. People who have ciguatera may experience nausea, vomiting, and neurologic symptoms such as tingling fingers or toes. They also may find that cold things feel hot and hot things feel cold. Ciguatera has no cure. Symptoms usually go away in days or weeks but can last for years. People who have ciguatera can be treated for their symptoms.

The following fish species have been found to be infected at different times: barracuda, black grouper, blackfin snapper, cubera snapper, dog snapper, greater amberjack, hogfish, horse-eye jack, king mackerel, and yellowfin grouper have been known to carry ciguatoxins. Reports of ciguatera fish poisoning have been published for coastal waters of the states of Florida, Texas, South Carolina, and Vermont, and the Bahamas.

Source: US CDC *Harmful Algal Blooms (HABs)*, accessed July 17, 2016 at http://www.cdc.gov/nceh/ciguatera/

Pressures on Water Resource Availability

Decreased water availability, exacerbated by population growth and land-use change, will continue to increase competition for water and affect the region's economy and unique ecosystems. The Southeast has the existing power plant capacity to produce 32 percent of the nation's electricity. Water used for steam and cooling in thermoelectric generation is nearly 30 percent of the total water used in the Southeast—more than in any other region. Net energy demand is projected to increase, largely due to higher temperatures and increased use of air conditioning. This will potentially stress electricity generating capacity, distribution infrastructure, and energy costs.

Regional Differences

The combined pressures of climate change and population growth are having different effects on the regions of the country. Brief summaries of the changes occurring now and predicted for the near future are included here for the following six regions of the country: the Northeast, Southeast, Middle West, Great Plains, the Southwest, and the Northwest. The next chapter will address the impacts of population growth on the water resources of the Nation.

Population and Water in the Northeast

The Northeast region extends North from West Virginia and Washington, DC, to reach Maine and the Canadian Border. More than 64 million people live in the region. Table 3.1 lists the estimated 2016 population of the 12 states and the District of Columbia. Region is home of one of the world's most important financial centers, the nation's capital, while also a large number of historical landmarks and a large vibrant agricultural industry that produces and processes $12 billion annually.

Table 3.1 Estimated population of each of the states in the Northeast region

State	Estimated 2015/2016 population
New York	19,378,102
Pennsylvania	12,702,379
New Jersey	8,791,894
Massachusetts	6,547,625
Maryland	5,773,552
Connecticut	3,524,097
West Virginia	1,852,994
Maine	1,328,361
New Hampshire	1,316,470
Rhode Island	1,052,567
Delaware	897,934
Vermont	626,741
District of Columbia	601,723

Source: US Census Bureau

Much of the Northeast is covered by forest, but the region also has large areas of grass and open croplands, coastal zones, beaches and dunes, and wetlands. At the same time, rising sea are threatening much more of the coastal areas' ecosystem's wetlands, however. The region has also been known for its rich marine and freshwater fisheries, much of which is being impacted by the loss of tidal marshlands. The region's natural areas that contribute important ecosystem services to the groundwater supplies and contribute and protect surface water supplies, buffer shorelines, and sequester carbon in soils and vegetation are being lost to population growth.

Heat waves, heavy downpours, and sea level rise pose growing challenges to many areas of the 12 states that comprise the Northeast: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. Despite its reputation for a generous supply of participation, the region has also suffered from periodic droughts; the Northeast's most severe drought in the last hundred and 130 years occurred between 1961 and 1966, when the region suffered a precipitation deficit of over 50 inches (Gellis 1985).

Summers are warm and humid, especially to the South. The Northeast is often affected by extreme events such as ice storms, floods, droughts, heat waves, hurricanes, and major storms in the Atlantic Ocean off the northeast coast, referred to as *nor'easters*. The Northeast has experienced a greater increase in extreme precipitation than any other region in the United States; between 1958 and 2010, the Northeast saw more than a 70 percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1 percent of all daily precipitation events).

Effects of Warmer Temperatures

Between 1895 and 2011, temperatures in the Northeast increased by almost 2°F and precipitation increased by approximately five inches, or more than 10 percent. Coastal flooding has increased as a result of a rise in sea level of approximately one foot since 1900. Winter and spring precipitation is projected to increase; projections for the end of this century range from about 5 to 20 percent increases in winter precipitation. Projected changes in summer and fall, and for the entire year, are generally small at the end of the century compared to natural variations. The frequency of heavy downpours is projected to continue to increase as the century. Seasonal drought risk is also projected to increase in summer and fall as higher temperatures lead to greater evaporation and earlier winter and spring snowmelt. Global sea levels are projected to rise one to four feet by 2100.

Climate Change and Water in the Southeast

Water resources in parts the Southeast have generally been abundant and sufficient to support large populations in urban areas, rural communities, unique ecosystems, and economies based on agriculture, energy, and tourism. However, the region also experiences extensive droughts, such as the 2007 drought in Atlanta, Georgia, that created water conflicts among three states. In northwestern Puerto Rico, water was rationed for more than 200,000 people during the winter and spring of 1997–1998 because of low reservoir levels. Droughts are one of the most frequent climate hazards in the Caribbean, resulting in economic losses. In order to extend the availability of existing groundwater resources, Florida is one of the four states most active in employing recycled water wherever possible.

Water supply and demand in the Southeast and Caribbean are influenced by many changing factors, including climate, population, and land use., With projected increases in population, the conversion of rural areas, forestlands, and wetlands into residential, commercial, industrial, and agricultural zones is expected to intensify. The continued growth of urbanized areas will continue to increase demands for water while at the same time place greater pressure on the environmentally sensitive wetlands bordering urban areas. Higher sea levels will increase saltwater intrusion into freshwater supplies from rivers, streams, and groundwater sources near the coast. With increasing demand for food and rising food prices, irrigated agriculture will expand in some states. Also, population expansion in the region is expected to increase domestic water demand. Such increases in water demand by the energy, agricultural, and urban sectors will increase the competition for water, particularly in situations where environmental needs for water conflict with other uses.

Climate Change and Water in the Midwest

Climate change in the Midwest is expected to result in summers of extreme heat, heavy winter downpours, and flooding. These events in turn will affect local infrastructure, health, agriculture, forestry, transportation, air and water quality, and more. They will also amplify the already-existing range of risks to the Great Lakes.

The Midwest has a population of more than 61 million people (about 20 percent of the national total) and generates a regional gross domestic product of more than $2.6 trillion (about 19 percent of the national total). The geography of the Midwest consists of vast stretches of agricultural lands, forests in the North, the Great Lakes, substantial industrial activity, and major urban areas, including eight of the nation's 50 most populous cities. This once heavy industry heartland has experienced depopulation of its rural areas, socioeconomic changes brought about as a result of the collapse of much its base heavy industry, air and water pollution. It is particularly susceptible to both climate variability and climate change.

Most of the Midwest region's population lives in cities, which are particularly vulnerable to climate change-related flooding and life-threatening heat waves. Climate change is also increasing atmospheric pollution, heat island (in cities) effects. Expected effects of climate change are already visible; flooding, drought, late spring freezes on natural and managed ecosystems, ecosystem disturbances, land-use change, landscape fragmentation, atmospheric pollutants, and economic shocks such as crop failures or reduced yields due to extreme weather events; these are all increasingly present in the region.

Weather records reveal that the rate of warming in the Midwest has risen significantly over the past few decades. Between 1900 and 2010, the average Midwest air temperature increased by more than 1.5°F. However, between 1950 and 2010, the average temperature increased twice as quickly, and between 1980 and 2010, it increased three times as quickly as it did from 1900 to 2010. Warming has been more rapid at night and during winter. Projections for regionally averaged temperature increases by the middle of the century (2046–2065) relative to 1979–2000 are approximately 3.8°F for a scenario with substantial emissions reductions and 4.9°F with continued growth in global emissions. The projections for the end of the century (2081–2100) are approximately 5.6°F for the lower emissions scenario and 8.5°F for the higher emissions scenario. The frequency of major heat waves in the Midwest has increased over the last six decades. For the United States, mortality increases 4 percent during heat waves compared with non-heat wave days. During July 2011, 132 million people across the United States were under a heat alert, and on July 20 of that year, the majority of the Midwest experienced temperatures in excess of 100°F. Heat stress is projected to increase as a result of both increased summer temperatures and humidity. One study projected an increase of between 166 and 2,217 excess deaths per year from heat wave-related mortality in Chicago alone by 2081–2100.

Changing Precipitation Patterns

Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure. Precipitation in the Midwest is greatest in the East, declining towards the West. Precipitation occurs about once every seven days in the western part of the region and once every three days in the southeastern part. The ten rainiest days can contribute as much as 40 percent of total precipitation in a given year. Generally, annual precipitation increased during the past century (by up to 20 percent in some locations), with much of the increase driven by intensification of the heaviest rainfalls., Precipitation patterns affect many aspects of life, from agriculture to urban storm drains. Flooding can affect the integrity and diversity of aquatic ecosystems. Flooding also causes major human and economic consequences by inundating urban and agricultural land and by disrupting navigation in the region's roads, rivers, and reservoirs. For example, the 2008 flooding in the Midwest caused 24 deaths, $15 billion in losses from reduced agricultural yields, and closure of key transportation routes.

Water infrastructure for flood control, navigation, and other purposes is susceptible to climate change impacts and other forces because the designs are based upon historical patterns of precipitation and stream flow, which are no longer appropriate guides.

Snowfall varies across the region, comprising less than 10 percent of total precipitation in the South, to more than half in the North, with as much as two inches of water available in the snowpack at the beginning of spring melt in the northern reaches of the river basins. When this amount of snowmelt is combined with heavy rainfall, the resulting flooding can be widespread and catastrophic. Historical observations indicate declines in the frequency of high magnitude snowfall years over much of the Midwest, but an increase in lake effect snowfall. These divergent trends and their inverse relationships with air temperatures make overall projections of regional impacts of the associated snowmelt extremely difficult. Large-scale flooding can also occur due to extreme precipitation in the absence of snowmelt (e.g., Rush Creek and the Root River, Minnesota, in August 2007 and multiple rivers in southern Minnesota in September 2010). These warm-season events are projected to increase in magnitude. Such events tend to be more regional and less likely to cover as large an area as those that occur in spring, in part because soil water storage capacity is typically much greater during the summer.

Changing land use and the expansion of urban areas are reducing water infiltration into the soil and increasing surface runoff. These changes exacerbate impacts caused by increased precipitation intensity. Many major Midwest cities are served by combined storm and sewage drainage systems. As surface area has been increasingly converted to impervious surfaces (such as asphalt) and extreme precipitation events have intensified, combined sewer overflow has degraded water quality, a phenomenon expected to continue to worsen with increased urbanization and climate change. The US EPA estimates that there are more than 800 billion gallons of untreated combined sewage released into the nation's waters annually. The Great Lakes, which provide drinking water to more than 40 million people and are home to more than 500 beaches, have been subject to recent sewage overflows. For example, stormwater across the city of Milwaukee recently showed high human fecal pathogen levels at all 45 outflow locations, indicating widespread sewage contamination. One study estimated that increased storm events will lead to an increase of up to 120 percent in combined sewer overflows into Lake Michigan by 2100 under a very high emissions scenario (A1FI), leading to additional human health issues and beach closures. Municipalities may be forced to invest in new infrastructure to protect human health and water quality in the Great Lakes.

Increased precipitation intensity also increases erosion, damaging ecosystems and increasing delivery of sediment and subsequent loss of reservoir storage capacity. Increased storm-induced agricultural runoff and rising water temperatures have increased non-point source pollution problems in recent years. This has led to increased phosphorus and nitrogen loading, which in turn is contributing to more and prolonged occurrences of low-oxygen "dead zones" and to harmful, lengthy, and dense algae growth in the Great Lakes and other Midwest water bodies. Watershed planning can be used to reduce water quantity and quality problems due to changing climate and land use.

Climate Change and Water in the Great Plains

The Great Plains region includes the states of Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming (Fig. 3.3). Daily, monthly, and yearly variations in the weather can be dramatic and challenging. The region experiences

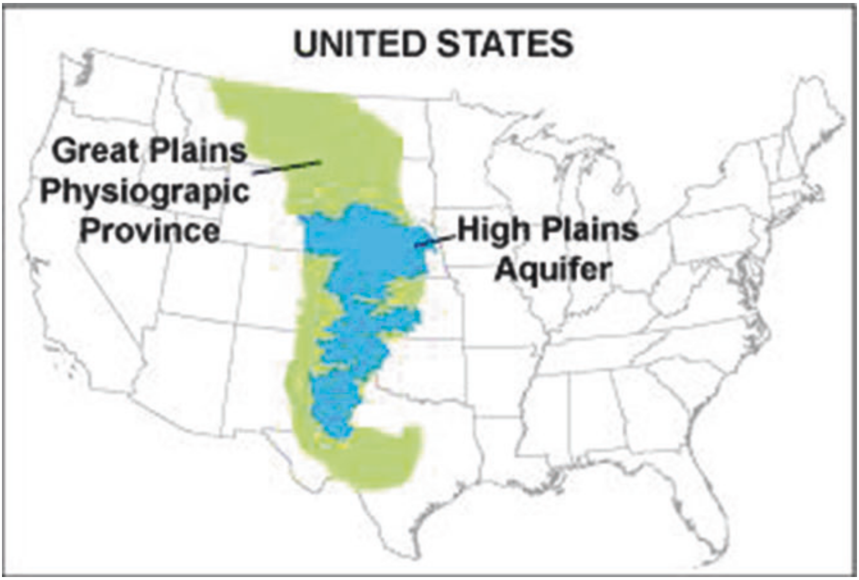

Fig. 3.3 Location of the High Plaines (Ogallala) Aquifer in the Great Plains region
Source: USGS

multiple climate and weather hazards, including floods, droughts, severe storms, tornadoes, hurricanes, and winter storms. In much of the Great Plains, too little precipitation falls to replace that needed by humans, plants, and animals. These variable conditions already stress communities and cause billions of dollars in damage. Climate change will add to both stress and costs. Rising temperatures are leading to increased demand for water and energy. Projections suggest more frequent and more intense droughts, heavy downpours, and heat waves, are to be expected as a result of the climate change no underway.

Rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs. Changes to crop growth cycles due to warming winters and alterations in the timing and magnitude of rainfall events have already been observed; as these trends continue, they will require new agriculture and livestock management practices.

The current trend toward more dry days and higher temperatures across the Southern Plains will increase evaporation, decrease water supplies, reduce electricity transmission capacity, and increase cooling demands. These changes will add stress to limited water resources and affect management choices related to irrigation, municipal use, and energy generation. Increased drought frequency and intensity can turn marginal lands into deserts.

Changing extremes in precipitation are projected across all seasons, including higher likelihoods of both increasing heavy rain and snow events and more intense droughts. Winter and spring precipitation and heavy downpours are both projected to increase in the North, leading to increased runoff and flooding that will reduce water quality and erode soils. Increased snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods, as is already common along the Red River of the North. More intense rains will also contribute to urban flooding.

A pattern of more precipitation in the northern Great Plains and less in the southern Great Plains were seen in 2011. The southern portion of the Great Plains was subjected to exceptional drought and recording-setting temperatures in Texas and Oklahoma. Many locations in Texas and Oklahoma experienced more than 100 days over 100°F, with both states setting new high temperature records. Rates of water loss were double the long-term average, depleting water resources and contributing to more than $10 billion in direct losses to agriculture alone. The intensity of heat waves is expected to continue to grow.

The Northern Plains were exceptionally wet, with Montana and Wyoming recording all-time wettest springs and the Dakotas and Nebraska not far behind. Record rainfall and snowmelt combined to push the Missouri River and its tributaries beyond their banks leaving much of the Crow Reservation in Montana underwater. The Souris River near Minot, North Dakota, crested at four feet above its previous record, causing losses estimated at $2 billion.

Projected climate change will have both positive and negative consequences for agricultural productivity in the Northern Plains, where increases in winter and spring precipitation will benefit productivity by increasing water availability through soil moisture reserves during the early growing season, but this can be offset by fields too wet to plant. Rising temperatures will lengthen the growing season, possibly allowing a second annual crop in some places and some years.

In the Central and Southern Plains, projected declines in precipitation and greater evaporation due to higher temperatures will increase irrigation demand and exacerbate current stresses on agricultural productivity. Increased water withdrawals from the Ogallala and High Plains aquifers would accelerate depletion of the aquifers and limit the ability to irrigate., Holding other aspects of production constant, the climate impacts of shifting from irrigated to dryland agriculture would reduce crop yields by about a factor of two.

Farming has been the dominant industry in the Great Plains area since the late 1880s. Farmers in the Plains States have long irrigated using ground and surface water. For example, in the late 1800s, some farmers were irrigating crops using surface water diverted from the Platte and Arkansas Rivers, while others were irrigating using shallow groundwater pumped to the surface by windmills. Through the early 1940s, depth to water in the Ogallala or High Plains Aquifer and the slope of the land surface were major factors controlling the distribution of irrigated acres. The map in Fig. 3.3 shows the location of the aquifer in the central portion of the Great Plains section of the county. By the early 1960s, technological advances in pumps allowed irrigation in areas with deeper (greater than 100 feet below land surface) groundwater, and the development of center-pivot irrigation systems allowed irrigation on rolling terrain.

In the area that overlies the High Plains aquifer, estimated acreage irrigated with groundwater increased rapidly from the 1940s to 1980, but did not change greatly beyond 1980. However, the proportion of irrigated acreage in each state relative to total irrigated acres did change substantially over time in some states: in 1980, 21 percent of irrigated acres were in Kansas and 38 percent of irrigated acres were in Nebraska; 20 years later, 15 percent of irrigated acres were in Kansas and 45 percent of irrigated acres were in Nebraska. Annual groundwater withdrawals from the High Plains aquifer for irrigation compiled about every five years by the USGS and agencies in each State, increased from 4 to 19 million acre feet from 1949 to 1974; from 1980 to 2000, groundwater withdrawals for irrigation have varied from 2 to 18 percent of 1974 withdrawals for irrigation in 2000 by county ranged from less than 0.01 million acre feet to more than 0.25 million acre feet. In 2015, groundwater pumping in the High Plains aquifer supported 30 percent of the irrigated agriculture.

Table 3.2 shows projections of groundwater in storage in the states in 20-year intervals to 2110 and the projected level of the water withdrawals as a percentage change in groundwater level compared with the level at the time of the pre-1930 development of the aquifer (Steward and Allen 2015). Nebraska has the largest amount of groundwater stored. The far right column shows the steady depletion of the High Plains Aquifer from 1930 to its projected level in 2110. The average rate of depletion appears to have peaked in 2996, but different times for the states withdrawers, with a peak in 1999 for Texas; 2002 for New Mexico; 2010 for Kansas; 2012 for Oklahoma; and a projected 2023 for Oklahoma. Peak withdrawals do not occur before 2110 for Nebraska, South Dakota, or Wyoming

Water and Climate Change in the Southwest

The Bureau of Reclamation's SECURE Water Report for 2016 identified climate change as a growing risk to western water management and cites warmer temperatures, changes to precipitation, snowpack and the timing and quality of stream flow runoff across major river basins as threats to water sustainability. Water supply, quality, and operations; hydropower; groundwater resources; flood control; recreation; and fish, wildlife, and other ecological resources in the Western states remain at risk. The Secure Water Act of 2009 required the Department of the Interior to conduct regular studies on water supplies in regions where the Bureau of reclamation was the primary manager of surface water resources. The first report was produced in 2011; the second report was published in 2016. Specific projections of the effects expected over the rest of this century include:

Table 3.2 Projected groundwater storage and percent change for selected Plains states, 1930–2110

Year	CO	KS	NE	NM	OK	SD	TX	WY	HPA
1930	133(0%)	420(0%)	2599(0%)	54(0%)	145(0%)	71(0%)	578(0%)	89(0%)	4093(0%)
1950	132(1%)	413(2%)	2611(–0%)	56(2%)	146(–0%)	71(–0%)	560(3%)	88(0%)	4077(0%)
1970	127(5%)	397(5%)	2614(–1%)	53(8%)	144(1%)	72(–1%)	521(10%)	87(2%)	4014(2%)
1990	118(11%)	365(13%)	2608(–0%)	47(18%)	140(4%)	72(–2%)	460(20%)	85(4%)	3897(5%)
2010	107(20%)	322(23%)	2594(0%)	40(31%)	132(9%)	72(–2%)	387(33%)	83(6%)	3738(9%)
2030	94(30%)	279(33%)	2574(1%)	35(39%)	123(15%)	73(–2%)	328(43%)	81(8%)	3587(12%)
2050	81(39%)	245(42%)	2551(2%)	33(43%)	116(20%)	73(–2%)	274(53%)	78(12%)	3413(17%)
2070	70(47%)	218(48%)	2524(3%)	31(46%)	109(25%)	73(–2%)	262(55%)	77(13%)	3364(18%)
2090	61(54%)	196(53%)	2493(4%)	30(47%)	104(29%)	73(–2%)	242(58%)	74(17%)	3273(20%)
2110	53(60%)	179(57%)	2460(5%)	29(49%)	98(32%)	73(–2%)	227(61%)	71(20%)	3190(22%)

Notes: Projected groundwater storage for each state and High Plains Aquifer are in billions of cubic kilometers (10^9 m^3) and as a fraction of 1930 storage

Source: Data from (Steward and Allen (2015)

- A temperature increase of 5–7°F by the end of the century;
- A precipitation increase over the northwestern and north-central portions of the western United States and a decrease over the south-western and south-central areas;
- A decrease for almost all of the April 1 snowpack, a standard bench-mark measurement used to project river basin runoff; and
- A 7 to 27 percent decrease in April to July stream flow in several river basins, including the Colorado, the Rio Grande, and the San Joaquin.

Climate Change and Water in the Northwest

Over the last 100 years, the average annual temperature in the Northwest has risen an estimated 1.3°F. The effects of climate change are not only expected to continue, they are expected to accelerate. Projected increases are from 3°F to 10°F by the end of the century, with the largest increased occurring in the summer months. Over the remaining years of the century, a 30 percent decline in the amount of rainfall in the summer months is predicted. The region has experienced a decline in the amount of total snowfall and in the amount of precipitation falling as snow. A record low snowpack was recorded in Washington state in the winter of 2015.

Much of the Northwest's supply of surface and groundwater is stored in winter Cascade Range snowpacks. The effects of climate change are altering this natural reservoir system by changing the timing of the snowmelt and the total amount of water in streams and rivers. Changes in stream flow are likely to strain water management and worsen existing competition for water between municipal, agricultural, industrial, and energy production users (40 percent of the Nation's hydropower is generated in the Northwest). Higher temperatures and continued population growth are likely to result in it becoming impossible to meet additional water demands with existing water supplies.

In 2004, the *Climate Change* journal published a report by Barnett et al. on an evaluation of a series of computer simulations on the effects of climate change on the western United States, with a focus on three major western river basins: the Columbia, Sacramento/San Joaquin, and the Colorado. Their analysis was based on the National Center for Atmospheric Research Parallel Climate Model, a more conservative model regarding the predicted degree of climate warming over a 50-year period due to greenhouse gas concentrations. They considered this a "best case" future scenario. The report's conclusions began with the following statement:

> The clearest change indicated by the climate change simulation generated by this project is a general large-scale warming over the West: a warming that by the middle of the century reaches an addition 1–2°C as compared to [the] present. The most significant impact of this warming would be a large reduction in mountain snowpack and a commensurate reduction in natural water storage . . . *What this work shows is that, even with a conservative climate model, current demands on water resources in many parts of the West will not be met under plausible future climate conditions, much less the demands of a larger population and a larger economy.* (emphasis in the original) (Barnett et al. 2004, 6)

The Pacific Northwest comprises the states of Washington Oregon, and Idaho, with much of Northern California influenced by the same climate conditions. The region is divided by the Cascade Mountain range, resulting in a generally moist climate on the Pacific Coastal side of the range and a dry, semi-arid rain-shadow climate East of the range. The Oregon coastal range and the Olympic Mountains in Washington produce a similar but less significant rain shadow effect West of the Cascades. Two of the three major river basins in the western United States, the Columbia and the Sacramento/San Joaquin basins, are included in the region.

The Columbia/Snake River system is the most significant surface water source in the Pacific Northwest. These rivers are major sources of surface water used for irrigated agriculture and energy production in Idaho and eastern Oregon and Washington. The system also supports a significant salmon run. Climate change-influenced changes in the snow-melt feeding the Columbia River system are predicted to make it impossible to support spring and summer salmon runs and summer and fall hydroelectric power generation. Earlier snow-melt will also make it impossible for other smaller but important snow-melt-fed rivers such as the Yakima River in eastern Washington to meet current demands for summer agriculture irrigation.

California's Sacramento River rises in northern and flows South to the Sacramento Delta and San Francisco Bay. Drought in the Central Valley of California, one of the West's most important agricultural and hydro-power regions, has been shown to be unable to meet existing water system demands. Declining amounts of freshwater and large withdrawals for urban supplies is already resulting in incursion of saline water into the delta and disruption of the existing ecosystem.

Applying Adaptation Water Management

The US Bureau of Reclamation (Reclamation) identifies climate change as a major risk to effective western water management in the western half of the United States. In recent decades, climate science has high-lighted a broad suite of future challenges for managing western water, in addition to risks already posed by natural variations in climate and pressures associated with growing populations. In November 2014, Reclamation published its Climate Change Adaptation Strategy to build on existing actions and identify new activities that extend climate change adaptation efforts across Reclamation's mission responsibilities. The report was included in its 2016 report to Congress (USBR 2016b).

Since its establishment in 1902, Reclamation constructed and now manages a large number of dams, power plants, and canals within the 17 western states (Fig. 3.4). Reclamation is now the largest wholesaler of water in the Nation. It provides more than 10 trillion gallons of water each year for municipal use and provides water to approximately 10 million acres of irrigated farmland that collectively produce 60 percent of the Nation's vegetables and 25 percent of its fruit and nuts.

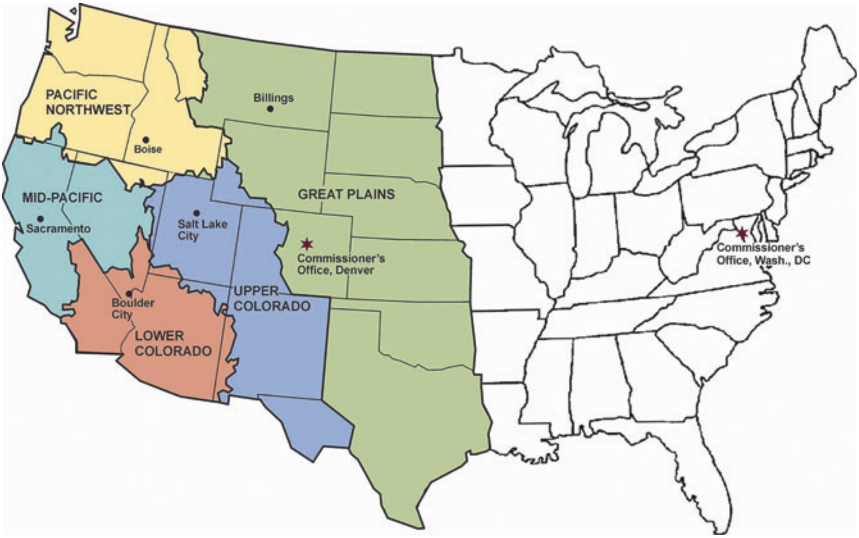

Fig. 3.4 The 17-state region of operations for the US Bureau of Reclamation
Source: USBR (2016)

Reclamation is also required to assess and report on the impacts of climate change to water resources, as well as developing and implementing actions to mitigate the impacts of this change. Reclamation's climate change mitigation strategy includes promoting adaption planning, increasing water management flexibility, improve infrastructure resiliency, and expanding information sharing by water-interest government agencies and other stakeholders.

The USBR 2016 report to Congress reviews possible adaptive strategies for dealing with the effects climate change on water management in five areas of operations: supply augmentation, demand management, system operations, ecosystem resiliency, and data and information management. Individual options in each area are shown in Fig. 3.5.

Reclamation partners with the US Army Corps of Engineers, USGS, the NOAA, and other agencies through the Climate Change and Water Working Group in an effort to identify mutual science needs for short-term water management decisions and long-term planning, including adapting to climate change. By assessing the current state of knowledge,

	POSSIBLE RECLATION BUREAU ACTIONS			
Data and Information	**Supply Augmentation**	**Demand Management**	**System Operations**	**Ecosystem Resiliency**
Improved data access	Water reuses and desalination	Municipal and Industrial water conservation	Modified reservoir operations	Recreational and environmental flow management
Improved modeling tools	Water rights acquisition	Agricultural water conservation	Conjunctive water management	Water quality improvements
Improved observation data	Imported water	Evaporation control	Hydropower modernization	Invasive species control
	Surface and groundwater storage	Water marketing	Infrastructure modifications	Habitat restorations
				Watershed management

Fig. 3.5 Categories of possible actions to adapt water management to climate change
Source: US Bureau of Reclamation (2016)

identifying where gaps exist, and finding opportunities to address those gaps, the group develops new actions for water utilities use in adapting to climate change.

Summary

Three mega-trends are forcing a transformational change on the way the Nation's water resource is managed. The trends are (1) shift in precipitation patterns and overall climate warming brought on by releasing carbon-based greenhouse gases into the atmosphere, (2) the accelerating pace of population growth and migration into already water resource-stressed regions in the South and Southwest, and (3) the continuing urbanization of the Nation and the resulting increase in stormwater runoff that, mixed with wastewater effluent discharges, is polluting many of the Nation's natural watercourses.

This chapter focused on the effects of climate change in the several distinct geographical regions of the country. Climate change brought on by warming of the atmosphere is changing global weather patterns everywhere, resulting in more precipitation in already wet regions and less rainfall in arid regions. In the United States, this is resulting in further drying of the arid Southwest, reducing the percentage of annual precipitation that falls as snow in the natural water resource reservoirs of the western mountain ranges, and increasing the occurrence of extreme weather patterns, particularly in the East and Southeast.

Climate warming is also resulting in melting of glaciers and polar sea ice. This is resulting in an expected global sea level rise of from one to four feet by the end of the century. Even more dire threats are predicted if the Greenland ice sheet and arctic land ice caps completely disappear.

The combined forces of global warming and population growth and regional shifts is having different effects on the various regions of the country. The Northeast is expected to undergo small changes in overall precipitation, but likely to have to cope with more extreme weather events. The South and Southeast, where population and urbanization are increasing rapidly, are subject to the incongruous mix of more severe storms occurring more often and the declines in available water surface and groundwater supplies. The water supply in the Midwest is expected to be least effected by climate change, although the pattern of spring snowmelt will become earlier and possible result in greater flooding. The semi-arid Great Plains, where excessive groundwater withdrawals for irrigated agriculture, is already experiencing large drops in the water level of the great Ogallala aquifer under eight states. That groundwater, which took thousands of years to accumulate, will take at least as long to be recharged. Water withdrawals for oil and natural gas fracturing is also polluting some surface and groundwater supplies in the region. Water supplies in the Southwest are essentially over allocated already. No new sources of supply are readily available, except for some proposals for desalination in states on the Gulf of Mexico. The Pacific Northwest is expected to become warmer and dryer. Clearly, water managers in the United States have their work cut out for them.

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4

External Pressures on the Resource: Growth and Urbanization

The American Water Works Association (AWWA) has warned for more than a decade that population growth and demographic shifts in the population are among the major trends that are altering the way the US water industry manages the water resource. Water industry managers must take these factors into account as they plan for the future. The number of people in the United States is expected to grow from the 324.5 million residents in 2016 to exceed 388.8 million in 2050 and only a little below 417 million by 2060 (Colby and Ortman 2015). Water utilities must plan now for how they will meet the increases in demand for potable water created by this population growth. The United States and global population totals and 2016 estimates, percent yearly change, median age of the population, percent of the US urban population, and the US share of the world population from 1955 to 2016 are shown in Table 4.1. Notable trends are the nearly doubling of the total US population from 1955 to 2016, the increasing median age of the US population from 30 years of age to 38.1 years in 2016, and the large increase in the share of the US population living in urban areas, from 67.2 percent in 1955 to 82.7 percent in 2016.

Clearly, more people are choosing to live and work in urban areas. Most of this growth is occurring in the southeast and southwestern

D.E. McNabb, *Water Resource Management*,
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Table 4.1 Population growth of the United States and the World, 1955 to 2016

Year	US population	Yearly change (%)	Median age (years)	Urban pop (%)	Share of world pop (%)	World population
2016	**324,118,787**	0.73	38.1	82.7	4.36	7,432,663,275
2015	**321,773,631**	0.76	38	82.5	4.64	7,349,472,099
2010	**309,876,170**	0.91	37	81.4	4.75	6,929,725,043
2005	**296,139,635**	0.92	36	80.5	4.83	6,519,635,850
2000	**282,895,741**	1.22	35	79.5	4.93	6,126,622,121
1995	**266,275,528**	1.04	34	77.8	5.01	5,735,123,084
1990	**252,847,810**	0.99	33	75.8	5.21	5,309,667,699
1985	**240,691,557**	0.95	31	74.9	5.42	4,852,540,569
1980	**229,588,208**	0.95	30	73.9	5.65	4,439,632,465
1975	**218,963,561**	0.89	29	73.8	5.95	4,061,399,228
1970	**209,485,807**	0.99	28	73.7	6.31	3,682,487,691
1965	**199,403,532**	1.38	30	57.6	6.61	3,322,495,121
1960	**186,176,524**	1.74	30	70.1	6.75	3,018,343,828
1955	**170,796,378**	1.59	30	67.2	6.76	2,758,314,525

Source: United Nations, Department of Economic and Social Affairs, Population Division sections of the country. Urbanization and climate change are said to be contributing to more and more harmful flooding as stormwater runoff reduces the normal stream flow and limits the natural absorption of stormwater. Climate change, discussed in Chapter 3, is bringing unprecedented changes to the supply of the water resource, in large part as a direct consequence of human actions that continue to exacerbate the global warming that scientists agree is now underway and speeding up.

High among the problems facing America's water managers is determining how to affordably reduce the effects of these external phenomena on their already aged infrastructure and in many cases, where to find the funding necessary to pay for replacement of old infrastructure and to pay for the new installations required by population growth, location movements, and urbanization. Adding to these difficulties is that these effects are not occurring at the same rate or in the same form in all parts of the Nation. One often occurring result is too little water in the locations that need it the most and too much water in regions generously supplied with all the freshwater they need. Overall, however, the effects of climate change on this critical resource have the very real potential for becoming an environmental, economic and societal catastrophe.

In the not too distant past, it was common to believe that the Nation's supplies of this resource were under stress largely as a result of prior mismanagement and wasteful husbandry. Surface water courses were considered to be accessible repositories of human waste. Pollution was thought to be the natural and unavoidable price of economic development. The Nation's resources were treated as if they were unlimited. More to the point: no single government group or agency was in charge of regulating the mismanagement. It was not until the 1960s that an awareness of the damages to human life occurring as a result of air and water pollution resulted in an increasing number and scope of a number of operational mandates were placed upon the way the resources of the Nation emerged. The new regulatory controls forced water resource managers to change the way they operated. More than a dozen federal agencies and many state and local agencies with some role in water resource management exist today. These agencies regularly compete to exercise oversight to and control over the more than 150,000 organizations that provide water and wastewater services in the country. In addition to federal mandates and regulations, these water providers are also under close regulation by state and local environmental and public health agencies.

From not enough attention to resource management, regulatory oversight has become both a guide and a problem for water managers, including the regulators themselves. Not enough trained regulators are having a difficult time ensuring that rules and regulations are always followed. In one Northwestern state alone, for example, there are 4,129 Group A (utilities serving 25 or more connections) water utilities, and thousands more less-regulated smaller Group B utilities. In just one semi-rural county, there are 338 of these regulated water utilities, and just one public health officer to monitor water and wastewater treatment. This is neither the most populous nor the largest county in the state. This pattern is repeated throughout the Nation.

Population Growth

For many different but related reasons, population growth and urbanization has made managing water a concern in all sections of the country. How to achieve and retain sustainability of and safety of supply in light of significant population changes today and even more expected in the near future is high on the list of these concerns. According to the US Census Bureau, by the middle of the century, the US population is projected to reach more than 388.8 million and may even surpass 400 million, and by 2060, it is expected to grow to 417 million. If present trends continue, most of that growth is going to take place in the country's already over-crowded urban areas. As the number of Americans grows they will also become older; by 2030, 20 percent are expected to be 65 or older (Colby and Ortman 2015).

Three Primary Problems

Water managers in all location have three primary problems they must deal with every day: problems of supply, problems of quality, and problems of the environment. Population growth is contributing to the problem of supply; many regions of the Nation have to find new sources of supply in an environment where all existing supplies are already over producing. Problems of quality are being affected by urbanization; surface water sources are often polluted by storm runoff in cities and towns. Changes in precipitation patterns and warming of the atmosphere occurring as products of climate change are having a tremendous impact on water supply, quality and the environment.

Changes due to population increase may be easiest to measure. Systems and resources designed to supply water and wastewater served to a population limit when they were developed—often 50 years or longer ago—must now be expanded if new customers are to be added. Most of the big gains in population are occurring in states in the South and the Southwest (Table 4.2). In 2016, 5 of the 11 fastest growing cities were in Texas. All but one (Ankeny, Iowa) of these fast growing cities in in a region of water supply concerns, and only two of the fast growing areas (Fort Myers, Florida and Murfreesboro, Tennessee) are located outside of the semi-arid west. The need for housing for this population growth is problem enough for cities enduring this type of growth, but because most if not all of the water and wastewater infrastructure to serve the growing population was probably installed 50 or more years ago, the water and wastewater systems are likely to be a bigger problem.

Table 4.2 Top ten cities with largest increase in population, 2014–2015

Rank	City	State	Numeric increase	2015 Total population
1	New York City	New York	55,211	8,550,405
2	Houston	Texas	40,032	2,296,224
3	Los Angeles	California	34,943	3,971,883
4	San Antonio	Texas	29,536	1,469,845
5	Phoenix	Arizona	24,614	1,563,025
6	Fort Worth	Texas	19,894	833,319
7	Dallas	Texas	19,642	1,300,092
8	Austin	Texas	19,117	931,830
9	Denver	Colorado	18,582	682,545
10	Charlotte	North Carolina	17,695	827,097

Source: US Census Bureau (2016)

There are two parts to the problem of supply: the first is locating and preserving sustainable sources of supply. The second is the need for installing, maintaining, repairing, or replacing the aging delivery system that exists in most of the country. An associated problem is the addition of housing units, which must then be supplied with water and wastewater services. Texas alone added something like 162,000 new housing units of this one-year period.

The Nation's largest cities have their own versions of these same problems to deal with. Most of the country's largest cities are growing larger fast, while a few others have to spread the cost of service, including repair and replacement, across a declining population. The ten large cities with the greatest numeric increases in population between July 2014 and 2015 and their estimated population in 2016 were led by New York (8,550,405), Los Angeles (3,971,883), Chicago (2.720,547), and Houston (2,296,224) and Table 4.3. New York had the greatest increase with 55,211 new residents.

Table 4.3 Population growth in the 20 largest US cities, 1960–2016

2014 Rank	City	2016 estimate	2005	1980	1960
1	New York, NY	8,550,405	8,143,197	7,071,639	7,781,984
2	Los Angeles, CA	3,971,405	3,844,829	2,966,850	2,479,015
3	Chicago, IL	2,720,546	2,842,518	3,005,072	3,550,404
4	Houston, TX	2,926,224	2,016,582	1,595,138	938,219
5	Philadelphia, PA	1,567,442	1,463,281	1,688,210	2,002,512
6	Phoenix, AZ	1,563,025	1,461,575	789,704	439,170
7	San Antonio, TX	1,469,845	1,256,509	785,880	587,718
8	San Diego, CA	1,394,928	1,255,540	875,538	573,224
9	Dallas, TX	1,300,092	1,213,825	904,078	679,684
10	San Jose, CA	1,026,908	912,332	629,442	204,196
11	Austin, TX	931,830	690,252	345,496	186,545
12	Jacksonville, FL	868,031	782,623	540,920	201,030
13	San Francisco, CA	864,816	739,426	678,974	740,316
14	Indianapolis, IN	883,173	784,118	700,807	476,258
15	Columbus, OH	850,106	730,657	564,871	471,316
16	Fort Worth, TX	833,319	624,067	385,164	356,268
17	Charlotte, NC	827,097	610,949	314,447	208,564
18	Seattle, WA	684,451	537,911	493,843	557,087
19	Denver, CO	682,545	557,917	492,365	493,887
20	El Paso, TX	682,545	598,590	425,259	276,687

Source: US Census Bureau

The Impacts of Urbanization

Urbanization—the altering of land for residential, commercial, industrial or transportation purposes—has been identified as one of the major sources of impairment of the Nation's water resources. At a workshop in 2002, representatives from federal, state, tribal, and local-area water quality organizations came together to develop the *Causal Analysis/ Diagnosis Decision Information System* (CADDIS) to support investigators in regions, states, and tribes in the determination of causes of damage to water sources and environments. CADDIS is a decision support system developed to help investigators find, access, organize, and share information useful for causal evaluations in aquatic systems. Urbanization was early identified as one of the major sources of water impairment.

Urban areas are defined in many different ways. One of the most often used definition by the US Census Bureau is a geographic area in which a population density of 1,000 or more people per square mile, and with surrounding areas with population density of 500 or more people per square mile. A definition used by the USGS in its national land cover database is a defined area in which 30 percent or more of the area is covered by "constructed materials," such as asphalt, concrete, or buildings (USGS 2016).

Quickening Pace

The pace of urbanization in the United States began to quicken after the end of World War II, as the federal government stimulated suburban housing construction and transportation system. Development required removal of trees and other vegetation, bulldozing of land for housing, industrial and commercial uses, filling of farm ponds, building of roads, and paved parking area. Urbanization has significant impact on many different elements of the Nation's water supply. Increased impermeable ground cover such as office buildings, factories, homes, and roads, associated with urbanization alters the natural cycling of water. "Changes in the shape and size of urban streams, followed by decreased water quality, are the most visible effects of increased imperviousness.

Greater frequency and severity of flooding, channel erosion, and destruction of aquatic habitat commonly follow watershed urbanization. Alterations in the aquatic environment associated with these hydrological changes greatly compromise the normal functioning of our waterways" (Ruby nd).

Although the data from the 2010 census are a bit old now, the trends they indicate are the same. In a news release updated in 2016, the US Census Bureau reported the rate of urbanization in the US outpaces the rate of population growth in the nation: population increased by 21.1 percent from 2000 to 2010, compared with the overall population growth of 9.7 percent over the same period. Urban areas, which the Bureau defines as "densely developed residential, commercial and other nonresidential area," were home to 80.7 percent of the US population in 2010, up from 79 percent in 2000. The Bureau collects data for two types of urban areas: "urbanized areas" with a population of 50,000 or greater, and "urban clusters" with a population of at least 2,500 but less than 50,000. There were 486 urbanized areas and 3,087 urban clusters in the United States in 2010 (US Census Bureau 2016b).

The US population's drift westward continues to have an impact on the water resource; of the 10 most populated urbanized areas, none were located in the already water-stressed West; seven of those were in California. The Los Angeles–Long Beach–Anaheim, California area was the most densely populated urbanized area with nearly 7,000 people per square mile. The San Francisco–Oakland California was the second most densely populated area with 6,266 people per square mile. The third and fourth most densely populated areas were also in California: San Jose (Silicon Valley) with 5,820 people per square mile and the Delano area (in the California Central Valley above Bakersfield) with 5,483 people per square mile. The New York–Newark, New Jersey area was the fifth most densely populated region with 5,319 people per square mile. California was the most urban of all the 50 states, with nearly 95 percent of the population living in urbanized areas. New Jersey was second with 94.7 percent of the population residing in urban areas. Maine with 61.3 percent and Vermont with 61.1 percent of their populations in urban area were the states least urbanized.

Table 4.4 United States total and urban population forecast, 2020–2050

Year	Population	Yearly change	Median age	Urban pop (%)	Urban population total
2050	**388,864,747**	1,478,090	42	90.1	350,338,147
2045	**381,474,297**	1,541,529	42	89.1	339,780,873
2040	**373,766,653**	1,700,087	41	88.0	329,038,034
2035	**365,266,220**	1,900,251	41	87.0	317,656,011
2030	**355,764,967**	2,136,083	40	85.8	305,356,412
2025	**345,084,551**	2,307,804	39	84.7	292,221,946
2020	**333,545,530**	2,354,380	39	83.6	278,758,373

Source: UN, Economic and Social Affairs Population Division data

The 2010 Census identified 36 new urbanized areas spread across the Nation from the Cape Girardeau Missouri/Illinois area with a population of 52,900, Grand island, Nebraska (50,440), Lake Havasu, Arizona (53,427), Manhattan, Kansas (54,622), and Mankato, Minnesota (57,784). Urbanization is projected to continue with no slowdown foreseen at least as far ahead as 2050. Ten-year changes in percentages of the country urbanized are: 2020, 83.6 percent; 2030, 85.8 percent; 2040, 88.0 percent; and 2050, 90.1 percent (Table 4.4).

Effects on the Water Resource

The EPA has identified three pathways by which streams and other surface water courses are affected by urbanization: channel and streambed alteration, wastewater discharges into the steam system, and paved over surfaces resulting in polluted surface runoff of stormwater. Streambed alteration includes stormwater damage and removal of riparian vegetation, which in turn reduces cover, warms water surfaces, and alters of destroys physical habitat. The water supply is directly affected by the diversion of surface to supply water and wastewater services for new homes, factories, and retail centers, as well as the building of wastewater collection, treatment and effluent discharges into local surface water courses. Changing a stream channel can cause flooding and erosion. As the pace of urbanization continued, dams and reservoirs had to be built to ensure that water was available for the growing population. All this paving over of the land surface resulted in a new problem that had to be dealt with: stormwater runoff. Stormwater was directed into newly constructed storm sewers, then channeled with wastewater effluent into surface streams not designed to handle that much water. The too-often result has been a combination of flooding in urban and suburban areas and pollution of streams and rivers.

Groundwater is affected by polluted storm runoff if urbanized regions. More paved over areas means less water can be absorbed into the ground, meaning that the underground aquifer will receive less water for recharging. Cities and large industries must withdraw great amounts of groundwater from larger and deeper to meet the needs of the growing population. Recent climate change has forced many large water suppliers to withdraw more groundwater as their surface water reservoirs dry up. Greater withdrawals and more surface stormwater runoff means a lower of the water table as withdrawals exceed recharging.

Things are not getting much better in the near future. Urbanization will continue to increase, and dramatically so in near future decades (EPA 2016d). Urban development of land in the contiguous 48 states is projected to increase from 5.2 percent of the country in 2015 to 9.2 percent of the total land base by 2040 or earlier. The percent of the US population residing in urban areas is expected to grow from 83.6 percent in 2020 to 90.1 percent in 2050 (Table 4.5).

How Urbanization Affects the Water Cycle

The water cycle, also known as the hydrological cycle, is the continuous exchange of water between land, water bodies, and the atmosphere (Ruby nd). When rain, sleet, or snow falls on the land, it follows various routes: some evaporates, returning to the atmosphere; some is absorbed into the ground or taken up by vegetation; the rest becomes surface water. Hard and covered surfaces in urban areas that do not allow water to penetrate the soil include rooftops, driveways, streets, swimming pools, patios, and other hard surfaces. Runoff water that is not absorbed by the ground or vegetation becomes the surface water that stored in

Table 4.5 The 15 fastest growing cities with 50,000 or more residents, 2014–2015

Rank	City	State	Percent increase	2015 total population
1	Georgetown	Texas	7.8	63,716
2	New Braunfels	Texas	6.6	70,543
3	Ankeny	Iowa	6.5	56,764
4	Frisco	Texas	6.3	154,407
5	South Jordon	Utah	6.0	66,648
6	Dublin	California	5.5	57,721
7	Pearland	Texas	5.3	108,821
8	Milpitas	California	5.3	77,604
9	Broomfield	Colorado	5.2	65,065
10	Mount Pleasant	South Carolina	4.7	81,317
11	Pflugerville	Texas	4.5	57,122
12	Fort Myers	Florida	4.4	747,013
13	Murfreesboro	Tennessee	4.4	126,128
14	Goodyear	Arizona	4.3	79,003
15	Buckeye	Arizona	4.3	62,138

Source: US Census Bureau (2016)

rivers, streams, ponds, and lakes and back into the ocean. Too much of this water in too short a time can quickly result in flooding. Precipitation in developed areas falls on these impervious surfaces, where it becomes stormwater runoff.

Changes in natural water courses that have occurred during the process of development often alter their ability to handle large amounts of water. Many of these streams are also where treated wastewater effluent is discharged. When less water percolates into the ground, groundwater aquifers are not recharged. The combination of an increase in water volume and a decrease in quality of surface water from urban pollution occurs. Flooding is also a result of these changes.

Creeks and rivers that absorb increased runoff are affected by greater volume, velocity, and duration of water. This erodes stream banks and increases erosion and sediment removed from the landscape and stream banks and deposited elsewhere. This results in channel erosion, clogged stream channels, and habitat damage. A description of how urbanization affects the water cycle was described in a flyer on how urbanization affects the water cycle prepared for and released by a consortium of California water agencies and associations:

> Roots anchor soil, minimizing erosion runoff. Pollutants collected on impervious surfaces are washed into streams, rivers, and lakes developed lands. Rain pours more quickly off of city and suburban landscapes, which have high levels of impervious cover natural lands. Trees, brush, and soil help soak up rain and slow runoff in undeveloped landscapes. Pavement and rooftops shed water and storm drains deliver water directly to waterways. Streets act as streams, collecting stormwater and channeling it into waterways. Trees and other vegetation break the momentum of rain and help reduce surface erosion. Storm water pools in indentations in the ground and filters into the soil. Vegetation helps collect stormwater by building organic, absorbent soil.
>
> There is a larger volume and faster rate of discharge than in less developed watersheds with large amounts of development cover. This often results in more flooding and habitat damage. With natural groundcover, 25 percent of rain infiltrates into the aquifer and only 10 percent ends up as runoff. Increased surface runoff requires more infrastructure to minimize flooding. Natural waterways end up being used as drainage channels, and are frequently lined with rocks or concrete to move water more quickly and prevent erosion. In addition, as deep infiltration decreases, the water table drops, reducing groundwater for wetlands, riparian vegetation, wells, and other uses. (Rudy, nd)

Extreme Weather Events in Urban areas

Global warming has been identified as a direct contributor to the increased occurrence and severity of extreme weather events around the world. In the United States, these events have included heat waves, prolonged periods of drought, larger than usual heavy downpours, floods, hurricanes, and forest fires. The combination of global warming and urbanization has resulted in an increase in the damage resulting from these extreme weather events. Water sector managers have been forced to prepare plans and carry out in-depth crisis response programs.

Extreme weather events are defined by the EPA as events that typically do not regularly occur, such as the droughts, floods, and volcano eruptions that historically have occurred centuries part; events that vary from the norm in severity or durations, such as heat waves and heavy rainstorms; and as events that result in severe damage to human life and infrastructure, such as hurricanes, cyclones, and earthquakes.

A number of changes in some types of extreme weather events have occurred in the United States over the last several decades, including more intense and frequent heat waves, less frequent and intense cold waves, and regional changes in floods, droughts, and wildfires.

Whether they are associated with climate warming, the number and severity of such extreme events are becoming more frequent and more destructive. Between 2011 and 2013 alone, the United States experienced 32 weather events that each caused at least $1 billion in damages.

Floods as a result from hurricanes or heavy downpours are particularly destructive to life and property. Four types of floods can occur; flash floods occur in mall and steep watersheds and often occur in arid or semi-arid regions without flood control protection. Other causes are dam or levee failure such as what occurred during Hurricane Katrina. Most flood-related deaths are the result of flash floods. Urban flooding is usually associated with short duration but very heavy downpours. Urbanized areas with their large areas of impervious surfaces contribute to the severity of such storms. Box 4.1 describes the damage caused by a 2016 flood in urbanized northern Louisiana.

Box 4.1 The August 2016 flood in urbanized Louisiana

The rain that started on August 11, 2016 in northern Louisiana was later determined to be the onset of what was to become a once in a thousand year flood. More than 20 inches of rain fell in an area centered on the cities of Baton Rouge and Lafayette; rainfall rates of two to three inches and hour were reported. The source was a convection system around a low pressure area and which became essentially stationary. The rainfall peaked at nearly 31 and a half inches as measured in Watson, a small town north-east of Baton Rouge. This was more than three times as much water as what was dropped on Louisiana by Hurricane Katrina. Many rivers, including the Amite and Comite rivers reach record heights. When the flood levels began to drop over 10,000 people were in shelters, 20,000 had been rescued. The flood caused an estimated $8.7 billion in damage, destroyed some 60,000 homes (later estimates raised this to 146,000 homes), and 13 flood-related deaths were reported.

An August 24, 2016 paper by the LSU Law School gave the following explanation of why the effects of the flood was so severe: "As the area that flooded in the August 2016 flood was developed over the past 100 years, houses, businesses, and roads gradually filled in the watersheds of the rivers that drain the area. As areas were paved and forests were replaced with cropland and housing developments, rain would run off into the watershed rather than being absorbed. The same amount of rain would produce more runoff and increased stream levels after development. Feeder streams were blocked or restricted to culverts, reducing the ability of local regions to drain into the rivers. The rivers were restricted by levees and flood control projects, which increases flooding upstream as the river height increases because the river cannot spread through the floodplain. Highways and other infrastructure acted as dams, flooding areas upstream. Flooding gets progressively worse for any given amount of rain because there is more runoff and less ability for it to drain. Local areas, down to the level of individual homes, which had never flooded before start to flood because their drainage is blocked and there is more runoff with the same amount of rain".

Source: LSU Law Center (2016)

According to the National Climate Assessment, heavy downpours have increased significantly over the last three to five decades. The heaviest rainfall events have become heavier and more frequent, and the amount of rain falling on the heaviest rain days has also increased. Since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains. There has also been an increase in flooding events in the Midwest and Northeast, where the largest increases in heavy rain amounts have occurred.

River flooding occurs often during spring snowmelts, rapid melting after snow or ice accumulation and in occurrences of prolonged heavy precipitation downpours such as that which occurred in Louisiana in August of 2016. Development along streambeds results in removal of natural riparian vegetation and redirecting natural water courses are having severe impacts upon surface water courses. Coastal flooding occurs most common as storm surges associated with hurricanes and cyclones and other tsunamis that are caused by offshore earthquakes or volcanic action. Rising sea levels as a result of melting of polar region icecaps is expected to be a major cause of coast flooding in future decades.

Prolonged heat waves and droughts are also included as weather changes caused by global warming. Droughts in Southwestern and High Plains states are placing heavy demands upon already over committed surface and groundwater resources. July 2015 was the warmest month ever recorded, and it is expected to get even warmer throughout the rest of the century.

Adapting to the Changing Operational Environment

Of all essential natural resources, the Nation's water supply resource is clearly among the most adversely affected by climate change, population growth, and the rapid pace of urbanization. Impacts on the resource from the weather changes resulting from the warming of the atmosphere include the increasing number of extreme weather events, sea level rises, shifting precipitation and runoff patterns, the increasing number and intensity of regional droughts, and withdrawals that far exceed the natural recharging of important aquifers and river systems. In addition to the increasing scarcity of this critical resource is the degrading of water quality associated with over-use of supply.

Recognizing the importance of these challenges to sustainable management of the resource, in 2009 the EPA initiated a program to aid managers of utilities in the water and wastewater sectors of the industry plan programs identify and overcome the many challenges brought on by climate change. That program—the Climate Ready Water Utilities Initiative—promotes adaptive planning and provides decision support tools for resource management. An updated and modified guide book was published in 2015. The new guide began with this caveat:

> Climate change presents several challenges to drinking water and wastewater utilities, including increased frequency and duration of droughts, floods associated with intense precipitation events and coastal storms, degraded water quality, wildfires and coastal erosion and subsequent changes in demand for services. While these impacts have been

> documented in numerous publications, finding the right information for your type of utility or geographic region can be difficult and sometimes overwhelming. Therefore, the goals of the Adaptation Strategies Guide are (1) to provide drinking water and wastewater utilities with a basic understanding of how climate change can impact utility operations and missions, and (2) to provide examples of different actions utilities can take (i.e., adaptation options) to prepare for these impacts. (EPA 2015b, v)

The adaptive strategies planning process guides drinking water, wastewater, and stormwater utilities managers in identifying and evaluating options for adapting to changing operational conditions. The options adopted should be based on impacts particular to the utility's capabilities and the regional conditions and climate impacts currently occurring and projected for its service area. Although example adaptation options are described in the Guide, no one-size-fits-all solution for adaptation planning is recommended. Managers are reminded that they must use the information included to assist them in developing plans that contain options suited to their specific needs. This includes consideration of their location, climate impacts of concern, and available resources. Utilities are encouraged to collaborate with state and federal authorities, interdependent sectors, and other nearby utilities early in the process.

To achieve the goals of an adaptive water management model in dealing with uncertainties such as the three mega-trends discussed here, Pahl-Wostl et al. (2007) recommended the following actions:

- The complex social–ecological nature of river basin environments and the inherent uncertainties associated with their management have to be taken into account in policy development and implementation.
- Water management strategies should be robust and perform well under a range of possible, but uncertain, future developments. This might imply the need for a diversification in management measures.
- The design of transparent and open social learning processes is a key requirement of sustainable water management regimes.
- Effort has to be devoted to building trust and social capital for problem-solving and collaborative governance.

- An increase in, and maintenance of, the flexibility and adaptive capacity of water management regimes should be a primary management goal.
- Entrenched perceptions and beliefs block innovation and change. Space has to be provided for creative and out-of-the-box thinking and experiments.
- There is a significant need to train a new generation of water management practitioners skilled in participatory system design and implementation.

Summary

Along with climate change, population growth and increasing urbanization of the country are two of the three mega-trends affecting water management in the early twenty-first century. To achieve the vital goal of sustainability, water managers must adapt their systems to these changing conditions. By the end of the century, the world is expected to be from 7 to 10 degrees (F) warmer, resulting in significant changes in precipitation patterns and rising of the sea level four feet or more. By the middle of the century, the population will have to increase more than 388.8 million, most of whom will reside in coastal areas and in the south and Southwest—many areas already facing water problems. In addition to supplying water and wastewater systems to the increases in population, cities in coastal area will have to rebuild much of their existing water and wastewater systems to cope with the rise in sea level.

Changes in water resource management due to population increase and urbanization are certain to far exceed the ability of most water utilities to pay for them and to pay for the replacement of ageing infrastructure already that is already a big problem. Systems and resources designed to supply water and wastewater served to a population limit when they were developed—often 50 years or longer ago—must now be expanded if new customers are to be added. Most of the big gains in population are occurring in states in the South and the Southwest. The need for housing for this population growth is problem enough for cities enduring this type of growth, but because most if not all of the water and wastewater infrastructure to serve the growing population was probably installed 50 or more years ago, the water and wastewater systems are likely to be a bigger problem.

The three mega-trends of climate change, population growth, and urbanization now affecting water management are exacerbating three basic problems they have already had to deal with: problems of supply, problems of quality, and problems of the environment. Population growth is contributing to the problem of supply; urbanization is affecting both surface and groundwater supplies as water sources are often polluted by storm runoff and flooding. Changes in precipitation patterns and warming of the atmosphere occurring is having a tremendous impact on water supply, quality, and the environment.

Maintaining sustainability of the water resource in all its forms in light of these mega-trends and other challenges has resulted in a call for new standards and new management processes. Adaptive management is one of these processes. Adaptive management has been defined as a systematic process for improving water management policies and practices by learning from the outcomes of previously implemented management strategies and practices.

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5

Beginnings of Water Management in the U.S.

Recognition of the need for federal involvement in managing the Nation's water resource began early in the United States. While the earliest efforts of government were directed toward maintaining and enhancing the Nation's rivers and harbors, the need to improve the availability of sustainable sources of water for human consumption and for agriculture was soon recognized as an important function of the central government. For decades, citizen involvement was been particularly effective in petitioning the federal government to aid in water management for agriculture. This chapter describes some of the federal government's earliest efforts at water management.

The Need for Water Management

As recognized 2015, water resource management is the activity of planning, developing, distributing, and managing the optimum collection, storing, delivery, and use of water resources. Ideally, water resource management planning has to consider all competing demands for water and seeks to allocate the available water supply on an equitable

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basis to satisfy all uses and demands while ensuring adequate supplies are available for future uses and following generations. Elected state administrators would ultimately have to create programs and develop the skills needed to ensure that there was sufficient water to meet the needs of people, agriculture, and industry. Ensuring adequate environment for a healthy fish population was low on their priorities. Managing water rights and setting in-stream transportation took precedence over dam regulations and water conservation. Only much later did the states come to recognize that, in addition to providing an adequate stream flow for transportation, they would also have to protect water quality, ensure safe drinking water, and support wildlife. But in the earliest days of the new nation, water management referred almost exclusively to managing the nation's navigable rivers and streams for the sole purpose of transportation.

Early Water Management Activities

The earliest attempts to manage the waters of the United States had little to with providing a secure supply of clean, safe water for the growing population. Rather, it was the desire of a few far-sighted Founding Fathers to ensuring free transportation for everyone on the country's many rivers, lakes and other watercourses. This was also part of the Federalists' reasons for promoting a strong central government to counter the Confederation's inability to fund desired improvements of those critical transportation assets. Replacing the Confederation with a strong central government was the only way the Trans-Appalachian West and its abundant water courses could be preserved against British, Spanish, and French incursions.

The first water-related law guaranteeing free use of the nation's waterways, the Northwest Ordinance, was passed on July 13, 1787. Officially titled "An Ordinance for the Government of the Territory of the United States North West of the River Ohio," is also known as the Ordinance of 1787. The bill was sought by the northeastern states in order to assure their citizens equal access to the new lands opening up to was referred to as the "Trans-Appalachian West." The Northwest Ordinance established a government for the Northwest Territory, comprised of the current states of Ohio, Indiana, Illinois, Michigan, Wisconsin, and parts of Minnesota and Pennsylvania, established the process for admitting a new state in the what was then the Northwest to the Union. It guaranteed that any newly created state would be equal in rights and responsibilities to the original thirteen states.

Much of the Ohio region had been surveyed by George Washington before the Revolutionary War. He toured the land again after the war prior to the Constitutional Convention. Upon return he strongly supported a strong central government able to finance developments to the region's waterways. After the war, one of first acts of Congress under the new Constitutional government was passage of amendments to the ordinance to also apply to the Southwest Territory (the eventual states of Kentucky, Tennessee, and Alabama). Later, it would then be applied to water courses in all new states entering the Union.

Considered one of the most important legislative acts of the Confederation Congress, the Northwest Ordinance guaranteed navigation on all river and other waterways was to remain free of tolls and taxes (the navigation clause of the ordinance). In this way, it came to be "justifiably regarded as the cornerstone of water policy of the United States" (Hull and Hull 1967, 3).

The First Rivers and Harbors Act

The next national expansion to gain federal attention occurred in the 1820s. Congress with the support of President James Monroe had appropriated funds for a survey of the Mississippi and Ohio rivers and their tributaries in 1820. The long series of bills that followed has been collectively come to be referred to as the *Rivers and Harbors Acts.* The first waterways improvements bill passed in 1824. Congress appropriated $75,000 to improve navigation on the Ohio and Mississippi rivers by removing sandbars, snags, and other obstacles. The work was to be administered by the U.S. Army Corps of Engineers (USACE). In 1825, newly elected President John Quincy Adams also announced his support for federal navigation investments. This was followed just two years later with another bill in 1826 that combined authorization for rivers and harbors for improving the waterway and harbor facilities on the Ohio River transportation system. Although the 1824 act to improve the Mississippi and Ohio rivers is often called the first of the rivers and harbors legislation, it was the 1826 act that was the first to combine authorizations for both surveys and the projects themselves, thereby establishing a pattern that continues through the next two centuries. In 1828, Congress then appropriated $1 million for construction of the Chesapeake and Ohio Canal, a plan that George Washington had long sought and invested in.

Early Department of Agriculture Water Involvement

The story of the early work of the US Department of Agriculture was focused on maintaining and improving agriculture—the nation's most important economic activity until after the First World War. Federal involvement in support of agriculture did not become an important function of the federal government until May 15, 1862, when President Lincoln signed into law the act of Congress establishing a Cabinet-level Department of Agriculture. The Department was charged with acquiring and disseminating the latest information of agriculture and distribute new and valuable seeds and plants to farmers (Buie 1979).

The new department's involvement in water occurred with passage of the Hatch Act in 1887. This act established state agricultural experiment stations. The work of those station included studies of the connection between water and soil productivity that the Weather Bureau's soil surveys office was conducting (transferred to the Department of Agriculture in 1889). This work expanded in 1894 with a Weather Bureau bulletin describing how to preserve and reclaim watershed soils.

The Department's long history of work on irrigation began in 1898 when Congress authorized research of this topic. The Division of irrigation was established within the office of Agricultural Experiment

Stations. Four years later, research on drainage and irrigation began in the Western Agricultural Extension Service. That word was transferred to the USDA's Office of Public Roads and Engineering, and in 1921 transferred again, this time to the Division of agricultural Engineering. This office was raised to Bureau status in 1931, with some functions transferred to the Soil Conservation Service (SCS) in 1938.

Through its management of dams and other water projects in the 17 Western states, the Department of Agriculture's Bureau of Reclamation has had the greatest impact on the water resource in the air and semi-arid West. This work began in 1905 when the Division of Dryland Agriculture was organized in the Bureau of Plant Industry and authorized to study methods of crop production under limited moisture supplies and semi-arid conditions. Before long, 22 permanent substations were opened in the Great Plains states to study dryland agriculture methods.

The Department's work in forested lands and the water resource was expanded with passage of the Weekes Act in 1911, authorizing the Department to examine, locate, and recommend purchase of the lands within the watershed of navigable streams to determine regulation deeded to determine which were to be administered as national forests.

Passage of the Federal Power Act of 1920

This important bill established the Federal Power Commission (FPC) and authorized the committee to license non-Federal development of water power on navigable waters and public lands. Amendments in 1925 authorized the FPC, working with the Army Corps of Engineers, to prepare a list of navigable streams and their tributaries to establish on which water power development appeared practicable. The 1927 Rivers and Harbors act authorized the Corps alone to complete the surveys. In 1928, passage of the McSweeney-McNary Forest Research Act authorized the Department to come up with the best methods for maintaining water flows and prevention of erosion.

The Army Corps of Engineers and the First Water Pollution Act

The Rivers and Harbors Act of 1899 was the first federal water pollution act in the United States (Kenney 2006). It focused on protecting navigation, protecting waters from pollution, and set the stage for adoption of the Clean Water Act of 1972. Section 13, referred to as *the pollutions section*, states that it is unlawful to discharge, deposit, throw, or discharge substances from shore or floating craft into tributary or navigable water. The Corps interprets the section in the following way: "Section 13 of the Rivers and Harbors Act of 1899 . . . provides that the Secretary of the Army, whenever the Chief of Engineers determines that anchorage and navigation will not be injured thereby, may permit the discharge of refuse into navigable waters. In the absence of a permit, such discharge of refuse is prohibited. While the prohibition of this section, known as the Refuse Act, is still in effect, the permit authority of the Secretary of the Army has been superseded by the permit authority provided for administration by the Environmental Protection Agency (EPA), and the states." The Corps' continued authority to protect, restore, and manage the environment comes from the Rivers and Harbors Act of 1899 that assigned the Corps the mission to prevent obstacles in navigable waterways.

Section 10 continued the policy of the navigation emphasis of the 1820s by prohibiting obstructions that limit the navigable capacity of any waters. More important, this section permitted the Corps of Engineers—and today within EPA standards—to enforce compliance without the approval of Congress. The restrictions spelled out in the Act are still in effect. The complete language of Section 10 is shown in Box 5.1.

Box 5.1 Section 10 of the Rivers and Harbors Act of 1899

It shall not be lawful to construct or commence the construction of any bridge, causeway, dam, or dike over or in any port, roadstead, haven, harbor, canal, navigable river, or other navigable water of the United States until the consent of Congress to the building of such structures shall have been obtained and until the plans for (1) the bridge or causeway shall have been submitted to and approved by the Secretary of Transportation, or (2) the dam or dike shall have been submitted to and approved by the Chief of Engineers and Secretary of the Army. However, such structures may be built under authority of the legislature of a State across rivers and other waterways the navigable portions of which lie wholly within the limits of a single State, provided the location and plans thereof are submitted to and approved by the Secretary of Transportation or by the Chief of Engineers and Secretary of the Army before construction is commenced. When plans for any bridge or other structure have been approved by the Secretary of Transportation or by the Chief of Engineers and Secretary of the Army, it shall not be lawful to deviate from such plans either before or after completion of the structure unless modification of said plans has previously been submitted to and received the approval of the Secretary of Transportation or the Chief of Engineers and the Secretary of the Army. The approval required by this section of the location and plans or any modification of plans of any bridge or causeway does not apply to any bridge or causeway over waters that are not subject to the ebb and flow of the tide and that are not used and are not susceptible to use in their natural condition or by reasonable improvement as a means to transport interstate or foreign commerce.

Source: Included in Kenney (2006) (www.eoearth.org/view/article/155764)

A number of additional rivers and harbor-related acts followed more or less regularly, with those of 1909, 1917, 1935, and 1958 particularly important. The Rivers and Harbors Act of 1909 expanded the Corps' Civil Works authority by authorizing the consideration of hydroelectric power generation in the planning, design and construction of water resource development projects (USACE 2007).

The 1917 Flood Control Act

The 1917 Flood Control Act was the first legislation to establish a role for the Army Corps of Engineers in flood damage mitigation. This was followed by the 1936 Flood Control Act, which gave the Corps a national flood protection role for the Depression-era Civil Works program. The Flood Control Act of 1944 gave the Corps a recreation role that was added as part of flood control at Corps reservoirs. The 1962 River and Harbor Flood Act would expand this role by authorizing the Corps to build recreational facilities as part of all water resource development projects (Table 5.1).

Table 5.1 Selected water-related legislation passed from 1928 to 1941

1928	Flood Control Act of 1928	This act in a series of flood control acts passed by Congress authorized the Army Corps of Engineers to design and construct projects for control of floods on the Mississippi River and its tributaries as well as the Sacramento River in California
1928	McSweeney-McNary Act	Authorized a comprehensive research program for the US Forest Service, including soil conservation, flood control and surveys of navigable rivers and streams This act was repealed and replaced by the Forest and Rangeland Renewable Resources Research Act of 1978
1928	Boulder Canyon Project Act	Authorized the Secretary of the Interior, to construct, operate, and maintain a dam and a main canal and appurtenant structures for controlling floods, improving navigation and regulating the flow of the Colorado River, providing storage and for the delivery of the stored waters for reclamation of public lands and other uses, and for the generation of electrical energy
1933	Civilian Conservation Corps Reforestation Relief Act	Formed the Civilian Construction Corps for flood control, irrigation, drainage, dams, ditching, channel work, riprap projects, planting trees and shrubs, timber stand improvement, seed collection, nursery work; stream improvement, fish stocking, food, and cover
1933	Tennessee Valley Authority Act	The Tennessee Valley Authority (TVA), a federally owned corporation created by Congress in May 1933 to provide navigation, flood control, power generation, fertilizer manufacturing, and economic development
1935	Soil Conservation and Domestic Allotment Act	Authorized programs to alleviate Dust Bowl soil erosion, particularly in the high Plains states
1936	Flood Control Act of 1936	Authorized engineering projects such as dams, levees, dikes, and other flood

Table 5.1 (continued)

		control measures by the Corps and other agencies, dictated that Federal investigations and improvements of rivers and other waterways for flood control and allied purposes will be supervised by the Chief of Engineers
1937	Water Facilities Act of 1937	Authorized the Secretary of Agriculture to plan and construct agricultural water storage and utilization projects in the arid and semi-arid area of the country on either private or government land
1941	Flood Control Act of 1941	Another of the regularly passed flood control acts. This one authorized construction of three dams and required construction of a flood control system in Los Angeles

Source: Various US agency reports

The 1917 bill, the Ransdell-Humphreys Flood Control Act, assigned the Corps of Engineers responsibility for flood control work on the Mississippi River, the Ohio River, and the Sacramento River plus some other smaller watercourses, with greatest emphasis on levee-building on the lower Mississippi River. Funding was not to exceed $45 million for all projects, with not more than $10 million being spent in any one fiscal year. It included surveys and estimates to determine the cost of protecting the Mississippi River basin from floods. It also provided for the salaries, clerical, office, traveling, and miscellaneous expenses of a newly appointed Mississippi River Commission. Areas benefiting from the flood control work were to contribute no less than one-half of the cost of construction. Once constructed, the levees were to be locally maintained, but remaining under direct federal government control. The act also required comprehensive studies of the watersheds on how the areas would be "affected by the proposed improvement, the probable effect upon any navigable water or waterway, possible economical development and utilization of water power, and other uses properly related to or coordinated with the project."

Federal Water Legislation in the Depression Era

After the 1929 stock market crash and onset of the Great depression, the federal government enacted a series of water-related legislation that involved the Corps of Engineers and Departments of Agriculture and Interior. A selected list of these bills with a brief discussion of their provisions are shown in Table 5.1.

In addition to a number of river and harbors projects across the nation, in the Western states the Rivers and Harbors Act of 1935 had as important objectives during the Great Depression both a public works program and a plan to provide financial help to the nation's farmers by authorizing a number of dams and irrigation projects. While many water projects in 1935 received approval, the House of Representatives insisted on voting separately on authorization for the Parker and Grand Coulee dams, as the following statement to House Resolution indicates:

> [For] the purpose of controlling floods, improving navigation, regulating the flow of the streams of the United States, providing for storage and for the delivery of the stored waters thereof, for the reclamation of public lands and Indian reservations, and other beneficial uses, and for the generation of electric energy as a means of financially aiding and assisting such undertakings, the projects known as "Parker Dam" on the Colorado River and "Grand Coulee Dam" on the Columbia River are hereby authorized and adopted . . . and the President, acting through such agents as he may designate, is hereby authorized to construct, operate, and maintain dams, structures, canals, and incidental works necessary to such projects, and in connection therewith to make and enter into any and all necessary contracts including contracts amendatory of or supplemental to those hereby validated and ratified. The construction by the Secretary of the Interior of a dam in and across the Colorado River at or near Head Gate Rock, Arizona, and structures, canals, and incidental works necessary in connection therewith is hereby authorized . . . by the Act. (H.R. 6250, 1935 Rivers and Harbors Act)

The 1932 election of Franklin D. Roosevelt as the Nation's 32nd President during the Great Depression brought on a number of new agencies, programs, and structural changes within the Departments with water-related interests. An early change in August of 1933 saw the Soil Erosion Service established as a temporary unit is the Department of the Interior. The new agency's charge was to carry out soil erosion prevention provisions of the National Industrial Recovery Act of 1933. However, all people and equipment of the agency was transferred to the Department of Agriculture and assigned a number of existing Agriculture programs, including the erosion control work camps that have been under control of the forest Service and erosion control experiment stations. The agency was renamed the SCS in a bill sighed on April 27, 1935. By the end of the year, the SCS was operating the 489 Civilian Conservation Corps (CCC) work camps providing technical assistance, manual labor and materials needed for new water-related and erosion control actions on private properties. The work included terracing, waterways improvements, check dams, gully controls, stock ponds, wind breaks, tree and grass plantings, wildlife habitat, and irrigation and drainage projects. Between April 1933 and March 1935, CCC workers constructed 1,100 recreational dams, 3,600 farm ponds, 2,000 water holes, 1.15 erosion control dams, and 2,600 other small reservoirs (Buie 1979, 10).

Flood Control Programs

With passage of the Flood Control Act of 1936, a new office was established and a new administer assigned in the Department of Agriculture: the Director of Flood Control. The office was given authority over policies and work plans, allocation of project funds, coordination of the three bureaus working on flood control. These were:

- **Soil Conservation Service**: responsible for farm land, streams that were a part of farm land management, and combined farm and forest land (in cooperation with the Forest Service).
- **Forest Service**: responsible for forest lands, streams that were an integral part of forest land management, and on intermingled farm and forest lands.

- **Bureau of Agricultural Economics**: Assist in economic sections of surveys, consider social and economic aspects of land use plans, and serve as economic advisors to the Director of Flood Control

Authorization of specific projects, watershed surveys, and other programs was attained in the Flood Control Act of 1936 and its amended acts in 1937, 1938, 1939, and 1941. Between 1937 and 1943 when the program was stopped because of the war, 212 watersheds were begun and 160 were completed. The completed surveys were expected to provide guidance for public works projects in the post-war period. An example, the Missouri River Basin Plan, is described briefly in Box 5.2.

Box 5.2 The Missouri River Basin flood control program

River basin studies by the Corps of Engineers and the Bureau of Reclamation in the 1920s and 1930s served as a foundation for the extensive development on the Missouri river and its tributaries in the mid-1940s. The Corps studies emphasized flood control and navigation. The Reclamation studies emphasized irrigation and hydroelectric power. The differences were ironed out, a plan was approved, and work was authorized by passage of the Flood Control Act of 1944.

Five dams were authorized on the Missouri River downstream of the Fort Peck dam, which had been completed in 1940. Including the reservoir of the earlier dam, the storage capacity of the six would exceed 75 million acre-feet. Also authorized were 103 smaller dams and reservoirs on the headwaters of the Missouri and its tributaries. The Corps was given responsibility for all main-stem dams and smaller dams that were included in the flood control and navigation package. The Reclamation Bureau was to be responsible for upstream reservoirs with primary use for irrigation and hydroelectric power generation.

Design of the combined system met with significant dislike by many residents of the Basin. As called for, the plan would flood out some 20,000 people and permanently cover around 900,000 acres of Missouri's best farm land. Annual loss from lost farm production was predicted to exceed $18 million, estimated to be three times the average annual losses due to floods. The problem with the plan was that it was "lopsided because all it did was to try to control and use the water by impounding it after it had run off the land into the big rivers; but what was really needed was first a program of land and water resource development that began to control and make use of the water on the land on which it fell and in the small streams, thus using the water al the way from the time it fell on the fields, forests and farms until it reached the big rivers." A new plan that included these concerns was submitted to Congress in 1949. This final plan "set forth a broad program specifically designed to conserve and improve the soil for sustained productive use, protect and enhance the forest resources, abate flood and sediment damages, provide for more efficient land use through irrigation and drainage, [and] protect the water resource."

Source: Buie (1979)

Post-War Water Management

The Water Supply Act of 1958 gave the Civil Works Program the authority to include water storage in new and existing reservoir projects for municipal and industrial uses. The Flood Control and Coastal Emergency Act and the Stafford Disaster and Emergency Assistance Act gave the Civil Works program direct authority to help the nation in times of national disaster. The Corps was also ordered to provide emergency assistance during or following flood events to protect lives, public facilities and infrastructure. The Stafford Act authorized the Corps to support the Federal Emergency Management Agency in carrying out the Federal Response Plan (now the National Response Plan), which requires 26 federal departments and agencies to provide coordinated disaster relief and recovery operations.

Title 10 of the US Code (Navigation and Navigable Waterways) and Title 33 authorized the Civil Works program to provide services to other federal entities, states, or local governments on a reimbursable basis. This work includes flood control, the improvement of rivers and harbors, research, and support to private engineering and construction firms competing for, or performing, work outside the United States. The Support for Others program involves the Corps in reimbursable work that was determined to be in America's best interests.

Clean Water Legislation

The availability of clean, safe water for most Americans is a relatively recent event. And, for most of the history of the government's concern with the country's water supplies, government was concerned with maintaining the nation's rivers as its major transportation arteries. Public health was little understood and not something that governments could do much to alleviate the periodic outbreaks that did occur. In some parts of the country that closed thinking has not disappeared.

Major water-borne cholera epidemics that occurred in 1849 resulted in 8,000 deaths in New York City and 5,000 deaths in New Orleans resulted in a demand for clean water in America's urban centers. One of the earliest successful treatment effort occurred in Louisville, Kentucky, in 1896.The Louisville water company installed a new water treatment method that combined coagulation of solids and sand filtration approach that remove 99 percent of bacteria from the water. Despite this success, official federal water quality safety standards did not come about until results of the first public water supply to be treated by chlorine was upheld by the court in 1908. Chlorine had been proven to be an effective disinfectant of drinking water during the 1890s in Europe. The first continuous municipal application occurred in Belgium in 1902. Chlorine had been added to the Boonton reservoir supply in Jersey City, New Jersey. Another outbreak occurred in 1854, killing approximately 2,000 people. It was in this year that the connection between polluted water and the disease was made by a British physician, Dr. John Snow. Snow was able to trace victims to a public pump in England that victims of the disease had all used before contracting cholera.

The last major cholera outbreak in New York City that occurred in 1866 resulted in the deaths of 1,137 individuals, most of whom were recent European immigrants. About 40 percent of the approximately 1.2 million people crowded into the city were poor Irish immigrants. The outbreak that had begun earlier in Europe was thought to have been brought to the city by European immigrants. The relatively low death toll for such a large population was credited to work in improving water supplies and sanitation services by the work of the city's Sanitation

Department. Their successes and increased knowledge resulted in calls for the federal government to do more to control such diseases.

Before a national standard could be put into place, however, Congress had to first pass the Public Health Service Act in 1912. This act authorized studies on the connection between water pollution and human health. With Europe leading the way and more US municipal water supplies opting for chlorination, the first water quality standards were adopted in 1914. However, the standards only applied to water supplies used in railroads that crossed state lines. The national application of minimum standards for drinking water in the United States only became required for all public water suppliers in the country in 1962. Complying with the standards was not immediately followed, as a 1969 Public Health Service Community Water supply study revealed. This resulted in passage of the Safe Drinking Water Act in 1974. This law required all community water systems with 15 or more connections or 25 or more customers to comply with Department of Health standards. Amendments in 1977, 1986 and reauthorization of the act in 1996 increased the scope of contaminants that had to be removed from water, set deadlines for meeting standards, gave the government greater authority to enforce standards, and authorized governments to take actions to protect groundwater resources. The 1996 reauthorization also authorized the EPA to develop rules for community water systems for regulating arsenic, radon, and other household chemicals from their water supplies.

The Clean Water Act of 1972 broadened the responsibility of the Corps by giving it authority and direction to regulate dredging and activities that result in fill being placed in the waters of the United States, including many wetlands. Additional legislation passed in the 1986 Water Resources Development Act further expanded the Corps' environmental role to include enhancing and restoring natural resources at new and existing projects, and the Water Resources Development Act of 1990 made environmental protection one of the Corps' primary water resources development missions.

Further EPA authorization on drinking water regulations and contaminants include the National Primary Drinking Water Regulations that limits levels of more than 90 different contaminants in drinking water, and the National Secondary Drinking Water Regulations, which are non-enforceable guidelines for contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards. The Safe Drinking Water Act (SDWA) also requires the EPA to identify and list unregulated contaminants which may require a national drinking water regulation in the future. The list must periodically be published (called the Contaminant Candidate List) and decide whether to regulate contaminants on the list. EPA uses this list of unregulated contaminants to prioritize research and data collection efforts to help us determine whether a specific contaminant should be regulated. Regulations for bottled water are administered by the Food and Drug Administration.

Evolution of Federal Involvement

Water policies initially involved the federal government as the only source capable of funding rivers and harbors improvements and managing the waterways for transportation and flood control. Water was considered a common resource, one subject to eminent domain, and vital for providing access to and from the territories west of the Appalachian mountains. Few of the new states or territories could finance or engineer the large scale water development and use projects of the early years of the Nation. As a result, federal agencies were developed to take on that responsibility, beginning with the Army Corps of Engineers. As Carriker and Wallace (2015, 1) have noted, “A prime purpose of federal involvement has been to ensure national economic growth by implementing and/or helping facilitate state water resource development. The logic was that where abundant, inexpensive, and high quality water exists, people will follow and prosper.” Delivery of water to villages and towns was left to private enterprise, while sanitation was generally ignored, a problem for individuals to resolve.

During the Progressive Era, the public's concern attitudes evolved to believe was that if the federal government did not take a leadership role in the planning, coordinating, and implementing of water resources policy, either no one else would or eventually, water supplies would end up under private, monopolistic ownership. The history of water supply, municipal public transportation, and railroad expansion was supported this contention. Another argument in support of early federal involvement was that a centralized authority would be necessary in times of national emergency. People's experiences dealing with natural emergencies such as floods or droughts supported this idea.

The early arguments led to the early turning over management of the nation's water resources to such agencies as the Army Corps of Engineers and the Departments of Agriculture, Health, and the Interior. By the second half of the twentieth century, environmental and human health concerns led to assigning authority over water quality to the new EPA. The calls for government help in serious efforts to develop clean, safe water supplies resulted in the new EPA developing management standards for public water utilities, corporate water users, and other stakeholders at regional, state, and national levels. They radically had to change its performance and develop ways to meet the new standard. To their benefit, new practices for upgrading of old facilities and ways of operating were available and could be adopted relatively quickly (Cleveland et al. 2014).

The United States still lacks a national water policy. However, Carriker and Wallace contend that there is ample evidence to suggest that a national policy cannot survive under present private water rights conditions. The Federal involvement in water management has evolved piecemeal from governmental responses to specific needs, such as maintaining rivers for transpiration in lieu of roads in the early years of the nation, control of rivers for flood damage protection, and inland waterways improvements, eventually evolving to include irrigation for agricultural development, environmental protection, public health, and now, national security. Responsibility for these and other aspects of water management remains in the hands of the many federal, state, and local departments and agencies.

Federal involvement today remains a random mix of policies grafted onto one another rather than a structure designed and based on good information about the nation's water needs. The Army s Corps of Engineers still manages rivers and harbors improvements and flood control projects; the Bureau of Reclamation manages builds and manages dams and reservoirs for flood control, power generation and irrigated agriculture in the Western half of the country. The EPA manages water quality everywhere. Well-organized interest groups come together to encourage their representatives in Congress to lobby with the authorizing and appropriating committees.

Summary

The water management efforts of United States have undergone a number of changes in direction and focus since the late nineteenth century. For the last 40 years of the 1800s and first half of the twentieth century, the nation's policy was focused on investment in improving water navigation and projects of reclamation and flood control projects aimed at supporting interior economic development. This included designing and constructing levies and hundreds of large dams for flood control and agriculture irrigation. Rivers and Harbors Acts were passed in nearly every legislative session, most directing Corps of Engineers projects on named rivers or harbors.

Federal water management activity for soil conservation and flood control began after the Department of Agriculture was formed in 1862. From 1862 to 1929, the Department underwent expansion in its program activities, many of which included research on the effects of surface water and soil erosion, irrigated agriculture, land drainage, establishing surface water runoff relationships on small agricultural areas, determining soil moisture relationships for selected crop types. It worked with other departments and the states in selection of possible dam sites and lands for designation as national forest. Working with the Departments of the Army and Interior, it participated in the licensing of the use of water for the production of electric power.

After the end of the World War II, the nation's water policy took a decidedly environmental and public safety direction. Much of the legislation that guided water policy for the next fifty years came out of the wave environmental concern that swept America in the late 1960s and 1970s. The third policy focus came to light in the first decade of the twenty-first century, when passage of the Water Resources Development Act and fears of declining supplies and global warming resulting in a national concern on conservation and sustainability. Climate changes with their pressures on water supplies may be quickly leading us into another shift in water policy.

Additional Reading

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6

Federal Regulators of the Resource

Government's involvement in managing the nation's water resources began early in the history of the nation. In fact, the North American colonies had a water policy long before there was a thought of an independent nation in the new lands. The many fresh water rivers, streams, and lakes in the Eastern colonies were the colonists' first highways; colonists and early colonial administrators agreed that those highways should remain open to free access to all and should be improved at government expense. Although the Articles of Confederation and Perpetual Union that served to bind the 13 original states together, and ultimately became the Constitutional government of the United States was not strong enough to enforce free access and too poor to finance the internal improvements necessary for interstate commerce. The thought was there would always be plenty of water in the newly independent states, even if sometimes drinking it made you sick, and we will get around to using it when we can.

Without a steady supply of clean, fresh water, the new territories could never have thrived, let alone become the preferred living environment of a growing majority of human populations. Without water to drink, wash dishes, bathe or flush, disease could, and often did, quickly

D.E. McNabb, *Water Resource Management*,
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destroy modern society. When drinking water supplies become polluted and wastewater systems fail, disease and death follow. Contaminated water causes many types of diseases, including cholera, and serious illnesses such as typhoid and dysentery. Water-related diseases cause 3.4 million deaths around the globe each year. The importance of clean water has resulted in some of the earliest civil engineering feats, including dams and aqueducts to store and move water for human consumption and agriculture. Adequate water and wastewater systems remain the sine qua non of all modern civilizations. At the heart of water management everywhere are government agencies.

Regulating the Water Resource

A large number of stakeholders became involved in managing the nation's water supply. The problem with managing the Nation's water resource comprehensively is that we do not have a comprehensive water resource regulatory policy. Neil Grigg pointed this out in his 2008 book on total water management. Regulation is, he explained, a "mélange of federal, state, and local laws and regulations that govern water service providers and individual water users. Because much of the water services are provided by local governments, regulation comes from federal laws implemented by state agencies. Other regulation is informal, through the political process" (81).

The federal agencies with early paramount responsibility for managing and protecting the nation's water supplies include the Bureau of Reclamation, US Army Corps of Engineers (USACE), the Department of Interior, the US Department of Agriculture's Soil Conservation Service, the former Agricultural Stabilization and Conservation Service, Cooperative Research and Extension Services, the US Forest Service, the Environmental Protection Agency (EPA), the Public Health Service, and the National Water Resources Council. These agencies become involved in questions having to do with one or more issues or specific aspect of the water and wastewater management world that touch upon their particular congressional mandates.

Often with mirror-image departments such as the EPA and Public Health, the individual states have responsibility for administering most federal regulatory mandates, although in some cases federal agency personnel may become personally involved in the resolution of a particularly difficult problem. In keeping with the polycentric nature of water management in the United States, each of the major agencies is discussed individually in the following pages. The discussion contains material for and follows agency-provided histories and other open sources.

US Army Corps of Engineers

The USACE has the distinction of being the agency with the longest history of water resource regulation and management in the United States. However, for almost all that history the US Geographical Survey (USGS) was concerned with keeping the nation’s rivers open for moving goods and people from point to point and improving the nation’s ports. Keeping ports open meant enforcing laws prohibiting dumping refuse in coastal waters. The official history of the Army Corps of Engineers provides the background for this section (USACE no date, retrieved in 2016).

The Corps can trace its history back to 1779 when the Continental Congress created a separate Corps of Engineers. However, that designation was changed in 1794 when Congress combined the service into a Corps of Artillerists and Engineers. It was not until 1802 that the separate Corps of Engineers still operating today was formed. During the first half of the nineteenth century, West Point was the major and for a while, the only engineering school in the country.

Rivers and Harbors Responsibility

From the beginning, many politicians wanted the Corps to contribute to both military construction and works “of a civil nature.” Throughout the nineteenth century, the Corps supervised the construction of coastal fortifications and mapped much of the American West with the Corps of Topographical Engineers, which enjoyed a separate existence from 1838 to 1863. The Corps of Engineers also constructed lighthouses, helped develop jetties and piers for harbors, and carefully mapped the navigation channels. The official history of the USACE described the great role the USACE played over the more than two hundred years of its history.

> Although its work on fortifications was important, perhaps the greatest legacy the early Corps of Engineers bestowed to future generations was its work on canals, rivers, and roads. America was a young nation, and rivers were its paths of commerce. They provided routes from western farms to eastern markets and for settlers seeking new homes beyond the Appalachian frontier. The rivers beckoned and enticed, but then could treacherously destroy the dreams of unwary travelers and shippers whose boats were punctured by snags and sawyers or stranded by sandbars. Both commercial development and national defense, as shown during the War of 1812, required more reliable transportation arteries. Out of those unruly streams, engineers carved navigation passages and harbors for a growing nation.

In 1824, the Supreme Court ruled that federal authority covered interstate commerce including riverine navigation. Congress soon passed two laws that, together, marked the beginning of the Corps' continuous involvement in waterways and other civil improvements. The General Survey Act authorized the president to have surveys made of routes for roads and canals "of national importance, in a commercial or military point of view, or necessary for the transportation of public mail," with the Corps given responsibility for the surveys. The second act, passed a month later, appropriated $75,000 to improve navigation on the Ohio and Mississippi rivers by removing sandbars, snags, and other obstacles. Subsequently, the act was amended to include other rivers such as the Missouri. This work was also given to the Corps

The Corps After the Civil War

After the Civil War, a special Army Engineer Board concluded that a system of locks and dams on the Ohio River was preferable either to continued dependence on wing dams and dredging or to the construction of a system of canals to bypass the Ohio's obstacles. Major William

E. Merrill, who was in charge of Ohio River improvements, needed to develop a system of river regulation dams that would easily allow passage of coal barges. In 1877, the Corps began constructing the Davis Island project, just south of Pittsburgh. Completed in 7 years, the 110 by 600-foot lock and 1,223-foot dam were the largest in the world at that time. The Davis Island Lock also was one of the first in the country to use concrete in place of stone masonry. The Corps' success at Davis Island led Congress to authorize extension of the project down the Ohio. Later, the Corps increased the initial 6-foot channel depth to 9 feet. The project was completed in 1929 at a cost of about $125 million.

The Corps' canal-building efforts continued in the twentieth century. After the federal government purchased the Chesapeake and Delaware (C&D) Canal in 1919, the Corps' Wilmington (Delaware) District directed a reconstruction effort to deepen the channel to 12 feet and add several bridges. Traffic soon increased, and as an immediate result, demands were made to enlarge it. The C&D Ship Canal became part of an intercoastal waterway envisioned to connect existing bodies of water in a line roughly paralleling the coast from Boston, south to Key West, and then west to the Rio Grande. The Corps retains responsibility for this canal and the entire intercoastal waterway of which it is a part.

Army topographers had surveyed some of the Great Lakes as early as 1823, but Congress did not appropriate funds for a systematic survey until 1841. Captain William G. Williams, who had been the general superintendent of harbor improvements on Lake Erie, headed the survey. From 1841 to 1860, Congress appropriated a total of $640,000 for the survey of the Great Lakes. Some 6,000 miles of shoreline needed to be surveyed. The surveyors determined latitude and longitude; measured the discharge of rivers into the Great Lakes; surveyed rivers, narrows, and shoals; developed charts and maps; and marked points of danger. A special iron-hulled steamer was constructed for the work. The Corps continued this survey work until 1970, when many of the survey office's functions were transferred to the newly established National Oceanic and Atmospheric Administration. The Detroit District of the Corps of Engineers assumed the responsibility for forecasting lake levels.

The Corps' Role in Water Resources Development

From 1950 on, changing values, political shifts, and economic constraints have resulted in major alterations in the Corps' water resources program. Beginning in the 1960s, society focused more on recreation, environmental preservation, and water quality than on irrigation, navigation, or flood control. Passage of the Wilderness Act in 1964, the Wild and Scenic Rivers Act in 1968, and the National Environmental Policy Act in 1969 were clear indications of these new interests.

The focus on the environmental consequences of natural resource exploitation contributed to rising opposition to water projects. The USACE became the nation's largest water resources developer—and a target for much of that criticism. The result was both a lack of confidence in government and opposition to water projects. Another problem was the federal budget. Beginning with the post World War II construction boom, an increasing number of people questioned the amount of federal dollars spent on water resources projects. However, the need for rehabilitating or replacing an aging water resources infrastructure was undeniable by the mid-1970s. There were approximately 3,000 unsafe dams in the country, and a number of locks on major navigable rivers were too old (about 40 years), deteriorated, and small to serve modern shipping. Both new locks and deeper ports were needed.

The Water Resources Development Act of 1986

The eventual result was passage of the Water Resources Development Act of 1986. The legislation reflected general agreement that nonfederal interests can, and should, shoulder more of the financial and management burdens, that environmental considerations were vital elements in all water resources planning. The law authorized about $16.23 billion in spending for water projects, of which the federal government was to pay approximately $12 billion, and nonfederal interests, such as states, port authorities, commercial navigation companies, and communities, the remainder; 377 new Corps of Engineers' water projects were authorized for construction or study.

The Corps' Environmental Protection Activities

The Corps' role in protecting the country's water resources evolved over the nineteenth century and twentieth century. It can be traced to the 1880s and 1890s, when Congress directed the Corps to prevent dumping and filling in the nation's harbors. In the Rivers and Harbors Act of 1899, Congress gave the Corps the authority to regulate most kinds of obstructions to navigation, including hazards resulting from effluents. In 1910, the Corps used the act to object to a proposed sewer in New York City, but the judge ruled that pollution control was a matter left to the states alone.

The Corps' own role grew marginally when the Oil Pollution Act of 1924 authorized the agency to apprehend those who discharged oil into tidal waters. With limited manpower and authority, the Corps enforced the statute poorly. By then, many Corps officers had accepted the view that pollution should generally be considered a state or local problem and that the Corps should be involved only when there was a clear threat to navigation. The Corps reported in 1926 that domestic sewage and industrial waste polluted most of the nation's rivers but did not seriously interfere with navigation. However, the agency conceded that pollution endangered fish in some areas.

The Corps of Engineers continues its authority over work on structures in navigable waterways under Section 10 of the Rivers and Harbors Act of 1899, and over the discharge of dredged or fill material authorized under Section 404 of the Federal Water Pollution Control Act Amendments of 1972.

The Bureau of Reclamation

The Reclamation Act of 1902 created the US Reclamation Service (later changed to Bureau of Reclamation) and committed the Federal Government to construct and maintain "irrigation works for the storage, diversion and development of waters." This charge meant constructing dams, reservoirs, and canals to irrigate arid and semi-arid lands in 16 Western states and territories: Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming (Fig. 6.1). Some of these states were still territories in 1902; Texas was added as a reclamation state in 1906. The Reclamation Act established a special "reclamation fund," intended to pay for the construction of the dams and canals needed to irrigate the West. Money in the fund would come, not from the US Treasury, but from the sale of public lands. The

Fig. 6.1 Regions of Bureau of Reclamation operations

Source: Bureau of Reclamation; Map Resources (map)|GAO-14-764

Reclamation Act limited people on Reclamation projects to 160 acres, required residence on the property, and use of at least half of the land for agriculture. A key provision stipulated that those using the water had to repay the government's construction costs within 10 years.

The Bureau of Reclamation's many water projects in the West led to homesteading and promoted the economic development of the semi-arid Southwest. The Bureau has constructed more than 600 dams and reservoirs including Hoover Dam and Lake Mead on the Colorado River and Grand Coulee on the Columbia River. In 2015, the official website of the Bureau included a list of 337 Bureau-owned and operated dams in the United States. Figure 6.2 is a Bureau of Reclamation photograph taken at the downstream base of Hoover Dam during a release of Lake Mead water.

The Reclamation Bureau is the largest wholesaler of water in the country, bringing water to more than 31 million people, and providing one out of five Western farmers with irrigation water for 10 million acres of farmland that produces 60 percent of the nation's vegetables and 25 percent of its fruits and nuts. The Bureau is also the second largest producer of hydroelectric power in the United States. It operates 53 powerplants that provide more than 40 billion kilowatt hours, thereby annually generating nearly a billion dollars in power revenues and produce enough electricity to serve 3.5 million homes.

The mission of the Bureau is to "assist in meeting the increasing water demands of the West while protecting the environment and the public's investment in these structures. We place great emphasis on fulfilling our water delivery obligations, water conservation, water recycling and reuse, and developing partnerships with our customers, states, and Native American Tribes, and in finding ways to bring together the variety of interests to address the competing needs for our limited water resources" (USBR 2016d).

Managing Water Quality

In the United States, bottled water and tap water quality are regulated by two different agencies: the EPA regulates tap water (municipal water or public drinking water) and the Food and Drug

Fig. 6.2 Hoover Dam with downstream water releases
Source: Bureau of Reclamation (2016)

Administration (FDA) regulates bottled water (Sharfstein 2009). The departments of health in each individual state are involved in the safety of both types.

The EPA's Office of Ground Water and Drinking Water issues and oversees a large body of regulations on the production, distribution and quality of public drinking water, including regulations on source water protection, operation of drinking water systems, contaminant levels, and reporting requirements. FDA regulates bottled water as a food. Under the FD&C Act, manufacturers are responsible for producing safe, wholesome, and truthfully labeled food products, including bottled water products. The water quality activities of the state of Rhode Island are an example of how states carry out this responsibility (Rhode Island Department of Health 2017):

- Monitors public drinking water quality.
- Enforces the Safe Drinking Water Act.
- Approves new public water sources and systems.
- Develops effective water system operations and management practices.
- Develops policies and systems to optimize water system sustainability.
- Creates public awareness of and participation in support of safe drinking water

The Environmental Protection Agency

The EPA is the federal government's chief public supply water protection and quality agency. It enforces clean water and safe drinking water laws as they are implemented by the individual states, provides standards and guidance for municipal wastewater treatment plants, and takes part in pollution prevention efforts aimed at protecting watersheds and sources of drinking water. The elements of what was to become the EPA were combined in an announcement by President Richard Nixon in his July 9, 1971 message to Congress. The various pieces had been pieced together from programs at other departments, including Agriculture (USDA), Health, Education and Welfare—now the Department of Health and Human Services (DHHS), the Atomic Energy Commission (AEC), the Federal Radiation Council (FRC), and the Council on Environmental Quality (CEQ). Others functions and responsibilities would be added from the National Air Pollution Control Administration (NAPCA); the bureaus of Water Hygiene and Solid Waste Management, The Army Corps of Engineers, and some functions of the Bureau of Radiological Health.

The Food and Drug Administration of Health, Education, and Welfare (HEW) gave up to EPA its control over tolerance levels for pesticides. The Department of the Interior contributed the functions of the Federal Water Quality Administration (FWQA) and portions of its pesticide research responsibilities. EPA gained functions respecting pesticide registration from the Department of Agriculture. From the AEC and the FRC, the new agency gained responsibility for radiation criteria and standards. From the CEQ came functions pertaining to ecological systems granted the Council by the National environmental Policy Act of 1969. Large contributors to the new EPA were the Department of the Interior, Department of Agriculture, and the Department of Health, Education and Welfare. Duties transferred from each of the three departments are listed in Table 6.1.

Two of the acquired programs—HEW's NAPCA and Interior's FWQA—represented the core of the federal government's pollution-control apparatus prior to the birth of EPA. The air program had been established in 1955 in reaction to a wide range of alarming problems: the suffocating blanket of smog covering greater Los Angeles; the 1948 atmospheric inversion that temporarily raised the death rate in Donora, PA, by 400 percent; and a London "fog" resulting from widespread burning of coal in 1952 that killed 4,000 people over a four-day period. NAPCA began as a research body with no regulatory powers. The Clean Air Act of 1963 gave NAPCA enforcement authority to attack interstate air pollution problems.

Water Pollution Control

Equally severe water pollution problems—untreated sewage and industrial waste, dying rivers and lakes—led to the founding of the Division of Water Supply and Pollution Control in the Public Health Service, where it remained from 1949 to 1953. As a consequence of passage of the Water Quality Act of 1965, it was transferred to the Department of the Interior in May of 1966. It was then abolished under the Water Quality

Table 6.1 Federal department programs transferred to the new EPA

Department	Program, function or facility
Interior (DOI)	Federal Water Quality Administration Function vested by the Federal Water Pollution Control Act Functions from studies on effects of insecticides, herbicides, fungicides an pesticides on fish and wildlife Functions vested by the Gulf Breeze Biological Laboratory of the Bureau of Commercial Fisheries, Florida Water Pollution Control Advisory Board and hearing boards in sections of the amended Federal Water Pollution Control Act
Agriculture (USDA)	Functions of the Federal Insecticide, Fungicide and Rodenticide Act Functions of the Federal Food, Drug, and Cosmetic Act Functions vested by the Environmental Quality Branch of the Plant Protection Division of the agricultural Research Service
Health, Education and Welfare (HEW)	Functions vest though the Environmental Health Service, including the National Air pollution Control Administration The Environmental Control Administration, including the: Bureau of Solid Waste Management Bureau of Water Hygiene Bureau of Radiological Health Functions vested for establishing tolerances for pesticides chemicals under the Food, Drug and Cosmetics Act The Air Quality Advisory Board

Source: Various US Federal agencies

Improvement Act of 1970, to be born again in Interior as the FWQA in 1970. The FWQA was authorized to give technical assistance to states and localities and to distribute construction grants for municipal waste treatment programs. Like NAPCA, the FWQA gained enforcement and standard-setting powers in the 1960s, but the actual exercise of these powers fell far short of expectations.

Major Water Quality Laws

The EPA's water regulatory authority is based on four laws: the Clean Water Act (CWA), Marine Protection and Sanctuaries Act, the Safe Drinking Water Act (SDWA), and the Shore Protection Act (SPA). The CWA provides the basic structure for regulating discharges of pollutants into the waters of the United States and for regulating quality standards for surface waters. The basis of the CWA was the Federal Water Pollution Control Act of 1948 (FWPCA). That Act was significantly reorganized and expanded in 1972; the *CWA* became the Act's common name after amendments to the original law in 1972. Under the CWA, EPA has implemented pollution control programs such as setting wastewater standards for industrial uses, and has set water quality standards for all contaminants in surface waters.

The CWA also authorized the EPA to regulate the discharge and treatment of wastewater. All dischargers of wastewater and treatment facilities must receive a permit from the National Pollutant Discharge Elimination System before they discharge any effluent. The permit process specifies discharge limits, monitoring, and control rule, and may require the facility to modify its system to reduce or eliminate discharge of harmful pollutants. As with drinking water operations, compliance by wastewater facilities are in large part overseen by state regulators.

The main federal law on water quality is the SDWA of 1974. The SDWA was established to ensure and to protect the quality of drinking water in the United States. This law applies to all waters actually or potentially designed for drinking use, whether from above ground or underground sources, and has recently been expanded to include a variety of semi-navigable or navigable water-related waters such as wetlands. The SWDA authorized EPA to establish minimum standards to protect domestic tap water and requires all owners or operators of public water systems to comply with these health-related standards. Amendments to SDWA in 1996 require the EPA to conduct a detailed risk and cost assessment, and to provide the best available peer-reviewed science when developing water quality standards. State government agencies may be approved to implement these rules for EPA, which sets the standards and oversees state, local, and water suppliers that implement the standards. Under the Act, EPA also establishes minimum standards for state programs to protect underground sources of drinking water from endangerment by underground injection of liquids such as fresh or saline water used in petroleum mining hydraulic fracturing (fracking) practices.

EPA's Office of Water (OW) ensures that drinking water is safe, and restores and maintains oceans, watersheds, and their aquatic ecosystems to protect human health, support economic and recreational activities, and provide healthy habitat for fish, plants, and wildlife. OW also implements portions of the Shore Protection Act. Other ocean water acts fully or partially administered by the EPA include the Beaches Environmental Assessment and the Coastal Health Act of 2000, the Clean Boating Act of 2008. The EPS's National Primary Drinking Water Regulations (or primary standards) are legally enforceable standards that apply to all public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water. Categories of regulated contaminants include microorganisms, disinfectants and disinfection byproducts, inorganic chemicals, organic chemicals, and radionuclides

The Food and Drug Administration

The Federal Food, Drug, and Cosmetic Act (FD&C) of 1928 and subsequent amendments assigned the FDA regulatory authority over food that is introduced or delivered into interstate commerce. FDA has established specific regulations for bottled water that include that define different types of bottled water, such as spring water and mineral water, and standard of quality regulations that include allowable levels for chemical, physical, microbial, and radiological contaminants in bottled water. FDA also has established current good manufacturing practice regulations for the processing and bottling of bottled drinking water. FDA monitors and inspects bottled water products and processing plants as part of its general food safety program. Because FDA's experience over the years has shown that bottled water has a good safety record, bottled water plants generally are assigned a relatively low priority for inspection.

Centers for Disease Control and Prevention (CDC)

The CDC operates two programs with responsibility for assuring aspects of the nation's water quality: the Environmental Health Services Branch) and The National Center for Zoonotic Vector-borne and enteric Diseases, Healthy Water information website. The environmental services branch provides free tools and guidance, training, and research to protect water quality, particularly recreational water and private wells. Permitting and inspection programs for drinking water and wastewater systems help to prevent outbreaks in restaurants, school cafeterias, swimming pools, and other facilities. Environmental health practitioners also investigate outbreaks to identify their environmental causes. They often are activated during emergency responses to perform crucial functions such as assessing shelters and food establishments, testing drinking water supplies, and controlling disease-carrying organisms (vectors). CDC's goal is to create a strong, sustained, and prepared environmental health workforce to meet today's challenges and improve the health and safety of all. State, local, tribal, and territorial environmental health service programs represent a key segment of the multidisciplinary approach required to ensure US citizens of safe food and water.

The environmental health services branch provides these water protection services for state and local health professionals:

- Drinking Water Advisory Communication Toolbox: Provides resources to help communities with all phases of water advisories including guidance, recommendations, instructions, templates, and other tools.
- Emergency water supply planning guide for hospitals and healthcare facilities when developing an Emergency Water Supply Plan to prepare for, respond to, and recover from a total or partial interruption of health facilities' normal water supply.

- Model Aquatic Health Code (MAHC): Free science-based guidelines for local administrators to reduce risk for water-borne illness outbreaks, drowning, and chemical poisoning at public pools and other aquatic venues.
- Program for private wells and other unregulated drinking water systems: Assistance to individuals and local communities to strengthen the performance of private and non-regulated local drinking water wells to ensure access to safe drinking water.
- When Every Drop Counts: Assistance to local health professionals to understand prepare for water-related health needs resulting from drought conditions.

The Healthy Water website provides information on drinking water, safe water for swimming, global water supply and quality, sanitation, hygiene and related emergencies and outbreaks, other uses of water, and water, sanitation, and environmentally related hygiene.

Other Department Water Programs

Although portions of their direct regulatory authority have been diluted, the departments of Agriculture, Interior and Health, Education and Welfare continue to play large roles in the management of the nation's water resources. Elements of their involvement are included in the following section. Again, the report is taken from open-source sources.

US Department of Agriculture

Through US Department of Agriculture's Rural Utilities Service Water and Environmental Programs (WEP), rural communities are able to receive technical assistance and financing necessary to develop drinking water and waste disposal systems. WEP also provides funding for the construction of water and waste facilities in rural communities and is the only Federal program exclusively focused on rural water and waste infrastructure needs of rural communities with populations of 10,000 or less.

WEP also provides funding to organizations that provide technical assistance and training to rural communities in relation to their water quality and waste activities. WEP is administered through National Office staff in Washington, DC, and a network of field staff in each State.

USDA provides a wide variety of assistance programs to non-profit organizations and public services agencies and utilities in rural areas. The programs shown in Table 6.2 assist small community organizations with some involvement with or which are specifically directed toward water and/or wastewater services in rural area.

Table 6.2 U.S. Department of Agriculture rural water-related development programs

Program	Description
Technical assistance for rural water systems (Circuit Rider Program)	This program provides technical assistance to rural water systems with day-to-day operation, financial or management problems. Assistance may be requested by officials of rural water systems or Rural Utilities Service staff. Rural Utilities Service has contracted with the National rural Water Association (NRWA) to provide consultants with experience in managing issues that may arise in the day-to-day operations of rural water systems
Emergency community water assistance grants	This program helps eligible communities prepare for, or recover from, an emergency that threatens the availability of safe, reliable drinking water for households and businesses
Household water well system grants	This program helps qualified non-profits and Tribes create a revolving loan fund (RLF) to extend access to clean, reliable water to households in eligible rural areas. Loan fund may be used to construct, refurbish, or service individually-owned household water well systems
Water & waste disposal loan and grant program	Provides funding for clean and reliable drinking water systems, sanitary sewage disposal, sanitary solid waste disposal,

Table 6.2 (continued)

Program	Description
	and storm water drainage to households and businesses in eligible rural areas This program assists qualified applicants that are not otherwise able to obtain commercial credit on reasonable terms
Water & wastewater disposal loan guarantees	Helps private lenders provide affordable financing to qualified borrowers to improve access to clean, reliable water and waste disposal systems for households and businesses in rural areas
Water & wastewater disposal pre-development planning grants	Assists low-income communities with initial planning and development of an application for USDA Rural Development Water and Waste Disposal direct loan/grant and loan guarantee programs.
Water & wastewater disposal revolving loan funds	Helps qualified non-profits create a revolving loan fund (RLF) that can provide financing for the extension and improvement of water and waste disposal systems in rural areas
Water & wastewater disposal technical assistance and training grants	Helps qualified, private non-profits provide technical assistance and training to (a) identify and evaluate solutions to water and waste problems; (b) assist applicants in preparing applications for water and waste disposal loans/grants; and (c) assist associations in improving operation and maintenance of existing water and waste facilities

Source: USDA (2016)

USDA National Water Quality Program

The Department of Agriculture sponsors a water quality initiative through its National Institute of Food and Agriculture (NIFA). NIFA was established by the Food Conservation and Energy Act of 2008 (the 2008 Farm Bill) to find innovative solutions to issues related to agriculture, food, the environment, and communities. The National Water Quality Program (NWQP) manages the water issues section of NIFA. The goal of the NWQP is to protect or improve the quality of water resources throughout the United States and its territories, particularly in agriculturally managed watersheds. It works with partners at the national, regional, state, and local levels to accomplish its goals (USDA 2016b).

NWQP brings university scientists, instructors, and extension educators into more effective and efficient partnerships with federal interagency programs to address water quality issues in United States agriculture. A key emphasis of the program is integration of extension, research, and education resources to solve water quality problems at the local level. NWQP is supported in part by the National Integrated Water Quality Competitive Grants Program and works with the ten regional districts of the EPA.

Recognizing that agriculture is one of the leading agents of non-point source pollution across the United States, the NWQP provides research, education, and extension activities to address pollution challenges in agricultural and rural watersheds. Working with representatives from land-grant universities and colleges, NWQP has identified eight issue areas have been that represent critical challenges to maintaining the quality of the nation's water resources in agricultural and rural watersheds. These issue areas are: animal manure management, drinking water and human health, environmental restoration, nutrient and pesticide management, pollution assessment and prevention, water management and conservation, water policy and economics, and watershed management.

The Agricultural Research, Extension, and Education Reform Act of 1998 authorized the Secretary of Agriculture to establish a competitive grants program for NIFA water quality funding, which includes four major categories: (1) *regional coordination projects* that use state water quality coordinators to promote regional collaboration, enhance delivery of successful programs, and encourage multistate and multiregion efforts to protect and restore water resources in ten regions consistent with the EPA regional structure; (2) *integrated projects* that implement focused research effort along with outreach education to address watershed concerns; (3) *extension education projects* that deliver outreach programs into target watersheds; and (4) *national facilitation projects* that coordinate and support implementation of successful programs that are relevant across the United States.

Interior Department Agencies

The US Department of the Interior manages America's natural resources through the activities of nine technical bureaus and a number of special offices. Although all nine of the Interior's bureaus have some water-related responsibilities, four are principle players in the implementation of the US water policy; they are the US Geological Survey, the Fish and Wildlife Service, the Bureau of Reclamation, and the Office of Surface Mining Reclamation and Enforcement. Other bureaus with some water-related responsibilities include the bureaus of Indian Affairs, Safety and Environmental Enforcement, and the National Park Service.

US Geological Survey

The USGS and the US Fish and Wildlife Service (USFWS) are two Interior Department agencies with extensive water-related responsibilities. The mission of the USGS is to collect and disseminate reliable, impartial, and timely information that is needed to understand the nation's water resources. The United States Geological Survey was established on March 3, 1879, when President Rutherford B. Hayes signed a bill appropriating money for various civil expenses of the federal government. In more than 135 years since its founding, the USGS has become the premier water-monitoring and science bureau within the federal government. Reorganization of the USGS in 2010 changed its former nine scientific discipline structure (such as Geology, Geography, Biology, and Hydrology) to what is now an issue-oriented organization that follows a bureau water science strategy. The new organization now focuses on seven science-mission areas, through which the mission is achieved through a process that begins with observation of the entire water cycle, understand the entire cycle through judicious application of the best science available; be able to predict changes in the nation's water availability from climate and land-use changes and natural disasters: in order to ultimately deliver science results and historical data to the public and other water scientists. The seven mission areas are:

- Climate and land-use change
- Core science systems
- Ecosystems
- Energy and minerals
- Environmental health
- Natural hazards
- Water

A water-science planning team of the water bureau was tasked with developing a ten-year strategic plan for the water mission area and the programs included. Accordingly, the planning team was to develop a water strategy that examined the water issues "facing society and to develop a strategy that observes, understands, predicts, and delivers water science by taking into account the water science and core capabilities of the USGS." The strategic focus was introduced in the 2007 publication of the *Facing Tomorrow's Challenges: U.S. Geological Survey Science in the Decade 2007–2017* study. The USGS's water section was explained in greater detail with the 2013 publication of the complete *Water Science Strategy: Observing, Understanding, Predicting and Delivering Water Science to the Nation* (Evenson et al. 2013).

Scientists and engineers at USGS identified five salient goals and facilitating objectives for the Water Science decade-long strategic plan. The five goals are (1) to provide society with the information on the amount and quality of water in all components of the water cycle; (2) advance understanding to the processes that determine water availability; (3) predict changes in the quantity and quality of water responses in response to changes in climate, population, land-use and management scenarios; (4) anticipate and respond to water-related emergencies and conflicts; and (5) deliver timely hydrologic data, analyses, and decision-support tools to support water-resource decisions. Table 6.3 identifies

Table 6.3 Water Science strategic goals and abbreviated objectives

Number	Strategic goal	Objectives
1	Provide information on water amounts and quality	1. Advancement of hydrologic monitoring networks and techniques 2. Advancement of monitoring for determining water quality 3. Assessment of water resources and suitability for meeting human and ecosystem needs
2	Advance understanding of processes determining water availability	1. Comprehensive understanding of geological controls over water availability 2. Understanding of effects of climate variation 3. Understanding of interactions within ecosystems 4. Understanding of human interactions with water availability
3	Predict changes in amount and quality of water resource	1. Development of models to predict potential effects of changes in population, land-use, climate and management practices 2. Prediction of availability of alternative water sources and effects of their use on the environment
4	Anticipate and respond to water-related emergencies	1. Identify current and future threats from water- related hazards 2. Deployment of observational systems for tracking hydrologic hazards and provide data for recovery 3. Understand conditions leading to water shortages that result in conflicts; provide assistance to communities in finding science-based solutions 4. Provide tools for managers to detect and respond to emergencies in water quality

(*continued*)

Table 6.3 (continued)

Number	Strategic goal	Objectives
5	Deliver data, analyses and decision-support tools	Development of new, integrated information dissemination in formats appropriate for the twenty-first century to act scientists and decision makers

Source: Evenson et al. (2014)

the several key objectives considered necessary for achieving each of the five goals.

The new water strategy is designed to facilitate the ability of the USGS water personnel to collect, interpret, and provide access to the wide variety of information needed to understand and manage the nation's water resources. Regional Water Science Centers support this mission through a data collection network and a hydrologic investigations program. Some of these activities are funded entirely by USGS, although most are supported through partnerships between the USGS, other federal agencies, state and local governments, and tribes. There is a science center office in all states, Puerto Rico and some smaller possessions.

The Fish and Wildlife Service

The mission of the US Fish and Wildlife Service is to work with other federal agencies, state and local fish and wildlife agencies, sports and environmental civil groups, and private citizens to "conserve, protect, and enhance fish, wildlife, plants and their habitats for the continuing benefit of the American people." The USFWS traces its history back to 1871 when the first US Commission on Fish and Fisheries was created. The commission was charged with studying and recommending solutions to the decline in the nation's freshwater and ocean fisheries. The first government fish hatcheries were authorized by Congress. In 1885, an Office of Economic Ornithology created in Department of

Agriculture to begin the first survey of the geographic distribution of nation's birds and mammals. A division of Biological Survey was formed the next year out of Division of Economic Ornithology and Mammalogy. In 1905, it was renamed the Bureau of Biological Survey. For most of its early life, the activities of the service were often managed as units of the Departments of Agriculture and/or Commerce (USFWS 2016).

The Fish and Wildlife Service in the Department of Interior was created in 1940 by combining the Bureau of Fisheries and the Bureau of Biological Survey and placing the new organization under the Department of the Interior. The service's River Basin Studies Program was established in 1946 in response to amendments to the Fish and Wildlife Coordination Act and growing demands for more protection of fish and wildlife resources threatened by large federal water projects.

The North American Waterfowl Management Plan signed in 1986 was enacted to protect waterfowl and wetlands and facilitate international cooperation in the recovery of a shared resource. The US and Canadian governments developed a strategy to restore waterfowl populations through habitat protection, restoration, and enhancement. Congress passed the North American Wetlands Conservation Act in 1989, in part, to support activities under the Waterfowl Management Plan. The Act provided matching grants to organizations and individuals who have developed partnerships to carry out wetlands conservation projects in the United States, Canada, and Mexico for the benefit of wetlands-associated migratory birds and other wildlife.

Surface Mining Reclamation and Enforcement

Another Interior bureau with important water responsibility is the Office of Surface Mining Reclamation and Enforcement (OSMRE). This agency is responsible for a nationwide program to protect the public and the environment from the adverse effects of surface coal mining operations. OSMRE has had to balance its responsible for the nation's need for continued coal production with protection of the environment. OSMRE was created in 1977 when Congress enacted the Surface Mining Control and Reclamation Act (SMCRA). OSMRE and its partners are also responsible for reclaiming and restoring lands and water degraded by mining operations before 1977. Initially, OSMRE directly enforced mining laws and arranged cleanup of abandoned mine lands. Today, most coal states have developed their own programs to do those jobs themselves, as Congress envisioned. OSMRE focuses on overseeing the state programs and developing new tools to help the states and tribes get the job done.

Other Interior Agencies with Water-Responsibilities

In addition to Interior's nine bureaus, a number of other offices have some special responsibilities. Two under the Secretary's Office are the Indian Water Rights Office and the National Invasive Species Council. Two under the Office of the Assistant Secretary for Policy, Management and Budget are the Coordinated Ocean, Coastal and Great Lakes Activities Office and the Office of Environmental Policy and Compliance.

Department of Health and Human Services (DHHS)

The National Quarantine Act of 1878 transferred quarantine functions from the individual states to the federal Marine Hospital Service; conversion of the Marine Hospital Service into the Public Health and Marine Hospital Service followed, in recognition of its expanding activities in the field of public health. In 1912, the name was shortened to the Public Health Service (PHS). The federal Communicable Disease Center was established in 1946, forerunner of the Centers for Disease Control and Prevention. The Cabinet-level Department of Health, Education, and Welfare (HEW) was created on April 11, 1953 under President Eisenhower. The Department of Health, Education, and Welfare (HEW) became the DHHS on May 4, 1980. DHHS is the agency responsible for federal programs for protecting the health of all Americans and providing essential human services. The Public Health Service (PHS) and Centers for Disease Control and Prevention (CDC); the Environmental Health Services (EHS) is a program under the CDC.

The Commissioned Corps of the US Public Health Service is a team of more than 6,500 full-time health professionals who deliver public health promotion and disease prevention programs and advancing public health science. As one of America's seven uniformed services, the Commissioned Corps fills essential public health leadership and service roles within the Nation's Federal Government agencies and programs. The Surgeon General, the leader of the PHS, reports to the Assistant Secretary for Health and in turn the Secretary of the USDHHS.

The CDC is the Public Health Service's (PHS) lead agency in developing and implementing programs in controlling and preventing environmental health problems, and conducts operational research aimed at developing and testing effective disease prevention, control, and health promotion programs. The CDC is the national center for research and activities in developing and applying disease prevention and control, environmental health, and health promotion and health education. The CDC mission includes assisting other federal agencies and the states in ensuring water quality and in controlling and preventing the incidence of water-borne diseases and illnesses.

CDC's National Center for Environmental Health Services (NCEHS) branch provides training, tools, and guidance, and research to help environmental health practitioners prevent food-borne illnesses and outbreaks, protect water, and improve related services, including protecting water quality. The website for CDC's National Center for Zoonotic, Vector-Borne, and Enteric Diseases and Healthy Water shares information on a variety of topics on water including drinking water; global water, sanitation and hygiene; healthy swimming/recreation water; water-related emergencies and outbreaks; and diseases, contaminants, and injuries.

The Health Studies Branch (HSB) of the NCEHS leads CDC's Clean Water for Heath Program (CWH), focusing on drinking water sources that are not regulated by the SDWA. CWH conducts activities in three areas: water-related exposure and outcome research, the Private Well Initiative, and technical assistance and outbreak response. The branch conducts investigations in response to outbreaks believed to have environmental causes and responds to natural and technologic disasters. The focus of these investigations includes outbreaks of water-borne diseases.

HSB also conducts extended research studies to more accurately define the relation between human health and environmental exposures. When requested, HSB provides technical assistance and expertise to state or local public health agencies. HSB's mission was described thus:

> Improvements in water quality have dramatically improved the public's health in the United States. However, some old challenges remain, and new ones are emerging. For some communities, access to plentiful healthy water is, or may soon be, limited by the presence of environmental pollutants in local water sources, drought and aquifer depletion that limits water availability, flooding events that overwhelm local treatment capacity, local weather changes associated with climate change, new and more stringent regulations, or failures in water-related infrastructure. HSB has an urgent mission to work with public health partners to protect public health by assessing and mitigating exposure to waterborne and related diseases. (CDC 2012c)

Summary

Federal involvement in Water Policy Water policies began with the federal government as the only organization big enough and with the technical knowledge to develop the Nation's rivers systems and its ports. The American people viewed water as a common resource, one subject to eminent domain. The new Federal government adopted these improvement schemes as a way of providing access to and from the territories west of the Appalachian mountains. Neither the individual states nor any of the new territories were able to finance or engineer the water developments in the early years of the Nation. As a result, new Federal agencies were developed given that responsibility. The first of these agencies was the Army Corps of Engineers. As Carriker and Wallace (2015, 1) have noted, "A prime purpose of federal involvement has been to ensure national economic growth by implementing and/or helping facilitate state water resource development. The logic here was that where abundant, inexpensive, and high quality water exists, people will follow and prosper."

An important concept that flowered during the Progressive Eras was that if the federal government did not take a leadership role in the planning, coordinating, and implementing of water resources policy, either no one else would or eventually, water supplies would end up under private, monopolistic ownership. Another argument in support of early federal involvement was that a centralized authority was effective in times of national emergency, or in dealing with emergencies such as flood or drought. It was believed that a single federal organization could respond "more quickly to help the general welfare than could the scattered and uncoordinated efforts of the states."

These arguments led to the early turning over management of the nation's water resources to such agencies as the Army Corps of Engineers and the departments of agriculture, health, and the interior. By the second half of the twentieth century, environmental and human health concerns led to assigning authority over water quality to the new EPA.

As Adam Reimer (2012) has reminded us, the Nation's water policy, such as it is, remains highly fragmented and is continually evolving. Numerous federal laws and agencies oversee various aspects of water policy, including both water supply and water quality; almost every session of Congress sees one or more water laws passed. The Department of Agriculture's Reclamation Bureau maintains and operates hundreds of dams, reservoirs, and other water supply and storage systems throughout the western half of the United States.

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7

Water Resource Management Comes of Age

As the early water quality standards were being formulated in the 1960s, an environmental protection movement was underway that also included efforts to identify a comprehensive water management for the nation. One of the early accomplishments of the time was publication by the US Public Health Service of the first comprehensive set of standards for drinking water in public transportation carriers in 1946, amended in 1958, and again in 1962. The American Water Works Association (AWWA), the water and wastewater industry's largest trade association, recommended that the standards should be applied to all public supply sources and systems (USPHS 1962). A list of the major water and wastewater legislation from 1948 to 1990 is shown in Table 7.1. This chapter reviews the major water laws that have emerged with the heightened attention to water policy over the next 50 some years following the Great Depression.

Post WWII Water Legislation

The first in a post-war series of water-related legislation, the Water Pollution Control Act (WPCA) of 1948, authorized the Surgeon General of the Public Health Service, working with other federal,

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Table 7.1 Selected environmental protection and water pollution legislation, 1948–1990

Year	Act	Public Law No.
1948	Federal Water Pollution Act	P. L. 80-845
1956	Federal Water Pollution Control Act Amendments	P. L. 84-660
1961	Federal Water Pollution Control Act Amendments	P. L. 87-88
1965	Water Quality Act	P. L. 89-234
1966	Clean Water Restoration Act	P. L.89-753
1969	National Environmental Policy Act	P. L. 91-190
1970	Water Quality Improvement Act	P. L. 91-224*
1972	Federal Water Pollution Control Act (Clean Water Act)	P. L. 92-500
1974	Safe Drinking Water Act	P. L. 93-523
1977	Safe Drinking Water Act Amendments	P. L. 95-190
1977	Clean Water Act Amendments	P. L. 95-217
1978	Great Lakes Water Quality Agreement (amended)	P. L. 101-596
1980	Safe Drinking Water Act Amendments	P. L. 96-502
1981	Municipal Wastewater Treatment Grants Amendments	P. L. 97-117
1986	Safe Drinking Water Act Amendments	P. L. 99-339
1987	Water Quality Act of 1987	P. L. 100-4
1988	Lead Contamination Control Act	P. L. 100-572
1990	Oil Pollution Act (amended Clean Water Act)	P. L. 101-380
1990	Water Resources Development Act	P. L. 101-640
1996	Safe Drinking Water Act Amendments	P. L. 104-482

Note: *Available sources assign the same Public Law number to both acts
Sources: Data from Kenney 1012, EPA and other sources

state, and local agencies, to prepare programs for eliminating or reducing the pollution of interstate waters and tributaries. The bill was considered an experimental approach and as such, was to run for five years. It was then extended for another three years and was then superseded by the WPCA of 1956. A chief objective of the WPCA was to improve the sanitary condition of surface and groundwater supplies. This resulted in an ongoing series of Public Health Service (USPHS) standards for water supplies. Regular upgrades by the PHS were necessary to identify additional chemicals found to be polluting public water supplies and for inform public suppliers of the need to modify their testing procedures to conserve waters for public water supplies, protect fish and aquatic life, for human consumption, recreational purposes, agricultural, and industrial uses. The Act also authorized the federal government to assist states, municipalities, and interstate agencies in constructing treatment plants to prevent discharges of inadequately treated sewage and other wastes into interstate waters or tributaries.

Amendments to the 1948 WPCA were enacted in 1961, 1965, 1966, 1970, 1972, 1977, and 1987. When the amendment of the 1948 law was enacted in 1961, it established the Department of Health and Human Serfics as a major water resource agency. The amendments also gave the Department of the Interior's Fish and Wildlife Service a role in administering water policy when it stipulated that federal agencies consider public health and fish and wildlife habitat when planning for any reservoir, storage to regulate stream flow when planning modifications for improving water quality control (FWS 2013). Authority over water quality given to the Department of Health, Education and Welfare (DHEW) required it to undertake research programs for determining effects of new pollutants and the necessary treatment methods for water quality in the Great Lakes, where pollution from industry, agricultural and acidification from coal-fired power generation exhaust. At the request of any state, measures that could be taken to ward off pollution of interstate or navigable waters were also specified. The 1961 law improved the 1956 version in the following ways by:

- Strengthening and broadening the governments' enforcement powers over water polluters by expanding federal control to include not only interstate waters but all navigable waters of the country, including coastal waters.
- Establishing the groundwork for construction of water pollution facilities throughout the nation.
- Providing federal support for state and interstate pollution control programs.
- Initiating more extensive research while endorsing regional different needs.
- Establishing a policy of water storage by construction of federal water reservoirs, thus ensuring stream flow in dry periods.

- Shifting authority for administering the federal water and wastewater program from the Surgeon General of the Public Health Service and giving it Cabinet-level importance by transferring it to the Secretary of the DHEW (Cohen and Sonosky 1962).

Water Resources Planning Act of 1965

The Public Health Service's standards were followed three years later by passage in 1965 of the Water Resources Planning Act (WRPA). The most important result of that act was President Johnson's establishment of the Water Resource Council (WRC) to oversee development and implementation of the nation's water policy and periodically carry out an assessment of the adequacies of water to meet local, state, and federal requirements. The 1965 legislation also required the states to develop water quality standards. A federally directed mandate was considered necessary since many watersheds and waterways crossed state boundaries. The water quality legislation signed by President Johnson in October of 1965 and its amendments enacted in 1977 were to give the federal government more power to protect and ensure the quality of surface and groundwater, while firmly reaffirming the rights of the individual states to manage implementation of water-related projects and programs.

The intent behind these laws was to include encouragement of conservation, development and use of water and related land resources "on a comprehensive and coordinated basis by the federal government, states, localities, and private enterprise with the cooperation of all affected federal agencies states, local governments, individuals, corporations, business enterprises, and others concerned" (WRC 1968, xi). A list of the functions of the WRC is included in Box 7.1. Membership on the WRC included the secretaries of the Agriculture, the Army, Health, Education, Welfare, Interior, and Transportation departments and the chairman of the Federal Power Commission. Associate members included the secretaries of Commerce and the Housing and Urban Development departments. The director of the Bureau of the Budget and the Attorney General were names as observers. The Secretary of the Interior was named Chairman. The Council was to meet quarterly, with associates meeting with the council's director bi-weekly.

Box 7.1 Water Resource Council (WRC) initial tasks and responsibilities

- To maintain a continuing study and prepare periodically an assessment of the adequacy of supplies of water necessary to meet water requirements in each water resources region.
- To maintain a continuing study of the relation of regional or river basis plans and programs to the requirements of larger regions of the nation.
- To appraise the adequacy of administrative and statutory means for coordination and implementation of the water and related land resources policies and programs of the several federal agencies, and to make recommendations to the President with respect to federal policies and programs.
- To establish, after consultation with appropriate interested Federal ad non-federal entities, and with the approval of the President, principles, standards, and procedures for federal participation in the preparation of comprehensive regional river basin plans, and for the formulation and evaluation of federal water and related land resources projects.
- To coordinate schedule, budgets, and programs of federal agencies in comprehensive interagency regional or river basin planning.
- To carry out its responsibilities with regard to the creation, operation and termination of federal-state river basin commissions.
- To receive plans or revisions thereof submitted by river basin commissions and to review and transmit them, together with their recommendations, to the President.
- To assist the states financially in developing and participating in the development of comprehensive water and related resources plans.

Source: USWRC (1968)

The next amendments to the WPCA occurred with passage of the Clean Water Act of 1966, which passed authority over pollution control from DHEW to the Department of the Interior. The shift authorized the Interior Secretary, in cooperation with the Secretary of Agriculture and the Water Resources Council, to conduct a comprehensive study of the effects of pollution, including sedimentation, in the estuaries and estuarine zones of the United States on fish and wildlife, sport and commercial fishing, recreation, water supply and power, and other specified uses.

According to the Director of Cornell University's Water Resources Center Leonard Dworsky, the major change in the 1966 act over earlier acts was the "clearly stated view of Congress that water pollution control is going to require vast sums of money and that the initial role of the federal government in this effort 'was a walk-on part in a huge drama, and a hesitating one at that. The 1966 act removes all hesitation and authorizes . . . $3.4 billion for the fiscal years 1969–1971'" (Dworsky 1967, 659).

These post-war legislative actions to shape a systematic national water policy grew out of a perceived need to catalog and begin better management of the nation's water resources. The resulting policy that is best described as a watershed approach came in 1968, when the WRC published its first national water assessment. This was followed a decade later by a more comprehensive second water assessment. Later efforts to update components of the second assessment to reflect conditions in the year 1995 were summarized in a 1999 report titled *National Assessment of the Potential Consequences of Climate Variability and Change. Copies of the reports have been published by the U. S. Geological Survey (USGS) and are available on the Internet.*

National Environmental Policy Act of 1969

Congress made the country's new concern over what was seen as growing damage to the environment official in 1969 when it passed legislation that stated explicitly that environmental protection was to be the policy of the United States. The National Environmental Policy Act (NEPA) of 1969 stated the purpose of the legislation was to "declare a national policy that will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation." NEPA also established a three-member Council on Environmental Quality to work in the Executive Office to advise the President on environmental issues and related scientific developments.

Federal and State Water Management

The nation's twentieth-century water policy changed politically in the decade of 1970s and 1980s. Belief in the ability of government to solve the nation's water problems that came to maturity during the Great Depression and President Franklin Roosevelt's New Deal was replaced by the "return to states' rights" thinking that came to fruition as the "New Federalism" during the 1969–1974 presidency of Richard Nixon. This policy was reinforced during the presidency of Ronald Reagan (1981–1989). New Deal projects like the Tennessee Valley Authority and the Bonneville dams on the Northwest Columbia River gave way to block grants to state governments to solve local problems in local ways (Box 7.2).

Box 7.2 Excerpts from President Nixon's New Federalism revenue sharing plan

We come now to a proposal which I consider profoundly important to the future of our Federal system of shared responsibilities. When we speak of poverty or jobs or opportunity or making government more effective or getting it closer to the people, it brings us directly to the financial plight of our states and cities. We can no longer have effective government at any level unless we have it at all levels. There is too much to be done for the cities to do it alone, for Washington to do it alone, or for the states to do it alone.

For a third of a century, power and responsibility have flowed toward Washington, and Washington has taken for its own the best sources of revenue. We intend to reverse this tide, and to turn back to the states a greater measure of responsibility—not as a way of avoiding problems, but as a better way of solving problems. Along with this would go a share of Federal revenues. I shall propose to the Congress next week that a set portion of the revenues from Federal income taxes be remitted directly to the states, with a minimum of Federal restrictions on how those dollars are to be used, and with a requirement that a percentage of them be channeled through for the use of local governments. The funds provided under this program will not be great in the first year. But the principle will have been established, and the amounts will increase as our budgetary situation improves.

This start on revenue sharing is a step toward what I call the New Federalism. It is a gesture of faith in America's state and local governments and in the principle of democratic self-government.

Source: President Richard Nixon (1969)

The conservation and environmental protection movement would eventually result in Army Corps of Engineers begin to recognize that more dams were not always the best solution to the irrigation, power generation, and flood control needs they were supposed to be. The nation saw the fruits of that change come to a peak in the first decade of the twenty-first century with a movement for removal of dams and remediation of wetlands.

In the years prior to Nixon's presidency, the weak thinking devoted to an environmental policy seen little regard paid the polluted water in appearing many of the nation's rivers, streams, and lakes. Publication in 1962 of Rachel Carson's *Silent Spring* helped solidify public attention to the dangers of the powerful pesticide DDT and past lack of concern over such environmental problems as air and water pollution. Congress had been forced reacted to public calls for greater attention to given to the environment and toward resource conservation and pollution control.

Birth of the EPA

The environmental protection policy of the United States can be said to have been born with passage of the bill in 1972 that resulted in establishing the Environmental Protection Agency (EPA). The second was passage of the Safe Drinking Water Act (SDWA) in 1974.

In May of 1969, President Nixon had formed a Cabinet-level Environmental Quality Council (EQC) as well as a Citizens' Advisory Committee on Environmental Quality. However, rather than being encouraged for his attention to the environment, environmentalist critics accused the President of only playing lip service to the protection movement. Nixon then appointed a White House committee in December, 1969, to consider whether there should be a separate environmental agency. Meanwhile, Congress had sent to the President a bill that would be known as the NEPA. This legislation also called for a strengthening of the powers of the Council. President Nixon, in an attempt to forestall criticism of NEPA and the EQC, then called for "a strong, independent agency." The mission of this proposed "EPA" would be to:

- Establish and enforce environmental protection standards.
- Conduct environmental research.
- Provide assistance to others combating environmental pollution.
- Assist the EQC in developing and recommending to the President new policies for environmental protection.

The EPA, fabricated from a number of duties and responsibilities housed in other agencies, began operations on December 2, 1970, in a small suite of offices in northwest Washington, DC. The initial organizational chart of the new EPA is shown in Fig. 7.1. An office of water quality in the proposed organization of the agency was included in Executive Order 1110.2 that was then released on December 4, 1970. One of the offices called for was that of the Water Office, a position that included the following responsibilities:

> The Office shall be responsible for a program of water pollution control designed to enhance and preserve the quality and value of the Nation's waters, and a program of water hygiene to minimize the health effects of contaminants in drinking water and recreational waters. The principal water pollution control responsibilities of the Office include 1) Federal financial assistance to help support the construction of municipal waste treatment facilities, encouragement of improved operation and maintenance of such facilities, and improved planning to assure that the grants contribute to effective basin-wide cleanup; 2) a water quality standards management program in cooperation with states, cities, and industry; 3) a research, development and demonstration program; 4) a national water quality monitoring system coordinated with monitoring activities of state and other Federal agencies; 5) a manpower development and training program; 6) a technical assistance and support program for public and private agencies and institutions; and 7) continued Federal financial assistance to state water pollution control agencies to assist them in carrying out their responsibilities for water quality management under the Federal Water Pollution Control Act. The principal water hygiene responsibilities of the Office include establishing and implementing drinking water standards for systems subject to Federal law and recommending shellfish and recreational water standards through programs of surveillance, research and development, technical assistance, and training. (EPA 2015a)

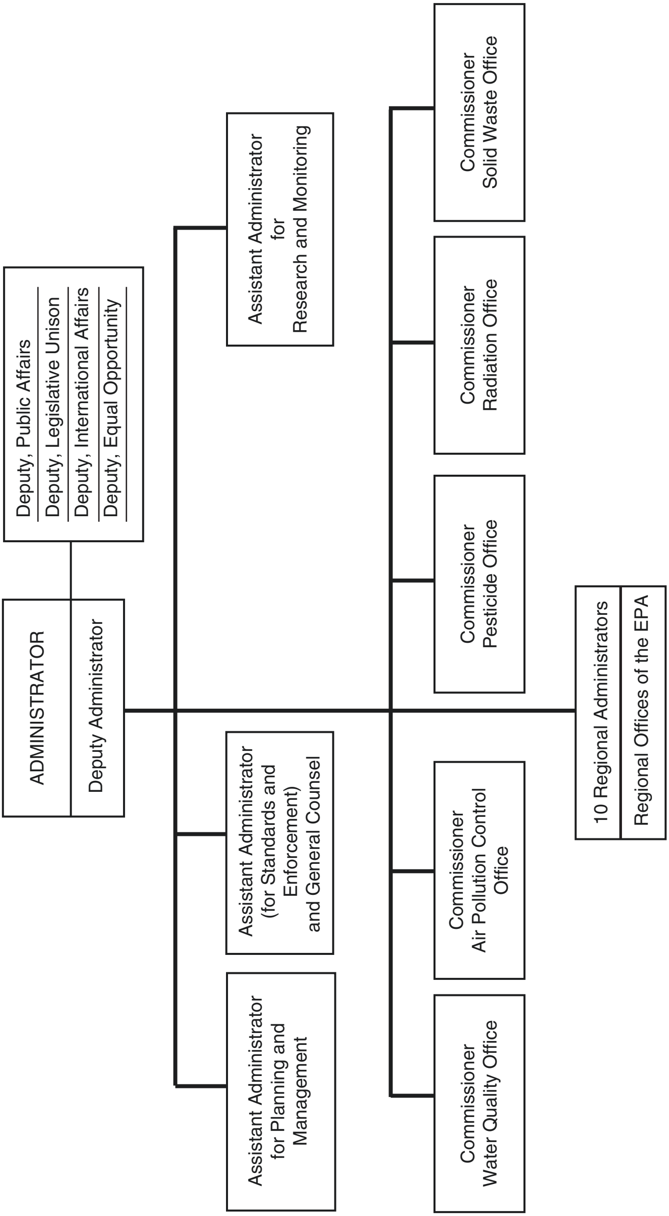

Fig. 7.1 Initial organizational structure of the EPA

The 1970s decade had begun with enactment of a number of important environmental laws, both of which signaled Congress's intention to clean up the nation's water supply while at the same time strengthening all environmental protection activities. The laws were (1) the Water Quality Improvement Act of 1970, (2) the Environmental Quality Improvement Act of 1970, and (3) the Safe Drinking Water Act of 1974.

The Water Quality Improvement Act of 1970

The Water Quality Improvement Act amended earlier legislation prohibiting discharges of oil in US waters to allow such discharges only when consistent with regulations permitted by Article IV of the 1954 International Convention for the Prevention of Pollution of the Sea by Oil. In issuing regulations, President Nixon was authorized to determine what quantities of oil would be harmful to the public health or welfare of the United States, including but not limited to, fish, shellfish, and wildlife, as well as public and private property, shorelines, and beaches. The Act also added prohibitions of hazardous polluting substances, control of sewage from vessels, mine pollution control demonstrations, Great Lakes pollution control, and cooperation by all federal agencies in pollution control (Meiklejohn 1970).

The 1970 Act requires anyone in charge of a vessel illegally discharging oil to notify the appropriate governmental agency as soon as he or she learns of the discharge. Failure to do so is punishable by a fine of up to $10,000 and one year imprisonment, making this the most severe sanction authorized by the Act. The Act gives the government the right to require the guilty vessel repayment for cleanup of the oil spill if it was caused by "willful negligence or willful misconduct," up to a maximum of $14 million.

Environmental Quality Improvement Act of 1970

The Environmental Quality Improvement Act was another of the environmental laws that emerged from growing public and political awareness and of the damage being done to the water, air, and natural environment of the country and the world in general. The first major purpose of this Act was to authorize the creation of an Office of Environmental Quality in the Office of the President to provide the staff needed for the Council on Environmental Quality (CEQ). The second was to "assure that each Federal department and agency conducting or supporting public works activities which affect the environment shall implement the policies under existing law." The act also added additional responsibilities to the chairman of the CEQ included in his new position as Director of the Office of Environmental Quality. The CEQ was established by NEPA to "formulate and recommend national policies" to promote the improvement of the quality of the natural environment. Until it was abolished in 1993, the President's CEQ was the White House Office that advised the President and coordinated executive branch policy on the environment (Box 7.3).

Box 7.3 Section of the Environmental Quality Improvement Act of 1970

The Congress finds

(a) That man has caused changes in the environment; that many of these changes may affect the relationship between man and his environment; and that population increases and urban concentration contribute directly to pollution and the degradation of our environment, therefore

(b) The Congress declares that there is a national policy for the environment which provides for the enhancement of environmental quality. This policy is evidenced by statutes heretofore enacted relating to the prevention, abatement, and control of environmental pollution, water and land resources, transportation, and economic and regional development; The primary responsibility for implementing this policy rests with state and local government; and the Federal Government encourages and supports implementation of this policy through appropriate regional organizations established under existing law.

Purposes

(a) To assure that each Federal department and agency conducting or supporting public works activities which affect the environment shall implement the policies established under existing law; and

(b) To authorize an Office of Environmental Quality, which, notwithstanding any other provision of law, [to\provide the professional and administrative staff for the Council on Environmental Quality established by Public Law 91-19.

Source: NEPA (National Environmental Policy Act: Policy and Compliance (nd))

Safe Drinking Water Act of 1974

The SDWA of 1974 was enacted to protect public health by regulating the nation's public drinking water supply. The law was then amended in 1986, 1996, 2002, and again in 2015. The Act assigned the EPA responsibility for monitoring the Act's provisions as they related to drinking water and its sources; including rivers, lakes, reservoirs, springs, and groundwater wells (SDWA does not regulate private wells which serve fewer than 25 individuals). SDWA authorized the EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. The EPA, the individual states, and local water systems were required to work together to make sure that these standards are met.

The EPA exercises its responsibilities through programs, standards, and treatment requirements for public water supplies, the injection of wastewater underground, and administers loans for infrastructure projects. Following the New Federalism approach, the 1974 law required the EPA to work with the states in implementing the standards. As of 2015, all but one of the 50 states participate in the Public Water Supply Provision program for regulating public water systems. EPA rules and regulations for Public Water Systems set standards for construction, operation, and maintenance of water systems. The standards for drinking water quality and reporting requirements for public water supply systems set standards for chemical and microbiological quality, and are the state equivalent of the national primary drinking water regulations.

Administering the duties specified in the Safe Drinking Water Act was assigned to the new EPA, which from then on was the premier agency responsible for ensuring that drinking water is safe and wastewater treatment meets all sanitary standards. EPA regulates six classes of drinking water contaminants: microorganisms, disinfectants, disinfectant byproducts, inorganic chemicals, organic chemicals, and radionuclides. A complete list of EPA- and CDC-recognized water contaminants as of February 2016 can be found in Appendix D (Fig. 7.2).

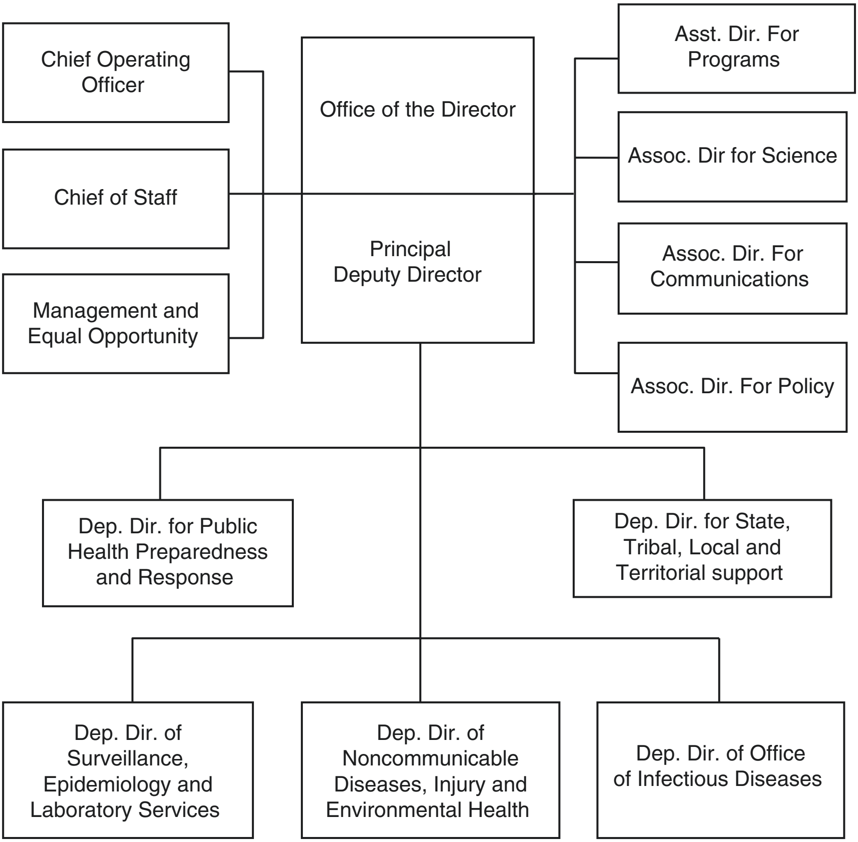

Fig. 7.2 Short organization chart of the Centers for Disease Control and Prevention

Source: CDC (2016)

1977 Amendments to the Federal Water Pollution Control Act (Clean Water Act)

The 1997 amendments to the CWA strengthened the federalist management policy asserting that each state had the authority to allocate water quantity levels within its jurisdiction, and that distribution of intrastate waters should not be impaired by this Act. This Act extended the following programs through 1980:

1. Water treatment works pilot training programs;
2. Development of a system of forecasting the supply of and demand for water pollution control specialists;
3. Grants for state pollution control programs;
4. Scholarships, training grants and contracts in the field of water pollution control;
5. Grants to designated agencies to assist in the development and operation of continuing area-wide waste treatment management planning processes;
6. Grants to the states for lake water improvement programs; and all other purposes of such Act other than those specified in these six categories.

The Act also authorized grants to municipalities in order to defray operation and maintenance costs of approved research and development projects. Also authorized were appropriations for waste treatment construction grants of $4.5 billion for fiscal year 1978 and $5 billion each for fiscal years 1979–1882.

Federal Water Management in the 1980s

The pace of water-related legislation enacted by Congress speeded up during the decade of the 1980s. Moreover, the aspects of the regulations also expanded beyond drinking water purity. In addition to the number and types of drinking water contaminants that had to be regulated, new laws and policies also dealt with ensuring the security of drinking water supplies and facilities and for guidelines to be followed by the federal government for determining whether to provide financial assistance for water-related construction projects.

1982 Water Security Amendment

Water source and system security provisions were added to the SDWA in 1982 by passage of the Public Health Security and Bioterrorism Preparedness and Response Act (PHSBPRA). Title IV, Sections 401–403 of the security act added requirements for community water systems serving more than 3,300 persons to prepare an assessment of the vulnerability of the system to a terrorist attack or other intentional acts intended to substantially disrupt the ability of the system. The assessment had to include water collection, pipes and other means of transporting water, water pre-treatment, treatment, storage and distribution facilities, electronic, computer, and other automated systems used by the public water system. The use, storage, or handling of chemicals, and the operation and maintenance of such system were also included. Community water system serving more than 3,300 people were also required to prepare or revise an emergency response plan that included plans, procedures, and equipment that can be used in the event of a terrorist or other intentional attack on the public water system.

1983 Rules for Federal Water Investments

The Principles, Requirements, and Guidelines for Water- and Land-Related Resources Implementation Studies (PR&G, also referred to as "Principles") govern how federal agencies evaluate proposed water resource development projects (CDC 2015).The Principles have given direction to federal agencies when evaluating and selecting major water projects since 1983; they were modified in 2007 and again updated in 2013. The 1983 guidelines were prepared under guidelines provided in the amended Section 103 of the 1962 WRPA.

The Principles are a public statement of how federal agencies are to implement mandated programs. In this way, the Principles function as an official statement of the US government's water policies. By specifying where and how federal dollars are to be spent on water and wastewater projects, congressional committee members have the final say on what, who, and how water policy is to be implemented. Since

Table 7.2 Guiding principles for US federal water projects

Principle	Discussion
Environmental justice	Environmental justice refers to the requirement for the fair treatment and meaningful involvement of all persons, regardless of race, color, regional origin, or income
Floodplain management	Floodplains are the regions that connect land and water ecosystems in which a high degree of important biodiversity exists and should be maintained. Federal investments in water should not allow the unwise use of floodplains and flood-prone areas
Healthy and resilient ecosystems	Water projects should protect and restore wherever possible the ecosystems and lessen any damage to the systems
Public safety	Federal water investments should include assessing existing and future conditions that threaten loss of life and injury
Sustainable economic development	Federal investments in enhancements to water resources and their management should contribute to the economic and environmental sustainability of society while also ensuring the well-being of the present and future generations
Watershed approach	Watersheds are land areas that drain to a common water body. The Federal government promotes a watershed approach to analysis and decision making on a wide range of potential solutions to water problems

Source: The Whitehouse.gov

1983, the Principles have provided direction to federal agencies when evaluating and selecting major water projects, including projects related to navigation on US waters, a region's storm resilience, restoration of wetlands, and basin-wide flood prevention. The 1983 standards used a narrow set of parameters to evaluate water investments that made it difficult for federal agencies to support a range of important projects that communities want, or in some cases precluded support for good projects. Lack of local support for a project selected by a federal agency or local government body projects was a sure path to substantial delays and even to the potential for denial of federal support (Table 7.2).

Safe Drinking Water Act Amendments of 1986

The first major amendments occurred in 1986 in order to speed up the EPA's program of listing the drinking water contaminants regulated by the EPA and to add to its groundwater protection activities (Tiemann 2014). From 1974 until 1986, the EPA had regulated just one additional contaminant beyond the 22 standards originally specified by the PHS. The 1986 amendments required the EPA to take immediate action to do the Following—and gave the agency the authority to enforce standards and regulations:

1. Issue regulations for 83 specified contaminants by June 1989 and for 25 more contaminants every three years thereafter;
2. Publically distribute requirements for disinfection and filtration of public water supplies;
3. Ban the use of lead pipes and lead solder in new drinking water systems;
4. Establish an elective wellhead protection program around public wells;
5. Establish a demonstration grant program for state and local authorities having designated sole source aquifers to develop groundwater protection programs; and
6. Issue rules for monitoring injection wells that inject wastes below a drinking water source.

Lead Contamination Control Act of 1988

Congress again amended the Safe Drinking Water Act with the Lead Contamination Control Act of 1988 (P. L. 100-572). The changes were intended to reduce the public's exposure to lead in drinking water by requiring the recall of lead-lined water coolers, and requiring the EPA to issue a guidance document and testing procedures for state agencies to use to help schools and daycare centers identify and correct lead contamination in school drinking water. The EPA fulfilled the mandate for publicizing the dangers of lead and how school and other non-residential building principles, managers, and owners should do to eliminate the danger of lead in water systems with the issuance in1994 of the 97-page manual, *Lead in Drinking Water in Schools and Nonresidential Buildings.* The booklet included the following warning and need for testing:

> Exposure to lead is a significant health concern, especially for young children and infants whose growing bodies tend to absorb more lead than the average adult. Pregnant women and fetuses are vulnerable to lead in addition to middle-aged men and women. Drinking water represents one possible means of lead exposure. Some drinking water pipes, taps, and other outlets . . . in homes and buildings may contain lead. The lead in such plumbing may leach into water and pose a health risk. The longer lead remains in contact with leaded-pluming, the more the opportunity exists for lead to leach into water. As a result, facilities with on again/off again water use patterns, such as schools and businesses, may have elevated lead concentrations . . . The only way to be certain that lead is not a problem in a particular home, school, or building is to test various drinking water outlets . . . for the substance (EPA 1994).

Federal Water Management in the 1990s

Water resources were on the minds of Congressmen and women as the 1980s came to a close. The two water-related bills in 1990 were an Oil Pollution Act that included amendments to the 1972 Clean Water Act, and a bill that provided for developing and managing water resources. Another Act enabling amendments to the SDWA was enacted in 1996.

The Oil Pollution Act of 1990

The Oil Pollution Act of 1990 (OPA) amended Section 311 of the Clean Water Act and the Federal Water Pollution Control Act. According to the EPA, the bill was passed in response to the Alaskan spill, and was intended to strengthen EPA's ability to prevent and respond to catastrophic oil spills. The existing trust fund financed by a tax on oil that was available to clean up spills when the responsible party was insufficient to achieve its purpose. The Act requires oil storage facilities and vessels to submit to the federal government plans, detailing how they will respond to large discharges. EPA has published regulations for aboveground storage facilities for oil and oil products. The Act was designed to expand oil spill prevention measures and to establish new requirements for oil transportation, cleanups, and response capabilities of the federal government and industry. The Act also established the Office of Pipeline Safety.

Water Resources Development Act

The Water Resources Development Act of 1990 was enacted largely to authorize the US Army Corps of Engineers to proceed with a wide variety of water projects in the 50 states and territories of the US Public works projects in specified locations for improvements to navigation, flood control, storm damage reduction, and the construction of water-related recreation projects were included. The bill specified the total cost, as well as the estimated federal and non-federal shares of each project. Among the project specified were flood control projects in Arkansas, Indiana, Texas, and West Virginia; a flood control project in the US Virgin Islands; shoreline projects in Michigan and Pennsylvania; design and construction of flood control measures in Kentucky; a project for the removal of silt and aquatic weeds in Minnesota; and projects for the rehabilitation and reconstruction of federal flood control levees on the Arkansas River and Red River.

1996 Safe Drinking Water Act Amendments

The requirement in the 1988 Act called for the EPA to identify and publish information about 25 or more water contaminants every three years. This and other mandates proved to be impossible for the EPA achieve, resulting in a more reasonable bill passed by Congress in 1996 (P. L. 104-182). Among the many issues addressed in the Act, the new amendments changed the 25 contaminants mandate, allowing the research to focus instead on solutions for the problems with the greatest health risk and to determine cost analyses for proposed new rules.

What became one of the most far-reaching change in the amendments was substitution of the former grants for specific programs with funding for a revolving loan fund to be established in each state that was to provide local public suppliers with funds for improving infrastructure and facilities for meeting required treatments. The 1996 SDWA amendments set a two-year time limit for the EPA to publish required guidelines for water conservation plans for public water systems serving fewer than 3,300 persons, public water systems serving between 3,300 and 10,000 persons, and public water systems serving more than 10,000 persons. The plans were to take into consideration such factors as water availability and climate. The 1996 SDWA also amended the Federal Food, Drug and Cosmetic Act by adding a clause to Section 410 that required EPA to issue quality standards for bottled water as well as surface and groundwater. The bottled water standards were to be no less stringent and no less protective of public health than the maximum contaminants identified in the national primary drinking water regulations (P. L. 104-182).

Summary

The nation's water policy has gone through at least five distinct iterations in its long history. It began with a focus on using the existing watercourses as a means for transportation through the dense forests of the Colonial period. This was followed by a state and federal effort to improve efficiency of the existing watercourses by construction of canals and removing hazard and building harbors. The third stage was one for which the nation is paying the price for yet today: urban growth and industrialization of river and lake waters that included using them as handy means of discharging factory toxic contaminants and human wastes. This stage also included the taming of watercourses and improving river channels to enhance transporting supplies to urban centers. In the eastern half of the nation, water supply essentially secured by dependable of rainfall. However, that rainfall often exceeded the ability of nature's watercourses to handle the excess and the focus of water management turned to flood control.

The fourth stage in America's water policy resulted from the construction of the transcontinental railroad and the opening the arid western half of the nation to agriculture, mining and the settlement that following economic opportunity. Now settlers were forced to cope with limited water resources. As a result, water rights shifted from a riparian base to a first come, first right policy. At the same time, water managers in Washington, DC, were convinced that this could be resolved relatively easily by applying the young nation's engineering and mechanical genius to the problem. Most of that knowledge was held by officers in the Army Cory of Engineers. Federal water policy shifted from flood control and transportation in the East to impounding the few large, free-flowing watercourses and channeling the saved water to where it could be put to work in the West. Long, hot, dry summers were no longer a worry as water became available for irrigation. However, as more immigrants settled in the dry western states, demand for water began to outpace supply. A new conception was born: diversion, together with a call for conservation. The problem today is that conservation alone will not be enough to overcome the effects of another man-made crisis: climate change that has altered the traditional pattern of regional participation.

The policy still being formulated in the second decade of the twenty-first century remains solidly cemented to the states rights and responsibilities philosophy ensconced in the New Federalism that began under Presidents Nixon and Reagan. Grants for water and wastewater treatment projects were replaced by loans administered through the states' revolving loan funds. As more states became hard pressed to fund the many mandated services they are required to provide, the local funds needed to replenish the funds were allotted to what seemed to be more important needs. Hence, water suppliers have had to find other loan sources and raise rates to pay for the repair and replacement of critically needed infrastructure.

America's water managers and regulators agree that the old piecemeal approach to managing the resources has to change. The EPA had to establish minimum standards for the more stringent water safety rules mandated by Congress. Water suppliers must adjust their operating systems to comply with the increasing severity of the regulatory environment while at the same time, forced to assure their aging infrastructure is capable of meeting water needs in this era of climate change. The EPA issued the following alert for the Nation:

> Managing water is a growing concern in the United States. Communities across the country are starting to face challenges regarding water supply and a need to update aging water treatment and delivery systems [water and wastewater] infrastructure.

Additional Reading

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8

Managing Water Conflicts

Water resource management is the human activity of planning, developing, processing, storing, distributing, and managing the optimum use of available water supplies and the means and wherewithal to deliver it. Water must be managed whether it is for a local water utility service area, a watershed, a state, a multistate region, or for a nation. Water resource managers must consider the competing demands for current and future availability of water in order to arrive at a solution that assures equitable allocation of available water on an sustainable basis. Resolving the many conflicts that arise between water's diverse stakeholders is a big part of the water manager's job.

A problem resulting from the separation of powers in US government has often been that management authority divided among many different agencies and between the federal and state levels of government makes it difficult and sometimes even impossible for a uniform policy to be established. That problem still exists today. Congress has assigned its policy determination over water and wastewater to the Subcommittee on the Environment and Economy of the Energy and Commerce Committee in the House of Representatives, and to the Environment and Public Works Committee of the US Senate. Appropriations for water and wastewater agencies are developed and administered by the Energy and Water

D.E. McNabb, *Water Resource Management*,
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Appropriations Subcommittee of the House Appropriations Committee. Four of the members of this 12-member appropriations subcommittee were from California and one was from Texas—both states hardest hit by the recent drought. Eventually, a total of $37.2 billion for water programs was included in the 2016 budget, an increase of $3 billion over the 2015 amount and $1.1 billion more than the President requested.

Typical of the efforts of the House of Representatives to influence federal water policy was the approval by the House Committee on the Environment and the Economy in 2015 of a bill to order the EPA to act on a problem of toxic algal blooms in Lake Erie. The legislation was submitted by Representative Bob Latta of Bowling Green, Ohio, after a renewal of toxic pollution that forced a ban on consuming Lake Erie drinking water in Toledo, Ohio. The algal blooms have occurred several times in the past and have been attributed to excessive nitrogen leaching into the lake from agricultural fertilizers. The bill gave the EPA 90 days to come up with a strategic plan to for Congress outlined steps it will take to reduce or eliminate the agricultural runoff into the lake from farms in Canada and the United States.

Senate Influence Example

In February of 2016, action by the Senate's Environment and Public Works Committee illustrated how the Senate influences the way the nation's water resource is managed. The Senate held public hearings on a proposed Stream Protection Rule. Originally introduced in 2009, as of May 2016 a final version had not been adopted. The proposed rule would revise regulations on surface water as a result of surface coal mining. Coal mining regulation under the Surface Mining Control and Reclamation Act generally does not fall under this Committee's jurisdiction. However, because the proposed change would adversely affect public health, the environment, endangered species policy, and surface water used in mining practices on public lands, all agencies with a stake in these areas were involved in the Interior Department's rule change (OSMRE 2016). Citizen groups and industrial associations also testified to this and earlier versions of the rule.

According to committee member Senator Barbara Boxer of California, the new rule would place limits on the dumping of mine waste in headwater streams at mountaintop removal coal mines common in Appalachia and elsewhere. She added that this practice is considered to be one of the "most destructive mining practices used today. Mountaintop removal coal mining has destroyed more than 500 mountains, buried more than 2,000 miles of headwater streams, and polluted thousands of miles of downstream surface waters. And the mining waste associated with these sites can include a host of toxic chemicals, including selenium, arsenic, and lead that can leach into streams and rivers, severely degrading water quality. For the first time, the proposed Stream Protection Rule will require coal mining companies to collect baseline data on water quality and require mining companies to monitor streams during mining and reclamation to ensure that downstream waters are not harmed. Having this information is critical for affected citizens to know if their sources of drinking water are being polluted and to hold federal and state agencies accountable for enforcing laws to protect drinking water" (Boxer 2016).

Managing Water Conflict by Executive Order

Executive Orders (EOs) have been issued to further affect water management rules and regulations, as well as all other legislation, issued by government agencies. An EO remains in effect as long as the issuing President remains in office or if it is renewed or revised by their successors. These descriptions of the two EOs were provided by the EPA in November of 2015. EO 12866, issued by President Clinton in 1993, requires agencies proposing rules to submit a cost–benefit analysis and risk assessment to the Office of Information and Regulatory Affairs in the Office of Management and Budget (OMB). After publication of such an action, the EO requires the federal agency and OMB make available to the public the documents exchanged between them during the review. The federal agency must identify any substantive changes between the draft submitted to OMB and the published rule and must identify those changes made at the suggestion or recommendation of OMB.

A second Executive Order, EO 13563, issued by President Obama in 2011, was designed to improve the regulation and regulatory review process. It reaffirms and amplifies the principles in an earlier order by encouraging agencies to coordinate their regulatory activities, and to consider regulatory approaches that reduce the burden of regulation while maintaining flexibility and freedom of choice for the public. It directs agencies, wherever feasible and appropriate, to seek the views of those likely to be affected by a proposed rulemaking before a notice of proposed rulemaking is issued. It also requires agencies to quantify expected benefits and costs of proposed rules as accurately as possible; to ensure that any scientific and technological information or processes used to support their regulatory actions are objective; directs agencies to provide timely online access for proposed and final rules, along with any relevant scientific and technical findings; and to afford the public the opportunity to comment on proposed regulations through the Internet. It also instructs agencies to periodically review their existing significant regulations with the goal of making their regulatory programs more effective or less burdensome.

On January 30, 2015, the President issued EO 13690, establishing of a Federal Flood Risk Management Standard (FFRMS) and a Process for Further Soliciting and Considering Stakeholder Input. The 2015 EO amended an EO 11988, issued in 1977for Floodplain Management, to include the FFRMS. Once implemented, the FFRMS will assist in reducing the risk and cost of future flood disasters by ensuring that Federal investments in and affecting floodplains are constructed to better withstand the impacts of flooding. The Applicability of Floodplain Management and FFRMS EOs to US Army Corps of Engineers Permitting Authorities was developed to provide clarification in response to a number of frequently asked questions received during open hearing periods.

Conflict Over Water Management Authority

The history of how the existing polycentric approach to managing America's water resource can be seen in the EPA's efforts to clarify over which water bodies it has regulatory jurisdiction. This story of how federal government agencies have quarreled over which agency is to manage the nation's water supply began in 1981 with a developer's attempt to overturn an EPA refusal to allow construction that would adversely affect wetlands that were not directly connected to a navigable water course. Previous Supreme Court decisions upheld the right of EPA and the Corps of Engineers to apply provisions of the Clean Water Act (CWA) to regulate navigable waters. Two additional court cases challenging the constitutionality of the CWA are good examples of how Court decisions shape domestic policy. The decisions on challenges to the scope of the two agencies' jurisdiction in water bodies not directly navigable were: *United States v. Riverside Bayview Homes* (Bayview), *Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers* (SWANCC), and *Rapanos v. United States* (Rapanos). The plaintiffs contested EPA's determination of the wetlands involved in the three cases as constitutionally identified "waters of the United States." In the 1985 Riverside case, the Court in an unanimous opinion supported the argument that the adjacent wetlands were "inseparably bound up" with adjacent navigable waters although no surface connection was apparent. This decision upheld EPA's inclusion of "adjacent wetlands" in the regulatory definition of "waters of the United States."

Authority to Regulate Wetlands

The authority of the EPA and the Army Corps of Engineers to regulate wetlands is rooted in the definition of navigable waters. Regardless of how tenuous is the potential effects that loss of any wetlands would have on the quality of the navigable waters, wetlands are considered necessary for maintaining a large water body. The EPA cited research that found that a single wetland can store more than one million gallons of water, and that non-navigable tributaries may account for more than three quarters of the total waterway network. Hence, this made the regulation of these tributaries and wetlands essential contributors to maintaining a river's navigability (Schang 2006; Meyer et al. 2003, 2007). Beginning in 2001, court rulings and administrative actions have begun to question whether EPA had the right to control all wetlands and non-navigable tributaries of waterways.

In the 2001 SWANCC case, the Court found that the use of "isolated" non-navigable intrastate ponds by migratory birds was not sufficient basis for federal regulation under the CWA. No clear association with navigable waters was apparent. However, in the 2006 Rapanos case, the constitutional questions was: "Does extension of Clean Water Act jurisdiction to every intrastate wetland with any sort of hydrological connection to navigable waters, no matter how tenuous or remote the connection, exceed Congress' constitutional power to regulate commerce among the several states?" The Court unanimously agreed that the term "waters of the United States" does include some waters that are not navigable in the traditional sense. Justice Kennedy's opinion was that the critical factor in determining CWA's coverage is based determination whether water as in the Rapanos case has a "significant nexus" to downstream traditional navigable waters such that the water is important to protecting the chemical, physical, or biological integrity of the navigable water (a *nexus* refers to a "connection." In case law, the term generally refers to the legality of a governmental restriction, and whether the means of restriction is justifiable in light of the right being restricted). Referring back to the SWANCC isolated pond decision, Justice Kennedy determined that the wetlands in the Rapanos question did possess the requisite "significant nexus if the wetlands alone or in combination with similarly situated wetlands in the region significantly affect the chemical, physical and biological integrity of other covered waters more readily understood as navigable" (Federal Register, 80 (124), June 29, 2015).

When the Court ruled in favor of federal regulatory activities over non-navigable waters in 1981, it set precedence that the Army Corps of Engineers followed for the next 14 years. It allowed the Corps to bar construction activities in isolated, non-navigable intrastate waters based on their use by migratory birds. The Corps of Engineers based their right to regulate construction activities in isolated wetlands on provisions in the CWA that protected wetlands under the migratory bird rule.

However, by a 5 to 4 vote, the Supreme Court ruled in 2001 that the migratory bird rule adopted by the Corps in 1986 exceeded the Corps' regulatory authority. In speaking for the majority, chief Justice William Rehnquist said: “permitting [the Corps] to claim federal jurisdiction over ponds and mudflats falling within the ‘migratory bird rule’ would result in a significant impingement of the states’ traditional and primary power over land and water use” (Anonymous in *Civil Engineering* 2001, 8). That decision continued to limit the agencies’ regulatory authority over non-navigable waters until 2015.

The decision to extend the federal jurisdiction from “navigable waters” to “waters of the United States” became common after an action brought by the United States in 1973 to stop the unauthorized dumpling dredged of sand, dirt, and dredged spoil on mangrove wetlands that are periodically inundated by the tide. The defendants were developing a 281-acre tract of land known as Harbor Isle by filling the waters of what was described as a “bayou,” “artificial mosquito canals,” a “mangrove swamp,” and as a “mangrove wetland” with sand, dirt, dredged spoil, and biological materials without required permits. The court declared the filling illegal under the Federal Water Pollution Control Act Amendments of 1972 and ordered the defendant to restore the area and establish a mangrove preserve area. The court found that the *navigability test* for federal jurisdiction over waters of the United States has been so broadened as to include virtually all waterways; the modern test for federal jurisdiction under the commerce clause is whether an activity is reasonably related to or has an effect on interstate commerce. Federal regulatory authority was no longer limited to navigable waters below the mean high water line. The areas to be filled in drained into canals that empty into Tampa Bay. The pollution carried by the fill material was determined to be subject to federal regulation under the FWPCA. The fact that the canals were man-made did not alter the court’s conclusion (*Environmental Law Reporter* 2016; Leagle.com 2015; Finnell 1978).

The Court’s decision included the following justification for upholding the government’s argument to include the canals and wetlands in its jurisdiction was based on wording in the final Joint House and Senate bill authorizing the Federal Water Pollution Control Act of 1972 (FWPCA). The Court opinion included the following explanation: “Congress exercised its power under the commerce clause by enacting the FWPCA, establishing regulatory programs to combat pollution of the nation's waters. Even though it seems certain that Congress sought to broaden federal jurisdiction under the Act, it did so in a manner that appears calculated to force courts to engage in verbal acrobatics. Although using the term 'navigable waters' in the prohibitory phase of the statute, the definition of 'navigable waters' is stated to be 'waters of the United States, including the territorial seas.' The definition stands with no limiting language" (Leagle.com 2015).

The Court repeated that Congress had the authority to make such a decision, without having to follow what it referred to as the old "established judicial philosophy that forbids a narrow, cramped reading" of water pollution legislation, and that the legislative history of the FWPCA supported this meaning. The Senate bill defined "navigable waters" to mean navigable waters of the United States. This included portions of waterways, their tributaries, territorial seas, and the Great Lakes. The Senate Committee on Public Works report added, "The control strategy of the Act extends to navigable waters. The definition of this term means the navigable waters of the United States, portions thereof, tributaries thereof, and includes the territorial seas and the Great Lakes." The House version, H.R. 11896, was terse, at best, stating that it referred to " . . . the navigable waters of the United States, including the territorial seas." The Conference Committee then deleted the word "navigable" from the House version, stating that the term "navigable waters" was intended to be given the broadest possible constitutional interpretation. The Conference version then defined the term "navigable waters" broadly for water quality purposes: "It means 'all the waters of the United States' in a geographic sense. It does not mean 'navigable waters of the United States' in the technical sense as we sometimes see in some laws."

The Court concluded that navigable waters was to mean what Congress clearly meant it to be: it applied to all water bodies, including streams and their tributaries, for water quality purposes. The old, narrow definitions of navigability, as had been followed by the Corps of Engineers since the Corps founding, was not longer going to govern matters covered by this bill. The Court determined it was compelled to conclude that "the former test of navigability was indeed defined away in the FWPCA. Congress defined 'navigable waters' as 'waters of the United States.' The Court agrees" (Leagle.com 2015).

A Second Jurisdictional Decision

The 1975 *Natural Resources Defense Council, Inc v. Callaway* contributed a second legal decision that would resolve all future questions that the definition of the federal governments' CWA jurisdictional justification was to be based on "waters of the United States" definition for the Constitutional statement of "navigable waters." In this 1975 case, the Natural Resources Defense Council and the State of New York contested the US Corps of Engineer's permit for Navy's plan to discharge highly polluted dredging sludge at sea location where tidal action and currents were likely to spread the pollution. The Corps of Engineers petitioned to deny the case because the waters did not fall under the Army Corps of Engineers traditional navigable waters definition. The court's decision to deny was based on the definition approved by Congress in the *United States v. Holland* case, as explained in the published opinion of the Natural Resources Defense Council case. By defining the term "navigable waters" in the Federal Water Pollution Control Act Amendments, it established the term to mean "the waters of the United States, including the territorial seas." This definition affirmed federal government's jurisdiction over the nation's waters to the maximum extent permissible under the Commerce Clause of the Constitution. Accordingly, as used in the Water Act, the term was not limited to the traditional tests of navigability. The Army Corps of Engineers was, therefore, without authority to amend or change the statutory definition of navigable waters.

As a result of these and other opinions, the EPA determined it had administrative law authority to establish a new rule defining and clarifying what exactly was meant by the phrase "waters of the United States" in the Constitution (Hawkins 2015). The new rule proposed by the EPA was to be a definition that was based on scientifically identified categories of waters. If approved it would expand the scope of waters subject to EPA oversight. A number of commercial firms and non-governmental agencies and associations contested the new definition and asked members of the House of Representatives to introduce a bill declaring the new rule null and void.

Eight classes of water courses were included in the new definition. The first three types were traditional navigable waters, interstate waters, and the territorial seas (i.e., the 12-mile extent of seas extending from the shore of US waters, including its island territories). These are considered jurisdictional by rule in all cases. The fourth water type, impoundments of jurisdictional waters (i.e., water behind dams and relevant reservoirs), is also jurisdictional by rule in all cases. Types five and six, tributaries and adjacent waters, respectively, are jurisdictional by rule because they are confirmed by science to have a significant nexus to traditional navigable waters, intrastate waters, or territorial seas. For all six jurisdictional types, no further analysis is required for determination. The final two types are waters may be found to be jurisdictional only after a case-specific analysis determines they have a significant nexus to traditional navigable or intrastate waters, or to a territorial sea. Five specific types of waters have proven to be subject to additional analysis: prairie potholes, Carolina and Delmarva bays, pocosins (deep, acidic wetlands in Eastern states, mostly in North Carolina), western vernal pools in California (soil depressions in areas where a hard underground layer prevents rainwater from draining downward into the subsoil; when rain fills the pools in the winter and spring, the water collects and remains in the depressions. When the water evaporates away, the pools become completely dry), and Texas coastal prairie wetlands. The rule also includes a number of additional definitions and areas in the 100-year floodplain or otherwise adjacent to traditionally navigable waters are also subject to further analysis.

Bills to deny application of the rule were introduced in the House and Senate. The House voted on January 13, 2016, by a vote of 253 to 166 to overturn the rule. The Senate had approved a similar bill in November of 2015. Supports of the resolution to overturn the new rule were challenging the EPA's proposal under the Congressional Review Act, which allows lawmakers the ability to vote to block regulations at any time during the first 60 days the legislature is in session. They claimed the Obama administration was "seeking to assert federal control over pebbles, ditches, areas that are occasionally wet and other large sections of private or state land in violation of the intent of the clean Water Act" (Cama 2016). Legislators endorsing the new rule defended the change by warning that repealing the rule would result in continued confusion over what waters should be regulated and which should not. The White House added its own support of the rule asserting that "the agency's [EPA] rulemaking, grounded in science and the law, is essential to ensure clean water for future generations, and is responsive to calls for rulemaking from the Congress, industry, and community stakeholders as well as decisions of the US Supreme Court (Cama 2016). Farmers and homebuilders argued that the EPA's new rule was a "broad overreach," and that it was so broad it would "add new bureaucracy to [prohibit], or even prevent, basic tasks such as draining small ponds and constructing basic buildings."

On January 19, 2016, President Obama vetoed Senate Joint Resolution 22 that would have overturned the new jurisdiction rule. The Senate voted to override the veto, but could only rustle up 52 of the 60 necessary votes to avoid a filibuster. The rule remained in effect.

The Public's Role in Resource Sustainability

Many organizations with a mission to support, protect, use, process, conserve, and distribute water exist in the United States. Many, from the United Nations to small church and educational organizations, also support development of clean, safe water in all sections of the Nation. Many of these organizations support lobbying efforts at the Federal and state government levels. They support presidents, legislators, governors, and agency heads that influence water policy. An example is the support for President Barack Obama's re-election given by Clean Water Action, a "one million member organization of diverse people and groups joined together to protect our environment, health, economic well-being and community quality of life." Among other goals, the organization focuses on ensuring clean, safe, and affordable water and preventing pollution that affects public health. They organize grassroots groups, coalitions, and campaigns to elect environmental candidates and solve environmental and community problems. They supported re-election of President Obama with this rational:

> The choice this year is clear. We can either continue moving forward to build a future of clean water and clean jobs, or we can go back forty years to a time when rivers caught on fire and the air in most cities was unhealthy to breathe. Under President Obama's direction, the US Environmental Protection Agency and other federal agencies have successfully advanced a number of forward-looking initiatives. These have allowed the Obama Administration to begin repairing damage done to environmental and health protections [done] under the previous administration and make headway on addressing long neglected priorities. (Clear Water Action 2012)

Water Conflicts Between the States

Water wars between the states are often bitterly fought and may linger for decades. Two such fights have taken place in the American South: one between Alabama, Georgia, and Florida (the Tri-state Water War), and one between North and South Carolina. The Tri-state Water War is over two river basins that are shared between Alabama, Georgia, and Florida: the Apalachicola–Chattahoochee–Flint (ACF) River Basin and the Alabama–Coosa–Tallapoosa (ACT) River Basin. The three states share water from the three river systems for drinking water, power production, agriculture, aquaculture, navigation, and recreation (ARC 2016). The Carolinas water war was over water from the Catawba River Basin.

Tri-state Water Wars

The Tri-state conflict began shortly after World War II when Congress authorized construction of the Buford Dam and creation of Lake Lanier. Lake Lanier is in the ACF Basin on the Chattahoochee River, about 50 miles upstream of Atlanta. Figure 8.1 is the map of the region in the

Fig. 8.1 Southeastern United States and location of the Tri-state Water Wars
Source: USGS

larger Southeastern United States. Some Atlanta-area communities in the ACF Basin withdraw water from the reservoir behind the lake. Other communities withdraw water released from the reservoir into the Chattahoochee River below the reservoir. A second dam, the Morgan Falls Dam, was constructed on the river downstream of the Buford Dam, creating Altoona Lake.

During the 1980s, the State of George, the Atlanta regional Commission, the Corps, the EPA, and others collaborated on a study to determine how Atlanta communities should meet their future water needs. The result was that the most cost-effective source, for communities in the Atlanta metropolitan area (metro Atlanta), was water from the two Chattahoochee lakes.

The three-state legal battle began in 1990 when the State of Alabama sued the Army Corps of Engineers to prevent it from implementing a

Corps-produced plan allowing metro Atlanta communities to buy storage space for water behind the dams. The suit was dropped in 1992 when the three states and the Corps agreed on more research, and allowing Metro communities to continue drawing what water they needed from the two lakes and to increase the amounts to meet reasonable increases in demand while the study was underway. The study was never completed, but it did result in ratification of interstate compacts for each basin in 1997. The compacts allowed metro communities to continue with the 1992 water withdrawals. The states failed to agree on ACF allotment quotas in 2003 and on ACT quotas in 2004.

Any hope for a final agreement between the three states ended in 2009 when the US District Court ruled that metro Atlanta was not authorized to withdraw any water from Lake Lanier. The Court then gave the three states three years to negotiate a deal and get congressional approval on a compromise that would allow metro Atlanta to continue to withdraw a specified amount of water from the lake. If an agreement was not reached, the Corps was to begin releasing water from Buford Dam at quantities released in the 1970s (SELC 2009): the message was come to an agreement or nobody wins and everybody loses.

After many more attempts, agreement was finally reached in 2011 and 2012. In 2010, a Federal court rejected Florida's claims that the Corps operations on the ACT violated the Endangered Species Act, and Florida decided not to appeal. In 2011, the US Court of Appeals released two findings: (1) it dismissed a case brought by Alabama, Florida, and others against actions by the Corps on Lake Lanier and (2) it ruled that Congress had specifically authorized the Corps to provide water from Lake Lanier to meet Atlanta's water supply needs when it authorized construction of the Dam. The US Supreme Court upheld this decision.

Water Conflict in the Carolinas

A bitter fight between North and South Carolina over water from the Catawba River and its basin was finally settled in July of 2011 without the help of the US Supreme Court (Walton 2011). If water use, water demand, or drought conditions change significantly from the conditions under which this deal was negotiated the agreement remains open for future lawsuits. In 2008, *American Rivers* named the Catawba the most endangered river in the United States.

The conflict centered on water diversions from the Catawba Basin by North Carolina, where millions of gallons of water are withdrawn each day for residential and industrial uses; more than 30 cities, 17 counties, and more than one million people depend on the river for drinking water. Energy and manufacturing industries use the river water for power generation and cooling. Several coal, nuclear, and hydroelectric power plants are located along the river.

The 300-mile Catawba River starts in the Blue Ridge Mountains of North Carolina and turns into the Wateree River in South Carolina, eventually emptying into the Atlantic Ocean. It serves as a ten-mile natural border for the Carolinas. The agreement includes updating a river basin water supply study every ten years.

Managing International Water Conflicts

The US State Department has responsibility for negotiating the nation's water agreements with Canada and Mexico. The department also takes an active role in international efforts to address critical water needs in developing nations. One way it does this is to include water needs into the nation's global food, security, health, and climate change programs. The official State Department brief includes this statement of intent:

> Water is a global issue that requires the attention of local, national and regional public, private and civil society actors. Our aim is to strengthen the institutional and human capacity of nations to efficiently and effectively access and manage water. To this end, US government agencies, including the Millennium Challenge Corporation (MCC) and USAID, are collaborating with international partners to help countries in need create national plans for water and sanitation. . . . In addition, the United States contributes to and partners with many international organizations that support water, sanitation and health . . . projects around the world. (US State Department 2011)

Water-Related Cross-Border Agreements

Water-related cross-border agreements are an important element in the Nation's relations with its north and south neighbors of the United States. These agreements are shaped by the patterns of assumptions and cultural beliefs that underlie and shape the country's relations with our neighbors and friends to the north and the south.

For most of the country's history, water-related agreements with foreign nations were concerned with efforts to acquire and maintain rights to transportation on our major waterways, many of which also extended into other sovereign territories. We were particularly interested in free access to transborder waterways. Gaining free navigation rights on the Mississippi River from Spain in colonial times was an important issue in the growth of the new nation. The history of Florida from the Georgia–Florida coast to the Mississippi River formed part of the pre-revolutionary war diplomacy between European powers, the United States and Spain and the American Indians of the area. The Mississippi River Valley and its adjacent territories became a focal point in the late eighteenth century for control of the areas west of the Appalachian Mountains. The Mississippi made it possible for farmers in the new land being settled west of the Appalachians to transport their products to market.

The United States and Spain eventually signed the Treaty of San Lorenzo (Pinckney's Treaty) in October of 1789, setting the boundary between the United States and Spanish Florida. Spain gave up a large area, including Natchez and key forts along the Mississippi River. More importantly, the treaty granted the United States free navigation of the river all the way to the Caribbean. Ensuring this right against any future obstruction by France or Great Britain to the Mississippi and the Port of New Orleans was one of the reasons for the Louisiana Purchase from France in 1803. For $11,250,000 and a cancellation of debts worth $3,750,000, for a total of $15,000,000, the Mississippi was in the hands of the United States for its entire length and what would soon become the more than a dozen new states.

A Long History of Conflict

The world has had a long history of international disagreements over access to water. In 1998 article in the *Colorado Journal of International Environmental Law and Policy*, researchers made reference to approximately 261 international watersheds in which US international relations are involved. The transboundary tensions that have had to be resolved by international treaty here in North America are as old as modern civilization. Thankfully, negotiations over water have almost always ended in peaceful agreements; the only known record of a water related war between states took place some 4,500 ago. United Nations researchers had determined that cooperative political agreements between states over water issues have resulted in 3,600 peaceful water-related treaties since AD 805, compared with just seven small wars, and that the seven also included other non-water issues (Hammer and Wolf 1998). The foreign policy aspects of a nation's water policies are shaped by its relations with its neighboring nations. Transboundary water treaties that the United States has negotiated have involved solutions to our water-use problems with Canada and Mexico.

Water Agreements with Canada

The oldest and most important water agreement between the United States and Canada is the *Boundary Waters Treaty of 1909*. The treaty set principles for the use, obstruction and diversion of boundary and transboundary waters; it is administered by an International Joint Commission. Today, more than 30 international water boards exist between Canada and the United States.

The United States negotiated formal treaties first with Britain and then with the new Canadian nation regarding joint use of the Great Lakes, the Saint Lawrence Seaway and a number smaller transboundary water courses. The origins of the Canada Boundary Waters Treaty go back to the 1890s, when the United States and Canada had difficulties in agreeing upon sharing irrigation waters from the St. Mary and Milk

Rivers in Montana and Canada, and several other rivers around the Great Lakes, including the Niagara River. Canada and the United States began their water agreement negotiations in 1902, but it was not until January of 1909 that the United States and Canada signed the Boundary Waters Treaty governing waterways shared across their common border. The treaty established an international joint commission to rule on issues involving irrigation, pollution, and dams on those waterways. The treaty did not specifically deal with Northwest waterways including the major regional transboundary waterways, but it eventually did have implications for the Columbia, the Snake and other of its tributaries. The joint commission later held hearings involving Columbia River pollution and the impact of the Grand Coulee Dam in Central Washington.

At least six major water quality joint programs have been added to the Boundary Waters agreement. In April of 1972, the two countries signed the Great lakes Water Quality Agreement. This agreement's major focus was to be controlling point-source pollution from industrial and sewage treatment facilities on both sides of the border. A second Great Lakes Water quality Agreement was signed in 1978, in which the two countries agreed to work toward restoration and subsequent maintenance of the chemical, physical, and biological integrity of the Great lakes basin ecosystem. An amendment in 1983 added phosphorous reduction to the list of pollution reduction goals and set targets for its reduction in Lake Erie and Lake Ontario, the easternmost of the Great Lakes. The scope of the treaty agreement was expanded in 1987 by the addition of air-borne pollutants and remedial action plans for cleaning up "toxic hotspots in the Lakes basin."

A series of public meetings in the Great lakes and St. Lawrence River basin were held in Canada and the United States to develop a set of issues, questions, and suggestions for both governments to consider as they begin renegotiating the Agreement. In 2009, the US Secretary of State and the Canadian Foreign Affairs Minister announced that the two countries agreed to produce an updated water quality agreement. Lake Erie was essential dead due to acidification and other pollutants. In 2000, it was found that the algae growing in the western half of the lake contained high concentrations of the toxin microcystin. As a result, the foul-smelling, rotting, algal mats, washed up shorelines and forced regional communities and water utilities to issue warnings to swimmers and tell residents their tap water had to be boiled. Beaches and recreational boating areas were rendered unusable and sport fishing was eliminated. A bilateral announcement of the completion of a new Great Lakes Water Quality Agreement was announced in 2012. The new agreement paid particular attention to controlling pollution of the Lakes caused by agricultural chemicals. A series of algae blooms in Lake Erie have been attributed to agricultural nutrient runoffs from both countries.

The Obama Administration created the Great Lakes Restoration Initiative and invested more than $1 billion to restore the Great Lakes ecosystem, the most significant investment in Great Lakes restoration in decades. Led by EPA, the initiative has removed more than 1 million cubic yards of contaminated sediment and protected or restored more than 20,000 acres of essential habitat. The federal government is committed to dozens of additional actions that will restore this vital freshwater ecosystem, including targeting, preventing, and controlling invasive species; restoring habitat; and reducing nutrient runoff that contributes to harmful algal blooms.

Water research cooperation between the United States and Canada became significantly easier in early 2014. Researchers at the US Geological Survey (USGS) announced that the United States and Canada merged hydrological maps covering water basins across the border between the two countries. The drainage systems on both sides can now be analyzed in greater detail than ever (Vieru 2014). The new system makes it easier to better track the levels of phosphorous flowing from Lake Champlain in Vermont into Quebec, something that would have been very difficult to do with two different hydrological maps. The USGS has been preparing digital hydrological maps of the United States for the past 20 years. For the border region, USGS partnered with Natural Resources Canada (NRCan) for the watershed map project. Figure 8.2 shows the US eight-digit identifying watersheds system and the five-digit Canadian watershed system north of the border, including the joint watersheds along both sides of the border.

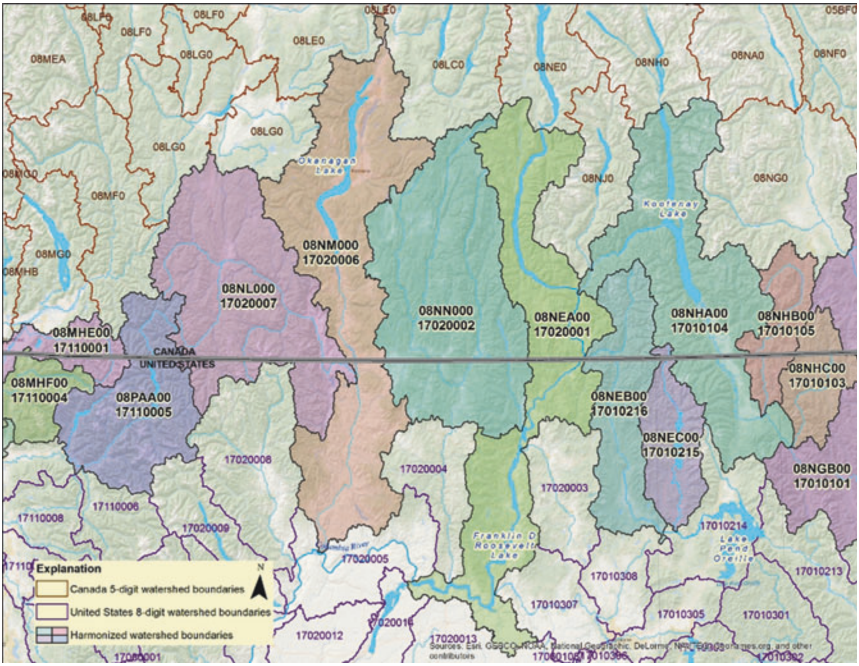

Fig. 8.2 US and Canada joint border watershed districts west of the Great Lakes
Source: USGS

Water Agreements with Mexico

The United States also has formal treaties with Mexico regarding the water of several transboundary rivers. The US–Mexico Water Treaty of 1944 concerned sharing the waters of the Colorado, Tijuana, and of the Rio Grande (Rio Bravo) rivers, for example. The treaty expanded the existing International Boundary Commission (established in 1889) to the International Boundary and Water Commission (IBWC), and gave it full responsibility for carrying out the treaty and making sure both countries met all stipulations and responsibilities spelled out in the treaty. The map in Fig. 8.3 shows the region covered by the agreement. The commission was authorized to conduct studies on the capacity for

Fig. 8.3 Map of the US—Mexico water agreement on the Rio Grande River region

Source: International Boundary and Water Commission (2002)

flood control and hydroelectric power generation in the region, to make recommendations with regards to the joint management of Tijuana River, and to set allocations for the rivers' waters. It also established a payment plan for Mexico to reimburse the United States for constructing and maintaining improvements that benefited the water supplies of Mexico.

The two countries have often been in dispute over who was following the agreements of the treaty and who was not. For example, in 2013 the US Senate demanded that Mexico comply with that portion of the treaty that dictates how Mexico provides the US surface water from six Mexican tributaries that feed into the Rio Grande. In exchange, the United States delivers water from the Colorado River to Mexico. Mexico was required to deliver to the US 1.75 million acre-feet of water every five years, which means 350,000 acre-feet annually unless "extreme drought" conditions in Mexico make the delivery impossible. The treaty allots to each country one-half of the water in the Rio Grande from tributaries not identified in the 1944 treaty. Often called "50/50 water," this portion of the Rio Grande consists primarily of unmeasured stormwater runoff entering the river from arroyos and creeks during periods of significant rainfall. The Texas Commission on Environmental Quality charged that Mexico owed the US Rio Grande Valley region more than 470,000 acre-feet of water, and has done so since failing to meet its treaty requirements since 1992. In 2002, water from the Rio Grande not reached the Gulf of Mexico while Mexico's water storage in its portion of the international reservoirs had dropped to less than 10 percent of capacity (Phillips 2002).

Managing the Colorado River

Mexico is also guaranteed water from the Colorado River, which begins in Colorado's Rocky Mountains and empties 1,500 miles later into the Gulf of California (Sea of Cortez). Before extensive damming of the river that began in the 1920s, at its mouth the Colorado fed one of the largest desert estuaries in the world at the northern end of the Gulf of California. The Colorado River delta's tidal wetlands once covered nearly two million acres and supported a large and diverse population of plant, bird, aquatic, and terrestrial life. Today little water enters the Gulf and the wetlands and the wildlife have disappeared.

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River." These laws and agreements apportion the water and regulate the use and management of the Colorado River among the seven US basin states and Mexico. Based on this body of law, Arizona has the right to use 2.8 million acre-feet of the Colorado River water annually (ADWR 2015).

The water treaty between the United States and Mexico that involved waters of the Colorado River and the Rio Grande and Tijuana Rivers became effective November 8, 1945. Mexico was allocated 1.5 million acre-feet of Colorado River system waters annually, to be increased in wet years to 1.7 million acre-feet and reduced proportionately during years of drought. The treaty dealt with overall Colorado River water quantity but did not specifically address the quality of water eventually delivered to Mexico. In 1962, the Mexican government formally protested to the United States regarding the quality of Colorado River water that was reaching the Mexicali Valley. A series of meetings and negotiations led to the adoption of Minute 242, executed in 1973, which obligated the United States to ensure the salinity of the delivered waters delivered to Mexico remained at nearly the same quality as that diverted for use within the United States.

The Salinity Control Act of 1974 included a brine discharge canal and a desalination plant for the conveyance and treatment of US irrigation and drainage water entering and further polluting the river before it is again withdrawn for irrigation in Mexico. This enabled the United States to deliver water to Mexico having an average salinity of 115 parts per million (ppm) plus or minus 30 ppm over the annual average salinity of the Colorado River. The treaty also authorized construction of 4 salinity control units and the expedited planning of 12 other salinity control projects as part of the basin wide salinity control plan. In 1978, the Colorado River Basin Salinity Control Forum reviewed the salinity standards and recommended continued construction of water treatment units identified in the 1974 Act, established effluent limitations for industrial and municipal discharges, and reduced salinity of irrigation return flows. The review also called for the inclusion of water quality management plans to comply with section 208 provisions of the CWA.

Primary responsibility for the US government's program was given to the Secretary of the Interior. The Secretary of Agriculture was instructed to support the effort within existing authorities. The Act was amended in 1984 to authorize two additional units for construction by Reclamation and directed the Bureau of land management (BLM) to implement a comprehensive program to minimize salinity in the Colorado River Basin. In 1996, the Secretary of Agriculture was directed to carry out salinity control measures in the Colorado River Basin as part of the Environmental Quality Incentives Program established under the Food Security Act of 1985, and authorized the Secretary of Agriculture to switch from only a loan to federal-state cost sharing for salinity control activities.

An amendment to the 1944 water treaty between the United States and Mexico was reached in 2013. The amendment (Minute 319) attempts to solve the long smoldering dispute over water between the two countries. However, the over-allocation of the river's waters in the 1920s, along with the growing populations in the river basin have made it too late to eliminate the water deficit that the Colorado River Basin is facing now and what will certainly become even more of a problem in the years of climate change to come.

Rio Grande River Water Agreements

The 1944 Treaty of Peace, Friendship and limits of 1848 regulated the use of both the Colorado and Rio Grande rivers for navigation only, reflecting the long history of water policy focus.

However, by the middle of the twentieth century and large demands on the rivers, it was apparent to both countries that a new treaty regulating other uses of the rivers and their tributaries. A treaty was negotiated while the United States, eager to retain Mexico's benign friendship, was still engaged in fighting the two-front World War II in Europe and the Pacific; the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande Treaty between Mexico and the United States signed in February of 1944 established the priorities for uses of the rivers that were to be followed by both countries; allocated the waters of these rivers and their tributaries between the two countries, established the IBWC to monitor and report on any disagreements or failures to adhere to the agreed upon allotments, and identified plans for joint participation on all future dam and other improvements on the rivers. This treaty placed clearly indicated that navigation on the rivers was no longer the most important feature in the country's water policy. The use priorities to be followed were: (1) domestic and municipal uses, (2) agriculture and stockraising, (3) electric power, (4) other industrial uses, (5) navigation, (6) fishing and hunting, and (7) any other beneficial uses that might be determined by the Commission.

Portions of the Rio Grande waters allotted to Mexico included all of the water reaching the main channel of the Rio Grande (the Rio Bravo in Mexico) from the San Juan and Alamo Rivers, including the return flow from the lands irrigated from the two rivers; one-half of the flow in the main channel of the Rio Grande below the lowest major international storage dam; two-thirds of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, and Salado Rivers and the Las Vacas Arroyo; and one-half of all other flows not otherwise allotted in the main channel of the Rio Grande.

Shares of the Rio Grande allotted to the United States included all of the waters reaching the main channel of the Rio Grande from the Pecos and Devils Rivers, Goodenough Spring, and Alamito, Terlingua, San Felipe, and Pinto Creeks; one-half of the flow in the main channel of the Rio Grande (Rio Bravo) below the lowest major international storage dam; one-third of the flow reaching the main channel of the Rio Grande from the Conchos, San Diego, San Rodrigo, Escondido, and Salado Rivers and the Las Vacas Arroyo, provided that this third shall not be less, as an average amount in cycles of five consecutive years, than 350,000 acre-feet (431,721,000 cubic meters) annually. The United States agreed to not acquire any right by the use of the waters of the tributaries in excess of the 350,000 acre-feet annually, except the right to use one-third of the flow reaching the Rio Grande from said tributaries, one-half of all other flows not otherwise allotted by this article occurring in the main channel of the Rio Grande, including the contributions from all the unmeasured tributaries not named in this article, between Fort Quitman and the lowest major international storage dam.

The agreement allotting Rio Grande river water worked more or less to both nations' satisfaction until the extended drought across all of the areas included in the treaty. The Bureau of Reclamation of the Department of the Interior, which is responsible for managing the allocations and distributing water to its various users, published of the impact the drought has had on the river that are described in Box 8.1.

Box 8.1 How drought and overuse affects the Rio Grande between Texas and Mexico

The Rio Grande forms the world's longest river border between two countries as it flows between Texas and Mexico. The river runs through three states in the United States, beginning in southern Colorado and flowing through New Mexico and Texas before it forms the border with Mexico. Most of the river is controlled and passes through several dam and reservoir systems during its 1,896-mile journey to the Gulf of Mexico. The river is managed through a complex system of compacts, treaties, and agreements that determine when and how much water is released along the river's length.

The amount and timing of water releases have varied in recent years due to drought. Recent USGS research have shown a decline in the amount of salt carried by the river due to a decrease of releases during the drought. Successfully managing water use along the river is important to the sustainability of agricultural and communities along the river. For the past several years, drought conditions contributed to decreasing flows along this 64-mile stretch, and sections of the river were dry during parts of the year.

Flow in the Rio Grande is affected by how water is used throughout the basin. For instance, the Albuquerque area of New Mexico has two principal sources of water: groundwater from the underlying aquifer system and withdrawals and diversions from the Rio Grande. From 1960 to 2002, pumping from the aquifer system caused groundwater levels to decline from about 40 feet along the Rio Grande in Albuquerque to more than 120 feet in the valley away from the river.

Source: USGS (2016)

Summary

Management of the Nation's water resource involves the interaction of many different stakeholders, many with conflicting goals and objectives for water in its many different forms. Resolving the conflicts that regularly surface between these various stakeholders is an essential task in water management. Achieving harmony between conflicting groups is made more difficult because final authority over the resource lies in the portfolios of many different federal, state, and local agencies, divided between the three branches of government, and is shared among the public and private sectors. An example over the fight for final authority over a range of water sources took place when the Senate, the EPA, the Corps of Engineers, the states, and local governments and water users fought over the right to regulate water sources not previously considered to be navigable waters. The fight had to be resolved by the US Supreme Court. The EPA does have authority to halt economic development in all wetlands. Additional court battles have been fought over regulations for controlling point source water pollution, mining and dredging.

Water wars between the states are more common than might be expected. Two such conflicts were described in this chapter: the Tri-state Water War between Alabama, Georgia, and Florida, and one between North and South Carolina. Water conflicts over water from the Colorado River system have resulted in this resource being over-allocated, further contributing to disagreements.

Water conflicts have also arisen between the United States. and its neighboring nations. Conflicts over access to and the right of navigation on the Great Lakes and St. Lawrence River began early in the history of the United States. How those conflicts and similar competing claims were settled show that international agreements over water can be successfully negotiated. Similar conflicts with Mexico over Colorado River and other Southwestern US rivers remain a concern and periodically become contentious.

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9

Retail Water Management

When water users across the United States are asked where their water comes from, after pointing to the tap, they are most likely to reply "from the utility." This is because they pay their water bills to a retail water utility and the local utility is where they turn to when they have a problem with their water supply. The local utility is the last stop on a long and often complex chain of organizations that make up the water industry. It is no secret that today many of these local utilities find themselves having to find ways of coping with a long list of common problems. These range from rising operating costs, negative customer reaction to rising rates, aging infrastructure, increasingly stringent regulatory requirements, population growth and changes, shifts in the nation's precipitation patterns associated with climate change, and a rapidly changing workforce. This chapter highlights some of these challenges and looks at how they affect utility's retail operations.

The water industry is divided into two categories of operations: wholesale and retail. Wholesale services include the physical collection, treating, storage, transporting, and delivery of water from a source to the operational boundaries of a retail water utility. Wholesale water is delivered in large quantities, often by open-air conduits and large

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diameter pipes to either a storage facility or a receiving network of retailer's mains. Retailers then carry the water to residential, industrial, commercial, or agricultural customers' property boundaries or to other storage locations, including aquifer recharge storage. In addition to installing, repairing, and replacing water mains and laterals to customers' systems, retail utilities' services to customers include all customer-contact activities: billing, account handling (payments, debt management, meter reading), customer queries, as well as water-efficiency advice and tackling leaks on customers' pipes. As Great Britain's Thames Water service explained, "All this activity requires fixed infrastructure (or assets)—pipes and treatment [facilities]—that cannot be 'contestable' (open to competition). Water and sewage pipe networks therefore remain natural monopolies within existing companies' regions" (Thames Water 2015).

History of US Water supply

Most Americans get their water from a publicly or privately owned and operated water supplier. Small suppliers typically water suppliers get their water from their own wells, although a few draw their water directly from rivers, creeks, or lakes. Suppliers of water with more than 25 customers must abide by the same standards of quality spelled out in government and state rules and regulations.

The removal of harmful metals and disinfection of water by distribution organizations has long played, and continues to play, a critical role in improving drinking water quality in the United States. Jersey City, New Jersey, was the first city in the United States to begin routine disinfection of community drinking water when it began disinfecting its water in 1908. Thousands of cities and towns across the United States followed suit in routinely disinfecting their drinking water, contributing to a dramatic decrease in disease across the country.

City and town dwellers' greatest needs in the first two-thirds of the nineteenth century were for systems for the provision of adequate supplies of clean water, together with a means of dealing with sewage. Inadequate supply of water and wastewater control needs was a major cause of sickness and death in the crowded, unsanitary cities. Well into the 1800s, town dwellers drew their water from shallow wells and discharged their raw sewage into creeks and rivers. The number of civic water systems grew slowly but steadily between 1800 and 1900. At the beginning of the nineteenth century, there were only 16 water systems in cities with a population of 5,000 or more; smaller cities still had to make do without running water. Only one of these was municipally owned; private investors owned 15. Twenty-five years later, the total number of water systems had only doubled to 32; 5 were municipal systems and 27 were private systems. More rapid growth in the number of systems had to wait until after the end of the Civil War. From the 83 systems that existed in 1850, the number grew to a total of 422 in 1875 and to 3,179 systems in 1896. The shift to municipal ownership was seen in 1875, when nearly 54 percent were public systems. The proportion declined a small amount in 1896: 1,690 or 53.2 percent were public systems.

Ever since those early successes, suppliers have successfully disinfect their water supply and remove harmful metals and other pollutants, and then deliver pure, freshwater to our homes, schools, offices, and industries. And, since the birth of the Environmental Protection Agency (EPA), water quality treatment has continued to be more effective. When we pay the supplier for the service, what we are mostly paying for the expensive filtration systems, the miles of pipes, treatment chemicals, and labor the deliverer has had to purchase, install, and maintain, without which we would not get safe water when we turn on the tap. The US water delivery system has worked well for years and water consumers get what they pay for. Still, many things can and often do go wrong in complex systems like these, and suppliers must forever be prepared to quickly repair a failure in the system. The problem is that much of the infrastructure necessary to treat and deliver that safe water has reached the end of its useful life and must be replaced.

The main purpose of a public water distribution system is to deliver safe water of the best possible quality, quantity, and continuity to consumers. When something in the system fails to do what it is supposed to do, procedures that have been developed by federal regulators to quickly respond to the emergency are usually quickly put into place. The failure can be traced to a structural failure, to internal or external source contamination, hydraulic failures, chemical treatment errors, unexpected source water quality failures, vandalism, management oversight, or, increasingly, simple the failure of a critical component in the systems aging infrastructure. Several examples of relatively recent breakdowns in the system follow.

In 2014, there were approximately 156,000 public water systems subject to regulations administered by the US EPA. The potential for failures in these thousands of water treatment and deliver systems is, therefore, greater than can be imagined. Infrastructure failures and other breakdowns in the system can happen at any time to all these systems. The three types of public water systems are community water systems (CWS), non-transient non-community water system, and transient non-community water system (TNCWS). Most of these systems are not standard community systems; in 2015, the EPA identified 103,583 systems as being either one or the two types of non-community systems. Community systems are typically municipal operations or function as special districts with elected commissioners. Close to 15 percent of US residents get their water from their own wells, although this number is declining as the country continues to urbanize. User of these well types are not required to disinfect or otherwise treat the well water they draw for human use; private well owners are responsible for testing their own wells to be sure their well water is safe to drink. However, the EPA does recommend well users monitor or treat private well drinking water.

Public-Supply Systems

The nation's public water system sector consists of two main sectors: the systems that distribute water to homes, institutions, and businesses where it is needed, and the general services organizations that provide engineering, management, and operations services to utilities and other suppliers. The majority of systems in the utilities sector are owned and operated by local governments or special districts and are referred to as public-supply systems. They account for approximately 84 percent of all CWSs. All public water systems are heavily regulated, both for sanitation and for environmental impact. Implementation of their activities is

Table 9.1 Top ten public supply water withdrawals and deliveries (million gallons per day)

	Public supply withdrawals by source public supply deliveries						
State	Population served (%)	Ground water	Surface water	Total	Domestic use	%	All others
California	93	2,830	3,470	6,300	3,870	61	2,430
Texas	90	1,130	2,860	3,990	2,050	51	1,940
New York	89	457	1,810	2,260	1,370	61	889
Pennsylvania	74	226	1,200	1,420	548	38	877
Illinois	91	367	1,140	1,500	934	62	571
Ohio	84	455	918	1,370	619	45	755
Arizona	97	585	628	1,210	912	75	301
Georgia	84	243	873	1,120	651	58	465
Michigan	73	204	883	1,090	548	50	540
New Jersey	89	198	682	1,080	605	56	475

Source: USGS (2014)

therefore guided by both federal state water policies. There activities begin with finding and exploiting a safe source of water. That source may be groundwater or surface water, or a combination of both.

Approximately 42,000 million gallons (Table 9.1) of water are withdrawn each day from ground and surface waters for public supply. This represents about 14 percent of total freshwater withdrawals and 22 percent of all withdrawals excluding thermoelectric power. In some States, public-supply water sources include desalinated seawater or brackish groundwater that has been treated to reduce dissolved solids.

Water to be distributed to end users is acquired from groundwater or surface water, or a combination of the two. Small CWSs commonly get their water from groundwater sources, whereas large systems obtain most of their water from surface sources such as streams or lakes. Delivery organizations must then transport the raw water from the source to a treatment facility via pipe or open canals. The water is moved by pump or gravity, or a combination of the two. Untreated water is often stored in reservoirs or lakes, which are may be in remote areas such as mountain ranges or facilities constructed in urban areas. For example, portions of the Southern California water supply is collected and stored as far away as Northern California and transported via a 444-mile long open canal through California's Central Valley, then via pipeline, to the Tehachapi Mountains where it splits into two branches: the West Branch and the East or maintstem Branch. At the end of the West Branch is Castaic Lake and Castaic Lagoon; at the end of the East Branch is Lake Perris, the southernmost facility of the California State Water Project. The water in the lakes is then stored until needed.

Public-supply distribution organizations then take ownership of the water and begin treatment to bring it to EPA and public health agency standards. Treated water is delivered to residential, commercial, and industrial users through a network of pipes, tanks, pumps, and valves. Water flow through the system is mechanically adjusted to ensure that the proper amounts and appropriate pressure are maintained. Failure can occur at any time at every stage of the distribution system.

More than 268 million people or an estimated 86 percent of the total population rely on public-supply water for their household use. They get that water from both ground and surface water sources. The USGS's 2014 report of water use in the United States included the following statistics about public-supply water withdrawals:

- 35 percent of all public-supply withdrawals were in the four States with the largest populations: California, Texas, New York, and Florida.
- 63 percent of water withdrawn for public supply in 2010 was from surface sources, such as lakes and streams.
- 37 percent of water withdrawn was from groundwater.
- Five States—California, Texas, New York, Pennsylvania, and Illinois—each withdrew more than 1,000 Mgal/d of surface water for public supply in 2010 and accounted for 40 percent of the total surface water withdrawals for public supply.
- In 36 States, including Puerto Rico and the US Virgin Islands, surface water sources provided more than half of the total public-supply withdrawals.
- Three States—California, Florida, and Texas—each withdrew more than 1,000 Mgal/d of groundwater for public supply in 2010 and accounted for 38 percent of total groundwater withdrawals for public supply.
- States that relied on groundwater for 75 percent or more of their public-supply withdrawals were Hawaii, Florida, Idaho, Mississippi, Nebraska, and Iowa.

Most of the public-supply withdrawals are delivered to customers for domestic, commercial, and industrial needs. Part of the total may also be used for public services, such as public pools, parks, firefighting, water and wastewater treatment, and municipal buildings, and some is unaccounted for because of leaks, pipeline and fire hydrant flushing, tower maintenance, and other system losses. Domestic deliveries represent the largest single component of public-supply withdrawals, averaging 57 percent of the total nationally.

Except for a few states and possessions, the water and wastewater delivery system has remained in the hands of non-profit, single-community, municipal and regional district systems. However, there is a distinct movement away from the public model toward a private governance model, much as is now the dominant model in Great Britain. The share of water delivered by private-supply organizations ranges from a high of 100 percent in the District of Columbia to 63 percent in Alaska. States with the highest and lowest shares of the water delivery in public hands are shown in Table 9.2. The difficulty of raising the large sums of cash necessary to provide service and replace aging infrastructure at the same time has resulted in a number of communities that have privatized all or portions of these operations. "Build and operate" contracts with commercial enterprises are also increasingly common. While this has provided some reductions in municipal

Table 9.2 Highest and lowest states with public-supply water delivery (percent)

States with greatest public-supply share		States with lowest public-supply share	
Arizona	97	Alaska	63
Arkansas	95	Idaho	72
California	93	Indiana	74
Colorado	94	Maine	58
Hawaii	96	Montana	71
Kansas	95	New Hampshire	66
Massachusetts	92	North Carolina	65
Nevada	94	Pennsylvania	74
North Dakota	93	South Carolina	75
Oklahoma	92	Vermont	71
Utah	98	Wisconsin	71

Source: USGS (2014)

payrolls, it has not greatly reduced the number and types of organizations or agencies in the industry. Municipal and district water treatment and service providers, agricultural water suppliers, federal and state agencies and departments, wastewater collection and processing operations, and private have been joined by private contractors in meeting this essential need.

Small and rural water and combined water and wastewater sectors of the public utilities industry are operating under a cloud of a complex, restrictive, and challenging future without the resources to take on all the problems they must deal with. They are stretching their available resources for meeting these challenges to the breaking point. Meeting government-mandated health, efficiency, and other factor requirements add to the small systems' difficulty in maintaining their service commitments. To meet their mandate of serving their publics, managers, and operators of these small and rural utilities struggle to keep up-to-date on the issues and trends that affect all aspects of their operations. They must innovate in order to survive.

Table 9.3 is a partial list of the many associations and groups that seek to influence water system rules and regulations. Regulatory agencies get their authority to issue regulations from laws (statutes) enacted by Congress or in some cases, agencies my function under delegated presidential authority.

Supply System Breakdowns

A water supply system or network is a system of water source, treatment distribution components that move water from where it is collected and treated to locations where it is needed and used. A water supply system typically includes a source (ground or surface water), a water purification facility, storage facilities, pumping stations, and pipe (or canal) networks, and a facility for collection system and treatment facility for processing wastewater. The system may include more than one supply source and more than one water distribution

Table 9.3 Partial list of water and wastewater associations in the United States and Canada

Agribusiness Council of America (AGA)	Water Environment Federation (WEF)
Air & Waste Management Association (AWMA)	Water Reuse Association (WRA)
American Public Works Association (APWA)	Water Industry Association (WAI)
American Society of Civil Engineers (ASCE)	Water Quality Association (WQA)
American Water Resources Association (AWRA)	Water Sports Industry Association (WSIA)
American Water Works Association (AWWA)	Waster Systems Council (WSC)
Association of Metropolitan Water Agencies (AMWA)	Water and Wastewater Equipment Manufacturers Association (WWEMA)
Association of Water Technologies (AWT)	**Regional Water Quality Associations**:
Canadian Water and Wastewater Association (CWWA)	Eastern Water Quality Association (EWQA)
Future Water Association (FWA)	Florida Water Quality Association (FWQA)
International Bottled Water Association (IBWA)	Missouri Water Quality Association (MWQA)
Irrigation Association (IA)	Pacific Water Quality Association (PWQA)
Mid-America Bottled Water Association (MABWA)	Texas Water Quality Association (TWQA)
National Association of Water Companies (NAWC)	**Regional Bottled Water Associations**
National Ground Water Association (NGWA)	Northeastern Bottled Water Association (NEBWA)
National Hydropower Association (NHA)	Southeastern Bottled Water Association (SEBWA)
National Onsite Wastewater Recycling Association (NOWRA)	Mid-America Bottled Water Association (MABWA)
National Rural Water Association (NRWA)	Central States Bottled Water Association (CSBWA)
National Association of Water Companies (NAWC)	Northwestern Bottled Water Association (NWBWA)
National Parks Conservation Association (NPCA)	Canadian Bottled Water Association (CBWA)

system. A failure can occur at any time and any location in a water supply system.

The US Conference of Mayors—leaders in the locations where most of the industry's infrastructure problems occur—described costs of repairing failing water systems problems they face a symptom of the aging water infrastructure. There were 300,000 water main breaks in North America in 2010 caused by widespread corrosion problems adding up to a $50.7 billion annual drain on the U.S. economy. Leaking pipes are also losing an estimated 2.6 trillion gallons of treated drinking water annually (17 percent of all pumped water in the United States), representing $4.1 billion in wasted electricity every year.

An example of a failure outside of the system is the May 1, 2010, failure that occurred outside of the Boston, Massachusetts delivery system. The break occurred in a ten-foot diameter water main outside of Boston. The break left two million Boston area customers without water for two days. The break was caused by human error: the wrong-sized bolts were used in the coupling to hold segments of the main together. Water pressure was too great and the bolts failed.

The break disrupted the connection between two water supply tunnels. With the water supply cutoff, the emergency water supply reserve system from surrounding ponds was routed to the main water supply. However, that emergency supply was a potential hazard for approximately two million residents of 31 cities and towns, including Boston. At the height of the rupture, approximately 8 million gallons of water was lost each hour. The spill was stopped the next day and repairs were begun on the pipe and clean-up started. A boil-water order was ordered because the backup reservoirs were untreated and unmonitored; similar situations elsewhere had resulted in bacterial contamination bad enough to cause sickness in otherwise healthy adults.

No health effects for vulnerable classes, such as infants, pregnant women, or those with a compromised immune system, were reported in secondary sources during this event.

The investigation that followed the incident found that the break was caused by failure of the coupling bolts. Inspection of recovered bolts and bolt fragments found that the bolts were poorly manufactured and sized incorrectly for the load. This type of failure could possibly be avoided with implementation of an asset management and purchasing system (Matichich et al. 2014).

Lead in the System

The US Center for Disease Control and Prevention asserts that American drinking water supplies are among the safest in the world. However, once in a while the system will break down. In one recent example, the failure was traced to caustic chemicals in the supply that caused lead to be leached from pipe in the delivery system. The community supplier failed to correct its mistake as mandated by federal and state the purity monitoring institutions. The damage was the result of an inexcusable refusal by the systems management to respond to the danger to its consumers and by the failure of water quality regulators to require a correction to the system. The cheaper water that Flint, Michigan's water supplier had found turned out to be highly corrosive. The river water that was drawn for domestic supply in 2013 and 2014 turned out to be extremely harmful to humans, and particularly so to children. While disinfection of the Flint water had effectively removed danger from harmful bacteria such as *Escherichia. coli*, it could not halt the corrosion taking place in the systems old distribution pipes. The caustic cheaper water ate away the water pipe, releasing harmful quantities lead into the drinking water. The problem was the apparent unwillingness of the water supply distribution utility administration to heed warnings of their operations staff that a problem existed, thereby allowing the extremely harmful effects of lead on children to continue.

On April 20, 2016, three mid-level managers were accused of crimes ranging from misconduct in office, water treatment violations, and to tampering with evidence. One administrator was an employee of the city of Flint, and two were administrators in the Michigan Department of Environmental Quality, the state agency charged with monitoring and administering water quality regulations. The charges were said to be based on the three men's roles in Flint's 2014 drinking water source switch and subsequent failure to properly treat its water.

Sick from Recreational Water

It is not necessary to drink water to get sick from it. In 2015, a City-run water park in California closed Thursday after dozens of guests reportedly fell sick after swiming in the park's five pools. Analysis after the closing revealed a chemical used to sterilize the water was the probable cause. About 40 people, mostly children, suddenly and at the same time became ill at the family park; 17 people were taken to the hospital, suffering from sore throats and skin rashes. Some were vomiting, according to a county health officer. Authorities were unable to find a source of the leak, but investigators did say that the use of sodium hypochlorite, a disinfectant that is about 10 times stronger than the average household bleach, could likely have been the cause.

Aging Retail Water Infrastructure

High on the list of water utility challenges is aging infrastructure. Water user groups, public and commercial suppliers of water and water services, federal state and local regulators of water: these and many other groups and individuals are increasingly concerned over the damage that is occurring in many water treatment delivery systems as a result of breakdowns in aging water infrastructure.

In March of 2013, the US Government Accountability Office released a report on the need for help in repairing and replacing crumbling water infrastructure. The need for the study was explained, in the following announcement: "The nation faces costly upgrades to aging and deteriorating drinking water and wastewater infrastructure. Frequent and highly publicized incidents of combined sewer overflows into rivers and streams, as well as water main breaks in the nation's largest cities, are the most visible manifestations of this problem."

Managing for Supply Sustainability

There are three dimensions to water systems reliability. One is surety of supply; another is resilience in the face of breakdowns or other emergencies; and the third is assurance of water quality. Surety of supply is the purview of water management. Resilience is the goal of the goal of sustainability planning. Maintaining water quality is a function of water utility administration. Each of these dimensions are discussed in the following.

Supply Sustainability Concerns

Water utilities in the United States and elsewhere in the world are a number of critical challenges, many of which are attributable to the climate change already under way. These changes are having an impact upon the natural weather forces that include long-term droughts and stronger intense storm conditions. There is little doubt that these adverse changes to the world's weather patterns are going to continue. Arid areas such as the western United States have become more arid and population growth is already taxing the limited water supplies available in many regions. In states such as Arizona and California freshwater resources are already under strain, and no end is in sight. Similar drought conditions are spreading to regions that have long enjoyed seemingly unlimited underground supplies of freshwater. Among the many challenges facing large and small water utilities today and which need to be addressed are the problem of decaying infrastructure, declining water resources, increases in water use, severe drought conditions in some areas and destructive rain storms in others, increasingly rigorous national, regional, and local environmental policies and the need to protect the security and stability of supply, distribution systems, and records.

According to the American Water Works Association, water and wastewater utilities in the United States and around the world are facing a number of common sustainability challenges. Among the more critical of these challenges are rising costs, chronic drought conditions in large sections of the country, old and insufficient infrastructure, increasingly stringent regulatory and documentation requirements, population growth and demographic structure changes, and a changing workforce.

A list of some of the conditions that can contribute to breakdowns in the system facing all water and wastewater services suppliers in the twenty-first century and which need to be addressed now were published in a revised edition of the industry journal *Public Utilities*. A selection of the many concerns is listed below, but does not include the severity of their impact:

1. Security of water sources, distribution networks, and records
2. Infrastructure disintegration
3. The impact of continued global warming and the predicted acceleration of the phenomena predicted in the near future.
4. Population growth and how it will affect water supply and distribution infrastructure.
5. Settlement patterns that see migration toward warmer and most arid regions of the country.
6. Changing trends in industrialization and industry's use and misuse of freshwater supplies, together with restrictions on factory location and water use.
7. National, regional, and local environmental protection requirements on surface water supplies.
8. Drought and desertification of many parts of the country.
9. Agricultural extension and intensive water use for certain crops.
10. Impact of drought conditions on hydroelectric energy production.
11. Unequal water distribution and efforts to share resources.
12. Political pressures for use-permits, withdrawal quotas and water right allocations, metering, and wastewater reuse and recycling.

Sustaining Water Quality

Continuous monitoring of the water flow at all stages in the system is conducted to ensure that contaminants do not exceed best practices standards and regulatory requirements, and to maintain proper flow and pressure. Digital Supervisory Control and Data Acquisition systems are often employed in process monitoring. To carry out the many tasks involved in collecting, moving, storing, processing, decontaminating, and delivering water utilities employ their own staffs or subcontract some of the activities to outside contractors. Large municipal systems often employ chemists, engineers, microbiologists, and full-time security personnel, as well as other trained specialists. Small utilities may use a small full-time staff with part-time help and special-purpose contract personnel.

Retail Water Systems Example

Water systems regardless of their size must deal with many of the same problems and plan for dealing with the same or similar challenges. The next section describes how these systems are finding themselves force to implement management process to deal with such problems as growth in the sized of their served populations, repairing and replacing aged and deteriorating infrastructure, and the impacts of climate change on their resource supplies. The section begins with the San Francisco City and County's consolidated wholesale and retail water system.

San Francisco's 2016 Wholesale and Retail Water Systems

The City of San Francisco operates a consolidated wholesale and a retail water system, and described that system in its 2016 Urban Water Management Plan (UWMP). The wholesale Hetch Hetchy Regional Water System (RWS) provides drinking water to more than 2.6 million residents and businesses in the San Francisco Bay Area. The RWS collects water from the Tuolumne River in the Sierra Nevada Mountains and from protected reservoirs in the East Bay and Peninsula. The RWS is a municipally owned utility operated by the San Francisco public Utility Commission (SFPUC), a department of the City and County of San Francisco, and serves both retail and wholesale customers. The RWS draws an average of 85 percent of its supply from the Tuolumne River watershed. The water is collected in Hetch Hetchy Reservoir in Yosemite

National Park. This water feeds into an aqueduct system delivering water 167 miles by gravity to Bay Area reservoirs and customers. The remaining 15 percent of the RWS supply is drawn from local surface waters in the Alameda and Peninsula watersheds. The split between these resources varies from year to year depending on the water year hydrology and operational circumstances.

The SFPUC provides water to both retail and wholesale customers. A population of over 2.6 million people within the counties of San Francisco, San Mateo, Santa Clara, Alameda, San Joaquin, and Tuolumne rely entirely or in part on the water supplied by the SFPUC. Approximately two-thirds of the SFPUC's water supply is delivered to wholesale customers, and the remaining one-third is delivered to retail customers.

San Francisco anticipated the need for new water resources early in the last century. The City and County of San Francisco holds both pre-1914 water rights and post-1914 water rights to store and deliver water from the Tuolumne River and local watersheds. Appropriative water rights allow the holder to divert from a source not connected to its place of use. These rights are based on seniority and the use of water must be reasonable, beneficial, and not wasteful. In 1914, California established a formal water rights permit system with passage of the 1913 Water Commission Act. With the Raker Act of 1913, the US Congress granted San Francisco rights of way for the construction and operation of Hetch Hetchy facilities, which are predominantly located on federally owned land in Yosemite National Park and Stanislaus National Forest. The Raker Act recognized the senior water rights of Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) to divert water from the Tuolumne River, and specified conditions for the release of water to the Districts and other conditions imposed by Congress for the protection of recreation in Yosemite and other purposes.

San Francisco Retail Operations

The system's retail operation is separate from the RWS. This in-City distribution system is also owned and operated by the SFPUC and serves a population of nearly 850,000 in San Francisco. In-City retail customers are primarily served with RWS supply, but a few customers receive groundwater and recycled water. Similarly, suburban retail customers are primarily served with RWS supply, but a few customers receive groundwater.

San Francisco's in-City distribution system (Public Water System No. CA3810011) was developed between 1860 and 1960. Major pipelines convey RWS supply from the Peninsula System to the City. Water to the eastside of the in-City distribution system is fed by pipelines that end at University Mound Reservoir. Water to the west side of the in-City distribution is fed by two pipelines that terminate at Sunset Reservoir and one that terminates at Merced Manor Reservoir. The in-City distribution system also includes ten reservoirs and eight water tanks that store water supplied by the RWS. Seventeen pump stations and approximately 1,250 miles of pipelines move water throughout the system and deliver water to homes and businesses in the City.

The in-City freshwater distribution system is the primary system serving San Francisco customers, although a small number of customers receive either groundwater or recycled water. The San Francisco Recreation and Park Department operates and maintains groundwater wells serving irrigation and other non-potable uses (e.g., lake filling, water exhibits) at Golden Gate Park, the San Francisco Zoo, and landscaped medians along the Great Highway (El Camino Real). The City's golf courses are provided recycled water for irrigation. Approximately two-thirds of the SFPUC's water supply is delivered to wholesale customers, and the remaining one-third is delivered to retail customers. In 2015, SFPUC delivered approximately 196 million gallons per day (mgd) of RWS supplies to its entire water service area, with an additional 2 mgd in local groundwater and recycled water to retail customers.

Retail customers include the residents, businesses, and industries located within City limits (the in-City retail service area). Retail service is also provided to a patchwork of customers located outside the City. The retail service area, particularly the in-City portion, is highly urbanized, dense, and growing. Open space and landscaped areas are limited, as are lot sizes. Construction is planned or already under construction at

Table 9.4 San Francisco water retail service area projected population growth, 2015–2040

	Projected Population					
Retail Service Area	2015	2020	2025	2030	2035	2040
In-City retail	857,508	890,400	934,800	981,800	1,032,500	1,085,700
Suburban retail	1,768	1,768	1,768	1,768	1,768	1,768
Total retail	**859,276**	**892,168**	**936,568**	**983,568**	**1,034,268**	**1,087,468**

Source: San Francisco Public Utility Commission (2015)

the few, large undeveloped or redevelopment areas that remain, most of which are located along the eastern shoreline of the City. The majority of current and planned development is composed of mixed-use, multi-family residential, and commercial high-rise buildings. One-third of total housing is single family. As new multi-family units are built, by 2040 the ratio will increase to nearly one fourth of as single family. Population data from 2015 projected to 2040 are shown in Table 9.4.

Like most if not all water utilities, the San Francisco consolidated system suffers from a large quantity of water losses for which it receives no compensation. The UWMP defined these losses as “the difference between the quantity of water supplied to customers and the quantity of water actually consumed by customers. It is comprised of (1) apparent losses, which include unbilled, authorized consumption for operational uses (e.g., fire fighting, pipe flushing, street cleaning, dust control, and low pressure fire hydrant use) and all types of inaccuracies associated with customer metering, data handling, and theft or illegal use; and (2) real losses, which include all water physically lost due to distribution system leaks, breaks, overflows, and other unbilled, unauthorized consumption.”

The SFPUC projects water loss to be a 6.0 mgd through 2040. This estimate reflects, among others, the anticipation of leaks and breaks due to aging infrastructure, continuance of system flushing after the drought, and active management of losses. The system manages real losses through its Automated Water Meter Program and Linear Assets Management Program. Installation to upgrade all in-City retail water meters with wireless advanced metering technology began in the spring of 2010. The Linear Assets Management Program replaces and renews distribution system pipelines and customer service connections for approximately 1,250 miles of drinking water mains in the City

Adoption of the Water Conservation Act of 2009 sets a goal of reducing urban water use by 2 percent by the year 2020. Each retail urban water supplier was required to determine baseline water use, expressed in gallons per capita per day during their baseline period All suppliers had to determine their target water use for the years 2015 and 2020 in order to help the State achieve the 20 percent reduction. The San Francisco system met its reduction targets.

Projected Climate Change Impacts on the Water supply

The San Francisco 2016 water management plan included a section on how it is anticipating and planning for dealing with the impacts on the sustainability of their system of climate warming. Portions of the report are included in Box 9.1.

Box 9.1 Effects of climate change on San Francisco's water supply

Observational data shows that a warming trend occurred during the latter part of the twentieth century and will likely continue through the twenty-first century. These changes will have a direct effect on water resources in California, and numerous studies have been conducted to determine the potential impacts to water resources. Based on these studies, climate change could result in the following types of water resource impacts, some of which are likely to affect the Tuolumne River watershed and local watersheds in the Bay Area:

- Reductions in the average Sierra Nevada annual snowpack due to a rise in the snowline elevation and a shallower snowpack at lower elevations, and a shift in snowmelt runoff to earlier in the year;
- Changes in the timing, intensity and variability of precipitation, and an increased amount of precipitation falling as rain instead of as snow;

- Long-term changes in watershed vegetation and increased incidence of wildfires that could affect water quality;
- Sea level rise and an increase in saltwater intrusion;
- Increased water temperatures with accompanying potential adverse effects on some fisheries and water quality;
- Increases in evaporation and concomitant increased irrigation need; and
- Changes in urban and agricultural water demand.

Source: San Francisco Public Utility Commission (2015)

In its 2012 report "Sensitivity of Upper Tuolumne River Flow to Climate Change Scenarios," the SFPUC assessed the sensitivity of runoff into Hetch Hetchy Reservoir to a range of changes in temperature and precipitation due to climate change. Key conclusions from the report were:

With differing increases in temperature alone, the median annual runoff at Hetch Hetchy would decrease by 0.7–2.1 percent from present-day conditions by 2040 and by 2.6–10.2 percent from present-day by 2100. Adding differing decreases in precipitation on top of temperature increases, the median annual runoff at Hetch Hetchy would decrease by 7.6–8.6 percent from present-day conditions by 2040 and by 24.7–29.4 percent from present-day conditions by 2100.

- In critically dry years, these reductions in annual runoff at Hetch Hetchy would be significantly greater, with runoff decreasing up to 46.5 percent from present-day conditions by 2100 utilizing the same climate change scenarios.
- In addition to the total change in runoff, there will be a shift in the annual distribution of runoff. Winter and early spring runoff would increase and late spring and summer runoff would decrease.
- Under all scenarios, snow accumulation would be reduced and snow would melt earlier in the spring, with significant reductions in maximum peak snow water equivalent under most scenarios.

Determining the system's potential vulnerable to future climate change began assessing vulnerabilities of water resources in the Bay Area Region

(Region). Vulnerability was defined as the degree to which a system is exposed to, susceptible to, and able to cope with or adjust to, the adverse effects of climate change. Climate change research by the SFPUC began in 2009 and is still underway.

Retail Water Management in Rockford

The water utility of Rockford, Illinois, serves a population of less than 150,000 from 26 groundwater production and water treatment facilities, with a staff of 62 full-time employees in the water division and 28 full-time equivalent supports personnel who are assigned to other divisions, including engineering and customer service. Like many small and medium-sized cities in the American Midwest, the utility's industrial and residential customer base has experienced slow decline for a peak of 152,871 in 2010 to an estimated 148,278 in 2015. The city is located on the Rick River in the northwest corner of Illinois. The utility produce 6.9 billion gallons of water in 2014, approximately the same as peak production in 1973.

The Rockford utility's distribution system is suffering from old age and extreme cold weather conditions; most of the water mains are more than 70 years old and, following a decade-long trend, resulting in an increasing number of failures. In all, 155 breaks occurred in 2013, just a few less than the peak of nearly 150 breaks in 2007. Close to have of the 2013 breaks occurred during extreme cold in January and February. The utility's water meters, most of which were installed in the late 1990s, are also beginning to fail; 500 m had to be replaced in 2014. The utility reports that old meters tend to register less water than is actually being withdrawn, resulting in further lost revenues.

Losses from water main leaks and service leaks are having a significant impact on the utility's operation costs. Approximately 23 percent of treated water production was lost to leakages in 2014. Losses from leakage have exceeded 15 percent of production in all but one year since 2004. Declining revenues make it impossible for the utility to replace failing water mains at a rate far below the recommend period.

Departure of older heavy industry and declining population has resulted in a steady decline of water sales over a 40-year period. Annual rate increases of 3 percent a year have not made up the losses: operating revues were $24.7 million in 2012, $23.4 million in 2013, and $23.7 million in 2014; operating expenses were $19.1 in 2012, $20.0 million in 2013, and $22.3 million in 2014.

The water division of the utility maintains 850 miles of water mains, 20 percent of which are older than 70 years, and has replaced 0.8 miles per year since 2008. It estimates that at this rate it will take more than 200 years to replace just the 170 miles of mains that were 70 years or older in 2014. The utility must also replace or refurbish a number of its existing wells and repair leaking storage tanks and reline reservoirs. The utility's 2014 Water Replacement and Infrastructure Improvement budget is $5 million annually; it estimates it will require from three to four times that amount to completely make needed repairs or replacements to the system.

Rockford's experience was included in this chapter not because it was an isolated example. Almost every water utility in the United States is suffering the same aging infrastructure and inability to identify where the finds to make needed repairs will be found. Importantly, the Rockford water utility is doing a superior job in meeting the retail water needs of its customers. Clean, clear drinking water that meets all EPA and public health standards were provided all year, with a total of just 16 customer complaints for the entire year—the equivalent of just one complaint for every 3,400 customers per year.

Effective Water Management

In 2008, the EPA and six water industry organizations came together to develop a Primer on water and wastewater utility management. The group identified the ten attributes in Table 9.5 as a list of reference points that all water and wastewater utilities can follow to become are effectively managed. The group explained that utilities could benchmark their own operations to the list as found in the best managed utilities.

Table 9.5 Attributes of effectively managed water utilities

Attribute	Discussion
Product quality	Produces potable water in full compliance with regulatory and reliability requirements
Customer satisfaction	Provides reliable, responsive and affordable services in line with accepted customer service levels. Receives and responds to regular customer feedback
Employee and leadership development	Recruits, trains and retains a competent, motivated, adaptive and safe-working workforce; provides opportunities for employee growth and advancement
Operational optimization	Provides timely, cost-effective, reliable and sustainable performance improvements in all facets of operations
Financial viability	Establishes and maintains an effective balance between long-term debt, asset values, operations and maintenance expenditures and operating revenues
Infrastructure stability	Understands the condition and costs of critical infrastructure assets; maintains and enhances the condition of all assets over the long-term at the lowest possible life-cycle cost and acceptable risk
Operational resiliency	Proactively identifies, assesses, and establishes tolerance levels for and effectively manages a full range of business risks
Community sustainability	Remains aware of impacts its decisions have on current and long-term future community and watershed health and welfare
Water resource adequacy	Ensures water availability consistent with current and future customer needs; manages operations to provide for long-term aquifer and surface water sustainability and replenishment
Stakeholder understanding and support	Engenders understanding and support from oversight bodies, community and watershed interests, and regulatory bodies for service levels, rate structures, operating budgets, capital improvement programs and risk management decisions

Source: EPA (2008 and 2017)

They could then use the attributes to select performance improvement strategies and priorities. The attributes list were not proposed in any order, but were intended as a set of opportunities for operational improvements.

Summary

The water and wastewater industry included both a wholesale and a retail sector. The wholesale sector consists of organizations like the Bureau of Reclamation that operated dams and water reservoirs in the 17 Western United States, state water suppliers such as the California Water Project that brings water from Northern California through the Sacramento-San Joaquin River Delta for delivery to users in the San Joaquin Valley, parts of the San Francisco Bay Area and Southern California, and regional and local agricultural water districts. The retail sector consists of public and private supply utilities that purchase or withdraw surface water or pump a supply of water from an underground aquifer, treat, store, and distribute water to residential, industrial, and commercial water users. A small number of water users get their supply from private wells.

The number of public water supply organizations has grown with the growth of the Nation, and in 2014 consisted of approximately 156,000 systems subjected to EPA regulation, and a large number of single user well users and local systems serving less than 15 people in a more or less temporary operation. These public-supply organizations are grouped into three classes: non-transient customers systems, transit customers, and non-regulated systems.

Water supply systems large and small suffer from roughly the same type of challenges to their operations that range from over-stressed supplies to trouble hiring and retaining trained system operators. Within this litany of challenges, the need to fund repairs and replacing aging infrastructure, securing supplies to meet demand of a growing population in some parts of the country while dealing with a declining customer base in other regions. How two water utilities are dealing with these problems is discussed in this chapter.

The EPA and six public and private water met in 2008 to identify and produce a management guidebook to help the Nation's water and wastewater utilities maintain a focus on what they identifies as all-important management and areas of operations. The guidebook identified ten attributes the group determined were evident in all well-management public

utilities, and recommended that all utilities seeking to improve their operations and performance consider adopting and adapting the attributed to their own operations.

Additional Reading

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10

Managing Wastewater

It is no longer possible to ignore wastewater when planning how to manage America's water resources. It has become a global issue, as well. According to the United Nations and the Organization for Economic Cooperation and Development, it is increasingly apparent that the wastewater management and water quality are interrelated and must be managed together. These two water forms, together with other water- and non-water issues, impact the water, energy and agriculture sectors, as earlier water withdrawals revealed. It has also been acknowledged that wastewater management clearly plays a role in achieving future water security in sections of the US South and West (UN Water 2016).

The good news is that many water system managers are looking at wastewater not as waste, but as a valuable resource that can be used to augment traditional supplies. New and better ways of treating water that has been used once now make this supply a valuable addition to the development of a long-term sustainability of our water resource. There are two types of wastewater; municipal and industrial. There are two main classes of municipal wastewater: water from sewage disposal and

D.E. McNabb, *Water Resource Management*,
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industrial wastewater. Figure 10.1 shows how these two classes of wastewater can be used again after processing.

Sewage system wastewater is mostly from households and includes sewage, gray, and blackwater. Sewage requires extensive treatment and sterilization; gray water is mostly water used for bathing and washing of clothing and dishes and requires much less treatment. Gray water, another domestic source, is seldom collected and treated separately from normal wastewater discharge.

Many different industrial processes generate wastewater. Water used to cool thermoelectric generators is also an industrial use. Water used in industrial uses may contain any combination of acids, metals, salts, oils and volatile compounds, chemicals, minerals, and solids. The treatment and disposal of industrial wastewater requires significantly greater work than is needed for municipal wastewater. This chapter looks at some of the programs now underway in the United States for improving management of wastewater, including the many new uses being planned or proposed for reusing wastewater.

There are between 15,000 and 16,000 publicly owned wastewater treatment systems in the United States. More than 75 percent of the US population has its sanitary sewerage treated by these wastewater systems; a declining number still use septic systems. Like freshwater policies, the EPA has delegated regulatory responsibilities over wastewater treatment facilities to individual state agencies. Close to 98 percent of publically owned treatment systems are municipally owned. According to the American Society of Civil Engineers (ASCE), in 2013 there were between 700,000 and 800,000 miles of public sewer mains in the country. Many were installed in the one or two decades after World War II and consequently, are approaching the end of their useful life. In its 2013 and 2016 infrastructure report cards, the ASCE gave the nation's wastewater system only a D+.

Today, wastewater is increasingly looked upon as another source of badly needed water; it is simply water that has been used—often more than once—but still can be used again for many different purposes. Before it is treated again, wastewater is almost always contaminated by various pollutants, depending on what it was used for. For example, medical wastewater is almost always highly contaminated, whereas water used for home showers (gray water) is usually only slightly in need of treatment before it can be used again. Blackwater, the water used as a carrier in flushed toilets, requires significantly greater treatment and sanitizing before it is acceptable for reuse.

The Composition of Wastewater

Wastewater has typically been classified only into two major categories of its source: (1) domestic or municipal wastewater and (2) industrial wastewater (includes agricultural irrigation wastewater). Domestic wastewater comes from residential sources including toilets, sinks, bathing, and laundry. Because it can contain body wastes containing intestinal disease organisms, it is treated and sanitized before the final effluent is discharged into ponds, a wetland or a watercourse. Industrial wastewater is discharged after used in manufacturing processes and commercial enterprises. Industrial wastewater that is used in industrial processes can contain such pollutants as residual acids, plating metals, and toxic chemicals; however, wastewater that has just only for cooling purposes as in thermoelectric generation is far less polluted and can usually be reused in the same plant. Wastewater that is not absorbed during agricultural irrigation can be collected and used again (Figs. 10.1 and 10.2).

Regardless of its source, all wastewater is defined as a liquid mix of suspended solids, biodegradable organic materials, pathogenic bacteria and other disease-causing organisms, and nutrients such as nitrates and phosphates. Another, shorter definition is: Wastewater is any water that has been adversely affected in quality by anthropogenic (i.e., caused by human) influence. Treatment and purification is necessary before this effluent is discharged into a watercourse. This treatment process removes the unwanted components before the effluent is either discharged or reused, say, for landscape or park lawn irrigation. A more appropriate definition of wastewater was included in a 2010 United Nations-sponsored study by Corcoran et al. defines wastewater as a combination of one or more of the following types of water and repeated several

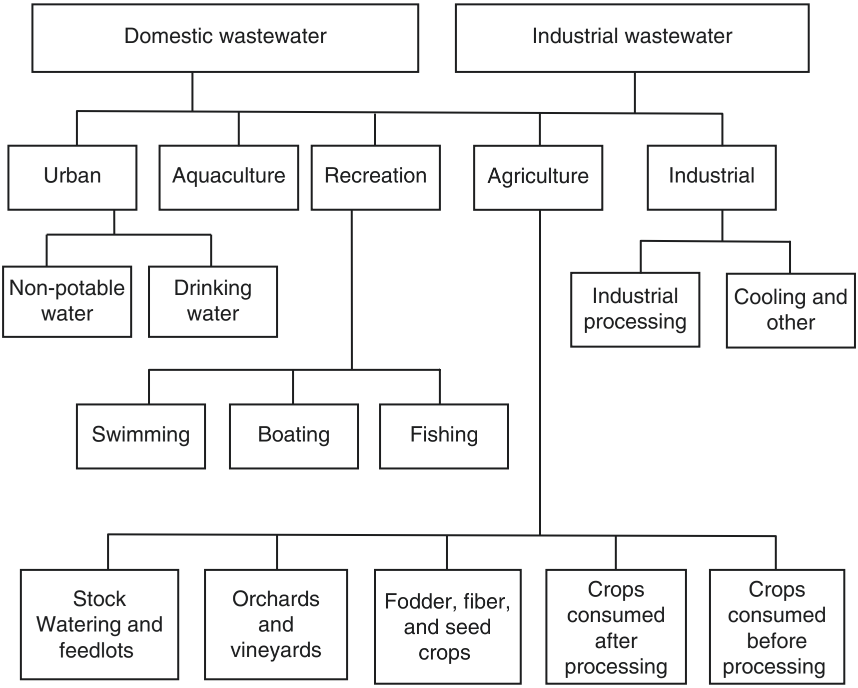

Fig. 10.1 Types of domestic and industrial resources and wastewater uses
Source: From material in a UN document by Helmer and Hespanhol (1997)

years later in an analytical brief released by the UN Water organization. Wastewater consists of:

- Domestic effluent consisting of blackwater (excreta, urine and fecal sludge) and gray water (kitchen, laundry, and bathing wastewater).
- Water from commercial establishments and institutions, including hospitals.
- Industrial water used for generating steam, in cooling of thermo-electric generation, and processing.
- Stormwater and other urban runoff.
- Agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter.

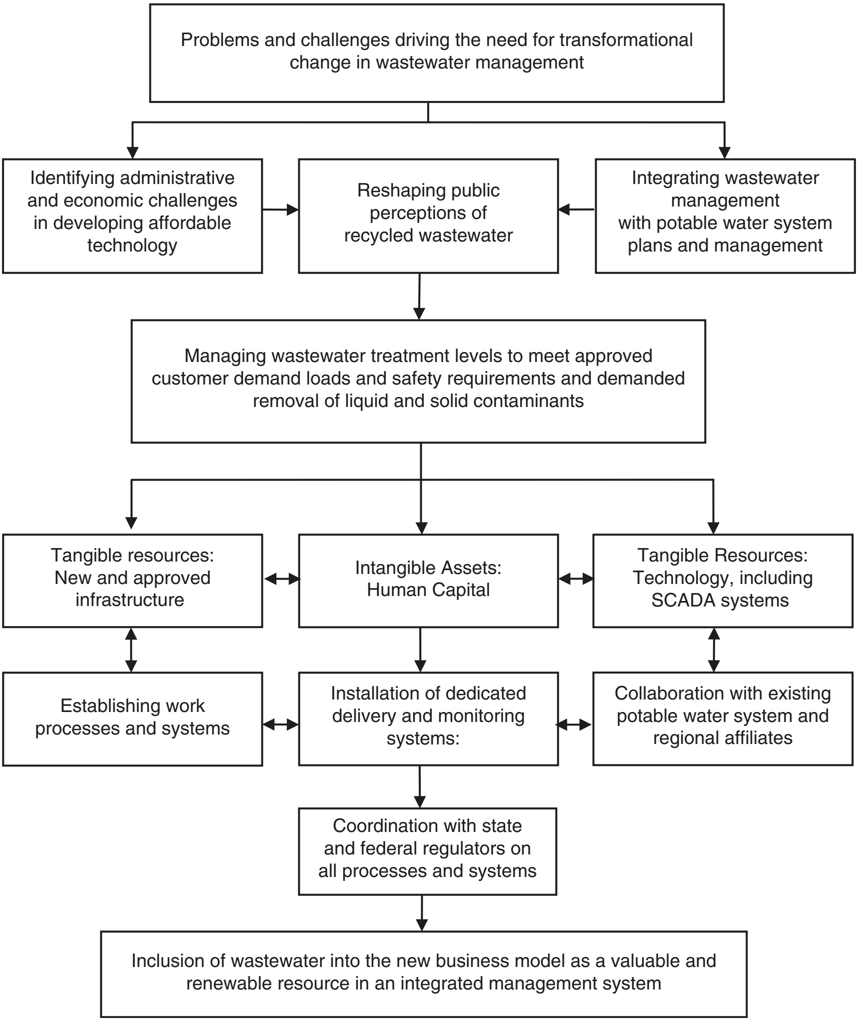

Fig. 10.2 Flowchart representation of an integrated wastewater management system

Source: From concepts in McNabb (2009, 2017)

Evolution of Wastewater Management

Wastewater management has of necessity been are more concerned with developing and implementing management programs and technologies for urban application than was ever the case for wastewater generated in rural areas (Burian 2000). Initially, dealing with urban and rural residential wastewater in colonial America was handled by individuals in similar ways: detached or semi-detached outdoor privies or inside collection followed by disposal of in a haphazard way in the yard, street, gutter, or an surface channel functioning as an open sewer. As city growth made disposal a problem, indoor privies were installed, with wastewater either collected in a vault or tub under the privy then discharged into a nearby cesspool.

Since the first organizational attention was paid to how to deal with the problems in the growing urban areas in the early 1800s, two management strategies have evolved: centralized and decentralized approaches, with the decentralized system being the predominate system until the end of the nineteenth century. Until the 1850s, most sewers were built for dealing with stormwater and winter snow and ice melt. No municipal wastewater systems operated; the few private sewer lines that did exist were constructed to serve a few locations, with the raw effluent transported a short distance to a nearby water course. The first pipes were wooden and deteriorated after a brief period underground. For rich and poor alike, privy vaults and cesspools were a constant problem. They often overflowed and required periodic cleaning. No engineering schools taught courses in water management. A municipal marvel of the time, the first modern centralized collection system, was constructed in Hamburg, Germany, in 1842.

Six reasons for the slow adoption of improvements in wastewater management that helped bring about a change from local decentralized wastewater management to centralized treatment have been suggested: (1) inability of vaults and cesspools to keep up with demands resulting from rapid population growth of the urbanization of the country; (2) construction of public water supplies and water closets that often included running water—all that new water over taxed the privy vault and cesspool system; (3) public health concern brought on by periodic mass deaths due to water-borne disease; (4) limited technology transfer—American civil engineers and municipal leaders had to travel to Europe to learn the latest technology; (5) changing socioeconomic conditions; and (6) a lack of alternative solutions. The United States grew rapidly during the nineteenth century, and much of the new immigrant population settled in cities. Clearly, the privy vault–cesspool wastewater management system could not cope with this growth. The solution was a collective sewage system, as this report indicated:

> In 1820, less than 5 percent of all Americans lived in urban areas (cities with a population larger than 8,000), but by 1860, the percentage increase to 16 percent and by 1880 had risen to 22.5 percent. From 1820 to 1880, most major cities in the United States experienced considerable growth. For example, Boston's population increased eightfold, New York City's tenfold, Philadelphia's thirteen fold, and Washington D.C.'S fivefold. The population of the country increased fourfold between 1850 and 1920, with the number of cities with more than 50,000 residents increasing from 392 to 2,722.

Prior to the construction of water lines that brought clean water from unpolluted sources; most city dwellers drew their water from local wells or streams, both of which became polluted by seepage from outdoor privies and disposal of human wastes. A series of cholera epidemics and other water-borne diseases helped stimulate interest in public health. Between 1832 and 1873, for example, cholera epidemics occurred in 1832, 1846, and 1866, and typhoid outbreak in 1848. Recognition of the connection between water and disease, the public health movement resulted in an quick end to the privy vault and cesspool system and installation of a collective sewer system in the nation's cities and towns, although the growth of suburbia after World War II with the increases in residential lot area, an increase in individual septic systems appeared.

As the nineteenth century was coming to a close, American engineers had identified the principles and technology needed for the planning and construction of centralized sewer systems (CSSs). By 1909, cities with populations of more than 30,000 had installed nearly 25,000 miles of sewers. A little more than 18,000 miles of these were combined sewer-surface drainage and storm runoff lines. In cities with more than 100,000 residents, there were more than 17,000 miles of sewers, of which 14,249 were combined sewers. The combined sewer and stormwater system became the dominant urban wastewater management system.

Growth of Wastewater Treatment

In 1905, more than 95 percent of the urban population discharged their untreated wastewater directly into rivers, streams, and lakes. The process had only been reduced in 1924 to wastewater from 88 percent of the population of the cities with more than 100,000 residents. What may have had the greatest influence in bringing about an increase in treating wastewater before discharge was development of the cost-effective way of treating large quantities of wastewater by the activated sludge process.

The industrial and economic expansion that occurred after the end of World War II brought on a number of problems for wastewater managers that they were unprepared for. In addition to traditional urban wastewater, new industrial wastes contained a number of toxic chemicals, complex organic compounds, and other substances that were previously not considered in wastewater treatment. In addition, the public's concerns over water and air pollution were aroused by Rachel Carson's 1962 book *Silent Spring* that warned of the dangers of DDT and the tragedy of the Love Canal, a pit used to pour highly toxic chemical wastes that was covered and later sold to the City of Niagara Falls. Later a school was built on the land and houses build nearby. After a series of still births and many babies born with birth defects, the site was identified as the most polluted region in the nation. One study found more than 400 types of chemicals in the air, water, and soil. The school closed in 1978, the land was sectioned off, and more than 200 families were evacuated.

Congress reacted shortly after the war to the growing concern over damage to the environment associated with air and water pollution by passage in 1948 of the Water Pollution Control Act. This first step authorized the start of government's comprehensive planning, providing technical services, research and financial aid for dealing with water pollution, including water affected by wastewater discharges. An amended Act in 1952 made the Water Pollution Control Act the permanent law of the land. The 1965 amendment was the first federal legislation to focus of protecting water quality. Despite these actions, water quality was found in the late 1960s after publication of Rachel Carson's book to still be deteriorating, Congress reacted with passage of another a much stronger bill, the Water Pollution Control Act in 1972. The 1972 Act set priorities for eliminating all water pollution by 1985 and authorized spending of $24,6 billion to make it happen. Included were grants and loans to help develop and construct wastewater collection and treatment facilities. The 1977 amendments encouraged municipalities to consider alternatives to the conventional CSSs.

By the end of the 1990s and start of the new century, the die had been cast for a policy of strict control over water quality and elimination of all forms of water pollution, including untreated wastewater. The wastewater management system in place to achieve these goals remains centralized wastewater management, with support for wastewater reclamation and reuse, and greater attention to wet-weather flow management. Decentralized wastewater management—the collection, treatment, and reuse of wastewater at or near its source—was serving approximately 25 percent of the population at the end of the century, with 37 percent of new suburban development indicating plans to adopt this management approach. The deep recession that hit the country later in the decade curtailed more extensive growth of the approach. The prolonged drought that occurred in the Southwestern United States has resulted in a widespread acceptance of the reuse of wastewater.

Modern Wastewater Treatment

Wastewater in developed nations is most often treated by several step processes to remove pollutants, biosolids, and particulates. The purpose is to improve and purify the water by removing some or all of the contaminants, making it fit for reuse or discharge into the environment. Discharge may be released in surface water, such as a river, lake, or stream, in wetland areas, or the ocean. Discharge into surface waters may eventually lead to some percolation into groundwater where it joins natural water in some type of aquifer that lies beneath the land surface of the earth. From it, this combined water may then be retrieved downstream for additional domestic or industrial use.

The wastewater treatment system occurs in a series of sequential processes, beginning with collection and proceeding through preliminary treatment, primary treatment, secondary treatment, disinfection, and finally, sludge treatment. In some municipal systems, a third or tertiary treatment is included. The most efficient primary and secondary treatments remove from 85 to 95 percent of pollutants from the wastewater stream before the effluent is disinfected and discharged into local waterways for dispersal.

In primary treatment, suspended and floating solids are removed. Screening traps solid objects, gravity sedimentation removes suspended solids, and floating objects are removed from the raw sewage. Primary treatment is referred to as a mechanical treatment, although chemicals are often added to speed up the sedimentation process. The settled solids, called primary sludge, are then removed, subjected to additional treatment and transported to landfills. The partially treated wastewater then flows to the secondary treatment system.

In the secondary treatment, what is known as the activated sludge process, remaining dissolved organic matter is removed in a biological process achieved when microbes consume the remaining organic matter, converting it into carbon dioxide, water, and energy for their own growth and reproduction. Air pumped into large aeration tanks mixes the wastewater and sludge. This stimulated the growth of oxygen-using bacteria and other organisms that are naturally present in sewage. The biological process is followed by another settling process (secondary sedimentation) to remove remaining suspended solids. Secondary treatment facilities include a basic activated sludge process, varying forms of pond and fabricated wetland systems, trickling filers and treatment forms that used additional biological activity.

Tertiary treatment is an additional treatment process that is employed after primary and secondary treatment has occurred. An example of a tertiary treatment is a secondary process modified to remove more phosphorus and nitrogen. Recycled water is water that have undergone a tertiary treatment. Although considered to be very expensive, the final process can remove more than 99 percent of all the impurities from sewage.

Disinfection is the final step in the treatment process. Here, the wastewater has often been sent to a "chlorine contact" tank where chlorine is added to kill bacteria, just as it is used in swimming pools. However, because chlorine can have harmful effects on fish and other marine organisms, other chemicals or processes such as ultraviolet (UV) radiation have been substituted.

Wastewater Resource Recovery

If wastewater is to take its place as a beneficial resource rather than a liability, wastewater managers must develop cost-effective technology for recovery of materials from wastewater, along with the recovery of usable water (Criddle et al. 2010). Management principles and process and are already firmly established wastewater is seen as a valuable source of reclaimable resources instead of just a necessary problem to be dealt with as quickly and as cheaply something to be discharged into the first convenient watercourse (Tilley et al. 2014). The changing attitude toward wastewater was described in a UN and World Health Organization report:

> Most of the more than 16,000 wastewater treatment systems in the US release treated water back into rivers, lakes or the ocean with little reuse. However, if drought conditions in portions of the US continue as predicted due to climate change, more water will be need locally for non-potable reuse applications, and possibly even to augment already stressed potable water resources. This would decrease the amount of expensive freshwater that needs to be imported. Improved recovery of energy at treatment plants could also offset costs of transporting and treating water. In the 21st century, wastewater treatment plants are likely to become resource recovery centers, where clean water, renewable energy, fertilizers and useful materials, such as biodegradable plastics, are recovered and used to meet society's needs. (Criddle et al. 2010)

There are a number of different ways that wastewater as a resource, including as a supplemental drought-resistant non-potable water source during periods of prolonged drought, a source of nutrients for agriculture, a soil conditioner, and a source heat any energy. The use of reclaimed wastewater in agricultural use has a long and successful history of successful use. Wastewater is 99 percent water and just 1 percent suspended and dissolved solids and chemicals. When successfully treated to the secondary level, water that was once a waste can be used for irrigating such non-direct applications as for forage crops, vineyards, and nut orchards. Tertiary treatment is necessary for direct application to most food crops. Agricultural applications are discussed in greater detail in the next chapter. Wastewater is rich in soil nutrients and when appropriately treated to the necessary degree can reduce the need for chemical fertilizers.

Anaerobic digestion of sewage is the bacterial decomposition of fecal solids. This produces a mixture of methane and carbon dioxide, components in flammable biogas. Biogas can be used as a fuel to generate electricity and heat. An example of how an Oregon municipal wastewater utility took advantage of this resource and benefited financially from its use is described in Box 10.1. Fecal solids, when properly treated, can be used in gardens and as a soil conditioner. A number of utilities bag and sell the product for local gardeners (Box 10.2).

Box 10.1 Changing technology results in income for wastewater treatment plant

An Oregon wastewater system is benefiting from new technologies that make it possible to convert wastewater biosolids into heat, energy and soil. The City of Gresham, Oregon was able to reach net zero in its energy use in 2015 by producing more energy that it uses, saving the city of close to 114,000 residents an estimated $500,000 in electricity costs.

Dealing with fats, oil, and grease (FOG) in traditional wastewater treatment systems has long been a problem for utilities. However, Gresham has operated a receiving station for FOG from local restaurants and service stations since 2012, enabling a doubling of its biogas production. FOG products are converted to biogas which is then used to generate heat and electricity.

Co-generators on the site use biogas generated in 1-million gallon anaerobic digesters to generate heat and generate electricity. Enough energy is produced to heat the plant and produce about ten percent more power than is needed to operate the plant. Extra power is provided to the local energy utility, although a system was not yet in place to receive income from the excess energy. Before the biogas process was on line, the treatment facility accepted liquid organic waste which was then dewatered and discharged into landfills or land-applied.

Source: Alanna Maya, *WaterWorld* (2016)

Box 10.2 Different types of reusable wastewater

The uses for what we once just called "treated sewage," and today refer to as potable wastewater has several different names that reflect its planned final discharge. Wastewater is now treated to two levels of sanitation: wastewater treated for potable reuse and water treated for non-potable reuse. These different labels are based upon different stages in the treatment cycle and the different final use planned for the treated water. Here are the meanings:

- **Non-potable reuse:** Recycled water that has been treated in a separate system that is not intended for augmenting a drinking water supply.
- **Potable reuse:** Recycled water that receives treatment to a level that makes it suitable for augmenting an existing surface or groundwater supply.
- **Indirect potable reuse:** Augmenting a natural water source with recycled waster after it has spend some time in and environmental buffer such as an aquifer or surface reservoir.
- **Direct potable reuse:** The intentional augmenting of an existing surface or groundwater supply with recycled water that has been treated to a potable level status.
- **Defacto potable reuse:** Treated wastewater that is discharged into a river or stream that unintentionally mixes with and is diluted by the existing natural supply; the combined source is then withdrawn from the river or stream by downstream users.
- **Planned potable reuse:** Augmenting a drinking water supply with recycled water in a planned project that is openly communicated with and approved by regulatory agencies and local stakeholders.

Source: Trussell and Trussell (2016)

Wastewater Management

Until the middle years of the last half of the twentieth century, Americans treated wastewater primarily as a means of protecting human health. Concern over the ecological health effects of poorly treated effluent from water-borne diseases was not a major concern of society until the mid-1960s. Since the early 1970s, the quality of the post-treatment effluent water has been the chief activity of the from 14,500 to 16,000 publicly owned treatment works that collect, treat, and discharge treated water and other point source discharges. The guiding principles of their actions were established by the Clean Water Act (CWA), originally passed in 1948 but significantly reorganized and amended in 1972. The amended CWA of 1972 became the version referred to in all subsequent discourse. The 1972 Act (CWA) formed the basic structure for regulating discharges of pollutants, including wastewater effluent, into the waters of the United States and regulating quality standards for surface waters. The CWA made it unlawful to discharge any point source pollutant into navigable waters, unless a permit is obtained. Point sources are discrete conveyances such as sewer or industrial water discharge pipes or man-made ditches. Individual homes that are connected to a municipal system, use a septic system, do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters.

Despite the improvement in effluent quality, point source discharges continue to be a significant contributor to the degradation of surface water quality. In addition, much of the existing wastewater infrastructure, including collection systems, treatment plants, and equipment, has deteriorated and is in need of repair or replacement.

Types of Treatment Varies by Type

Wastewater management processes vary with the types of incoming wastes they must deal with, and the standards they must meet for release of treated water back into the environment. Wastewater varies from toxic industrial waste, domestic or municipal waste to rainwater and urban runoff. Each has its own best management practices. Treatment facilities require constant maintenance, and new improvements to comply with the increasing number and severity of regulations (University of Michigan 2016).

Municipal Wastewater

Municipal sewage consists of sanitary wastes, foods, soaps, fats and oils, salts, and industrial chemicals. In many combined systems, it also includes stormwater from roofs and streets. Gray water can be discharged with little or no treatment. Blackwater requires most of the treatments used on wastewater. Most on-site treatment systems such as septic tanks and associated drain fields are common in rural area and are usually in need of little more than regular pumping of biosolids to remain functional.

Industrial Wastewater

Industrial processes generate many different pollutants in their wastewater. This may include any "combination of acids, metals, salts, oils and volatile compounds, chemicals, minerals, and solids. Separate processes treat each type of contaminant to acceptable levels. Solids can simply be filtered out. Acids are neutralized with lime to an acceptable pH level, and lime also precipitates heavy metals. Electrolysis precipitates dissolved compounds, which are separated mechanically" (Silbajoris 2016). After primary and/or secondary treatment, some highly polluted industrial wastewater may be sent for further treatment or entered into the usual municipal wastewater treatment stream.

Stormwater and Urban Runoff Management

Stormwater is rainwater and snow or ice meltwater collected from surfaces such as roofs, streets, and parking lots that do not allow any ground absorption of the runoff. Water from paved areas also carries litter, any fluids that vehicles might drop, sediments, pet waste and—in winter—road salt or deicing chemicals. Some municipal wastewater treatment systems have separate sewage and runoff systems, with untreated runoff discharged directly into local streams, although the use of roadside retention ponds that allow the runoff to be absorbed into the soil is becoming more common. Most older sewer systems combine it with sanitary sewage, which often causes combined sewer overflows, particularly during extreme weather events, and sudden storms that can overwhelm street drainage. As more of the land is paved over during urbanization, these overflows and commensurate flooding is occurring more often.

Green design is also becoming more common. This includes ways of capturing rainwater that falls on urban roofs to then use it for landscape irrigation or hold it for other uses such as fire suppression. Rain gardens can capture runoff and clean it of pollutants before releasing it; household rain barrels can catch roof runoff for garden irrigation use instead of allowing it to flow into an overloaded storm sewer system.

Wastewater Treatment Systems and Technologies

The 2014 highly respected second edition of the *Compendious of Sanitation Systems and Technologies* (2014) has provided a description and list of treatment requirements for nine different wastewater treatment methods. The nine systems, list from the most primitive to the most technology required, are:

System 1: Single pit system
System 2: Waterless pit system without sludge production
System 3: Pour flush pit system without sludge production
System 4: Pour flush pit with urine diversion
System 5: Biogas system
System 6: Blackwater treatment system with infiltration
System 7: Blackwater treatment system with effluent transport
System 8: Blackwater treatment to semi-centralized treatment system
System 9: Sewerage treatment system with urine diversion

Most systems in the United States are comparable to System 6, blackwater treatment with infiltration. This is a water-based system that requires a flush toilet and a collection and a treatment or storage and treatment technologies that are appropriate for receiving large amounts of water inputs into the system. The system receives and treats feces, urine flush water, anal cleaning water, cleaning materials and gray water. It may also receive some industrial and commercial wastewater, including some medical wastewater. The sludge that is generated from the treatment process must be removed and transported for further treatment and beneficial use or for direct discharge onto the soil.

Systems with separate urine collection are not generally found in the United States, but are increasingly found in areas regions of the world with a tradition of wastewater agricultural use. Urine is rich in nutrients and, because it is nearly sterile, urine can be stored and handled safely and is used as a liquid fertilizer. Wastewater from which urine is removed that still retains fecal materials is known as brownwater.

Disinfection Technologies

In the United States, chlorination is the most common means of disinfection. Chlorination may be followed by de-chlorination with sulfur dioxide to avoid deteriorating ecological health of the receiving stream and the production of carcinogenic byproducts. UV disinfection is the most common alternative to chlorination and has comparable energy consumption. Chemical additions of ferric salts and lime enhance coagulation and sedimentation processes for improved solids removal as well as removal of toxic pollutants (University of Michigan 2016).

Classes of unregulated compounds known as “contaminants of emerging concern” (CECs) are a concern for wastewater treatment managers. Of particular concern are a range of pharmaceuticals, personal care products, and perfluorinated compounds (PFCs). In the past decade, polybrominated diphenyl ethers and PFCs have become CECs due to their wide distribution and persistence in the environment. Some of these are endocrine (kidney functions) disruptors, compounds that alter the normal functioning of endocrine systems, including those that affect growth, reproduction, and behavior.

Managing for Sustainability

Sustainable wastewater management requires includes managing the resource from source to re-entry into the environment as either disposal of treated effluent or reuse as a component in the sanitation service chain (UN Water 2016). Although most urban communities in the United States are well served by wastewater service organizations, with rural areas functioning under approved septic systems, many of those systems are either in need of upgrading or replacing older infrastructure or are having a difficult time meeting service demands resulting from a growing population.

Many smaller systems were either designed for a single purpose when first constructed, or are overwhelmed by new and more severe sanitary regulatory requirements and new technology. Others remain purely water or purely wastewater service providers, even though managing wastewater in today's complicated and rapidly changing environment requires an integrated approach with consideration of all steps in the hydrology cycle. Moreover, water managers are encouraged to "*work with rather than against natural ecosystem processes* (UN Water 2016, 23; emphasis in the original).

Urban and rural wastewater systems, small or large service areas, differences in population density, and the level of economic development and technological capacity are all factors that must be considered when adopting a management system; no single approach can be applied to all systems. To meet the demands on their existing capacity, system managers must design a system and management approach that meets the needs of their community, the existing environmental requirements, and their available resources.

Wastewater as a Valuable Resource

In many parts of the country, the water supply is under greater and greater stress as climate change is changing precipitation patterns, and the population increases. For several decades, recycled water has been accepted as a substitute for drinking water for landscape watering and for irrigating agricultural crops not directly intended for human consumption. In the past decade, however, the use of recycled water to augment stressed surface and groundwater supplies has gained more and more acceptance. Moreover, advances in treatment technologies have reduced the cost to the point where recycled water is in many instances cheaper than natural supplies.

Applications for recycling used water to augment declining or overstressed sources of potable water are being studied and put to work in much of the Southwestern United States. Of the 13 known applications described by Trussell and Trussell in 2016, all but 2 are in 4 Western states, and 6 of those alone are in California. The Upper Occoquan Service Authority in Virginia operates a surface water augmentation program, and a similar surface water augmentation operation is operated by the Gwinnett Country Department of Water Resources in Georgia. The first published purposeful augmentation program of any type was the 1962 groundwater augmentation program by the Water Replenishment District of Southern California. A similar groundwater augmentation use of recycled water began in Orange County, California, in 1976. Beginning in 1999, the City of Scottsdale, Arizona, and a year later, the City of Los Angles, California, began potable groundwater augmentation. Groundwater augmentation programs began in 2009 and 2010 in Colorado, while Texas began a surface water augmentation program in 2013. California is also evaluating the feasibility of regulating two direct potable reuse approaches: (1) supplementing a source water aqueduct upstream of a drinking water withdrawal location or (2) by directly entering treated wastewater into a drinking water distribution system.

Summary

US wastewater system managers are enjoying the fruits of several decades of research in the treatment and reuse of wastewater. However, advocates of greater acceptance of the reuse of wastewater are still faced with the need to overcome a number of major challenges. Their systems must deal with a variety of competing operational demands that range from protecting public health, providing services to consumer, industrial and other customers, meeting domestic demand with little if any say in area economic development policies, accepting and processing the liquid wastes of industries, hospitals and institutions, to their constant requirement for maintaining environmental quality.

Added to these and related responsibilities, water and wastewater managers must prepare for and plan to deal with computer security and physical destruction threats to their infrastructure. Wastewater collection and treatment infrastructure is as critical to society as that of freshwater pipelines, roads, conduits, power supplies and the facilities in which they function (Van Leuven 2011). For those utilities operated combined sewer and stormwater systems, the threat of sanitary sewer overflow requires including stormwater management programs in all planning for dealing with flooding and other emergencies.

Like the managers of potable water systems, wastewater system managers face the daunting challenge of having to repair and replace much if not all of their aging infrastructure, let along build greater capacity to meet the needs of a growing population. Population growth and urban sprawl increase the collection (sewer) system needed to meet the demand increases. Renovation, renew and repair needs of the wastewater system can be more costly. If there is no renewal or replacement undertaken soon for the existing 600,000 miles of today's sewer systems, the amount of deteriorated pipe will increase from 10 to 44 percent of the total network by 2020. Investment in wastewater treatment systems is shifting from new construction projects to maintenance of original capacity and function of facilities, guided by their asset management and priorities plan.

The use of recycled or reused water, the source of which can be stormwater or treated wastewater, is increasingly accepted as a valuable resource available for augmenting stressed surface and groundwater potable supplies. The water is treated to different levels depending upon its final intended use. Public acceptance of recycled water to augment potable water supplies in arid and semi-arid regions of the country is increasing as droughts are occurring more often, lasting for longer and becoming hotter.

Additional Reading

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11

Managing Storm, Flood, and Runoff Water

Thus far in the book the discussion has focused on the first two arms of the water world: (1) freshwater from surface and groundwater sources we withdraw for human consumption, commercial, and industrial use, and (2) the collection and discharge of the wastewater effluent that is left after we are finished with its first use. This chapter begins the first of two chapters that look at three unconventional forms of water that are contributing to achievement of a modern sustainable resource: stormwater, urban runoff, and flood waters. Managing these unconventional water forms has become particularly important in all parts of the nation—but for very different reasons. Water managers in the sections of the country where shifts in precipitation patterns involve searching for cost-effective mitigation strategies, such as in the arid and semi-arid West and Great Plains states, the management task is how to take full advantage of these resources as a means of augmenting limited and increasingly stressed surface and groundwater supplies.

D.E. McNabb, *Water Resource Management*,
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Storm Water Management

As discussed in Chapter 4, the twin phenomena of population increases and growing urbanization of the United States are having a significant effect on the nation's water resources (NAS 2008). Although stormwater management can be applied in rural, agricultural areas, it is mostly considered an urban problem. Stormwater is rainwater or melted snow that runs off streets, lawns, and other sites. It may be collected in single-purpose storm drainage systems or collection systems that are combined with the wastewater system.

As more land is converted to urban and suburban areas, the natural flow of stormwater is altered forever. In direct systems, higher water volumes and urban-area pollutants are transported into rivers, lakes, and estuaries, degrading water quality and riparian habitat in most if not all urban stream systems. Untreated stormwater is generally directed directly into urban area rivers and streams. During extreme storm events, stormwater is collected in combined water and sewer systems that are unable to cope with extreme precipitation mixed with sewage. The result too often is overflowing of mixed raw sewage and polluted stormwater into the urban environment, as examples later will illustrate. Extreme storm events are predicted to increase in the Northern half of the country as a result of climate change and to increase in severity. The challenge facing urban administrators in finding ways of effectively coping with stormwater has been described by urban planners:

Across the country, jurisdictions have struggled for decades with how to manage storm water. They will likely face even greater future challenges as population and regulatory requirements both increase. Because jurisdictions must allocate limited funds among competing programs, stormwater management programs are commonly underfunded relative to identified needs. In addition, expenditures on stormwater-management programs are rarely evaluated for effectiveness and so they may neither address the most critical stormwater problems nor resolve the problems for which they were designed. (Visitacion et al. 2009, 150)

Stormwater is polluted by pet wastes, lawn fertilizers, rubber, oil and grease from trucks and automobiles, industrial operations, construction and demolition debris, and other sources flow directly into the water supply. Over extended single-purpose stormwater collection and drainage systems that directly discharge into a river or lake cannot help but pollute sensitive drinking water sources. The National Academy of Sciences estimates that urban stormwater now adversely affects 13 percent of the nation's rivers, 18 percent of all lakes, and 32 percent of estuaries into which it flows. These rivers and lakes water supply are often important water supply reservoirs. Moreover, structures and paved areas obviate the natural water-retaining ability of the soil and vegetation so that natural aquifer recharging no long occurs.

Since passage of the Clean Water Act (CWA) in 1972, the Federal government has incorporated storm, flood, and urban runoff water in its overall water policy. A new section was added to the CWA in 1987 to address the stormwater problem: the National Pollutant Discharge Elimination System. The policy focuses on reducing pollutants from industrial wastewater and urban sewage systems—what are called *point sources*. They do not address stormwater runoff.

The EPA began administering the National Pollutant Discharge Elimination System (NPDES) permit program to control water pollution by regulating point sources that discharge pollutants into the nation's freshwater resources. Stormwater either flows off impermeable surfaces such as streets where large amounts cause or contribute to floods instead of soaking into the earth where it can be absorbed by vegetation, is collected and piped or channeled to surface water bodies, or it is mingled with wastewater in sewers.

Mixed Stormwater and Wastewater

Combined sewer systems are wastewater systems designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. When stormwater is absorbed into the soil, it is naturally filtered and ultimately replenishes aquifers or flows into streams and rivers. When the stormwater appears at too fast a rate is cannot be absorbed into the ground. These waters can cause or add to floods that carry large amounts of surface pollutants into rivers, lakes, and ocean waters. They have become a major water pollution concern for the nearly 800 US cities with combined systems. Green Infrastructure, on the other hand, can mediate the damage. Green infrastructure includes approaches and technologies to capture and reuse stormwater to maintain or restore natural hydrologies (hydrology is the science of the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere; hydrologies are the systems that water moves through during its hydrologic cycle from earth, to air and back to earth).

Traditionally, combined sewer systems have transported mixed wastewater, stormwater, and urban runoff to a sewage treatment plant, where it is treated and then discharged as effluent into nearby surface waters. In times of extreme rainfall, the wastewater treatment facilities are unable to cope with the excess flow. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. Some designs utilize an overflow at the treatment plant that diverts the excess flow to chlorination facilities for disinfection prior to discharge. These overflows, called combined sewer overflows, contain not only storm water but also untreated human and industrial waste, toxic materials, and debris. Box 11.1 describes the trouble that can result when EPA investigation reveals mistakes a county waste treatment operation made in mismanaging its stormwater protection system.

Box 11.1 Failure to comply with EPA regulations results in fine for Kansas county

EPA Region 7 reached a settlement with a Kansas county waste landfill operation that requires the county to resolve its National Pollutant Discharge Elimination System (NPDES) permit violations under the Clean Water Act. As part of the settlement, the county is required to pay a cash penalty of $20,000. EPA investigations at the county 's Construction and Demolition Landfill and Transfer Station in 2015 found solid waste in storm drains, and what was determined to be the potential for contaminated stormwater runoff coming from scrap metal piles and other solid wastes. The county also failed to conduct self-inspections, monitor stormwater quality and conduct an annual comprehensive site evaluation—all activities required by the EPA for waste facilities and other stormwater sites.

As part of the settlement, the county is required to submit a report describing how it brought the operation into compliance with its NPDES permit within 90 days in addition to the cash penalty.

According to the EPA, material handling and storage, equipment maintenance and cleaning, and other activities at industrial facilities are often exposed to the weather. Runoff from rainfall or snowmelt that comes in contact with these activities can pick up pollutants, and transport them directly to a nearby river or lake, or indirectly via a storm sewer and degrade water quality. The NPDES permitting program in Kansas requires controls be in place to prevent stormwater from coming into contact with pollutants. Compliance with the facility's NPDES permit will help prevent unauthorized discharges into area surface waters and help ensure the health of the watershed.

Source: EPA news release March 3, 2016

When floods occur, stormwater and partially or untreated wastewater can be discharged directly into rivers, streams, or lakes, or backs up into residential streets and yards. Release of the excess flow is necessary to avoid flooding in homes, basements, and businesses and commercial centers. Hawaii has often been hard hit by excessive stormwater from heavy rain storms mixing with sanitary sewer flows. During the heavy rains that fell during winter of 2010 and 2011, Honolulu's combined stormwater and wastewater collection system was unable to cope with the flow, resulting in a number of raw sewage discharges into local surface waters. In one January 2011 night alone, the combined discharge resulted in nearly 33,000 gallons of untreated sewage released to the environment. Hawaii state and US Navy crews were called out to clean disinfect and deordize the overflow area. Overflows brought on by population growth and a combined system unable to cope with much heavier rains and normal sewage have continued to plague the Hawaii privately operated wastewater system. Combined stormwater and untreated sewage overflowed from manholes on roads in the vicinity of popular tourist beaches in 2014. Another reason for overflow problems has been the incursion of solid wastes carried into the sewage system by heavy stormwater flows. A major overflow in July of 2014, for example, from a sewer blockage was a blockage caused by tricycle parts, clothing, rocks, and sticks. The blockage caused overflow of raw sewage at a sewer manhole releasing more than 40,000 gallons of sewage into streams and canals leading to three popular surfing areas, resulting in closure of the affected beaches.

A similar but far more severe example was that of the aged sewage system of Indianapolis that has discharged as much as 7.8 million gallons of sewage and storm water into local creeks and rivers in a single year. A major infrastructure project had long been planned to correct the problem, but as of 2015 was still unfinished. A similar very large discharge of raw sewage occurred in Seattle, Washington in 2017.

Well into the twentieth century, municipalities around the globe regularly discharged the untreated or partially treated sewage and collected storm water into nearby freshwater sources or oceans. For example, the city of Seattle, Washington, long discharged its partially treated sewage into nearby Lake Washington until algal blooms and toxic conditions that led to fish die-offs. At its peak, 20 million gallons of effluent was dumped into the lake each day. Lake Washington was called "El Stinko" by local residents, whose complaints finally forced city and country administrators to remediate the problem. Conveniently, an even larger body of seawater, Puget Sound, was nearby. From 1963 to 1968, a massive tunnel and a new modern wastewater treatment facility were constructed that diverted Seattle's treated sewage effluent into the ocean instead of the lake. Lake Washington recovered and eventually became a clear lake again as its phytoplankton, zooplankton, and fish returned to their original composition. Most other similarly polluted lakes in the world cannot be so readily restored.

Managing Stormwater

The Center for Watershed Protection has identified three different approaches that communities manage stormwater: low-impact development (LID), green infrastructure (GI), and environmental site design (ESD). *LID* includes ecological protection systems and practices that enhance natural water cycle processes in economic development projects. LID practices enable or enhance the natural soil infiltration and evapotranspiration of stormwater, thereby protecting water quality and aquatic habitat.

The LID approach works with nature to manage stormwater as close to its source as possible by preserving and recreating natural landscape features, minimizing to overall construction of impervious elements in developments. The goal is to create functional site drainage that treats stormwater as a resource rather than a waste product. Its goal is to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and retain runoff close to its source instead of treating stormwater as a problem to be moved to drainage areas. LID uses small-scale landscape practices and design approaches that preserve natural drainage features and patterns.

The term *GI* to refer to the management of wet weather flows using LID processes such as natural areas that provide habitat, flood protection, cleaner air, and cleaner water. At both the site and regional scales, LID/GI practices aim to preserve, restore, and create green space using soils, vegetation, and rainwater harvest techniques. Practices used include bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. At the site scale, GI consists of site-specific management practices (such as interconnected natural areas) that are designed to maintain natural hydrologic functions by absorbing and infiltrating precipitation where it falls.

ESD copies natural system processes along the whole stormwater flow path by use of natural design principles throughout planning and developing the site. The objective is to replicate forest or natural hydrology and maintain water quality. ESD project design begins with including these practices at all stages of the design. They are then adhered to during construction and sustained as a low maintenance natural system. ESD's purpose is to reduce the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. Example practices include preserving natural areas, minimizing and disconnecting impervious cover, minimizing land disturbance, conservation (or cluster) design, using vegetated channels and areas to treat stormwater, and incorporating transit, shared parking, and bicycle facilities.

Stormwater Management Practices

Urban water managers have adopted a variety of structural and non-structural processes for controlling and managing the quality and quantity of urban runoff (Heaney et al. 2002). Structural processes range from constructed basins stormwater detention basis to roadside collection trenches. Nonstructural processes center on communications campaigns to inform and educate residents of the dangers of stormwater runoff. A list and brief description of the most commonly used methods is shown in Table 11.1.

Preliminary and site-specific results of the relative effectiveness of the practices vary with the predominant composition—solids or various

Table 11.1 Best practices used to control and manage urban stormwater

Practice	Description
Structural practices:	
Detention basins	Storage basins designed to empty after each storm; common in rapidly developing urban areas. Perform well in controlling local water quantity impacts of urban runoff
Retention basins	Similar to detention basins but for retention in a permanent pool; heavy amounts of stormwater discharged; increased physical and biological treatment occurs due to longer storage in the basins
Infiltration trenches	Used where space is limited. Runoff soaks into ground
Infiltration basins	Similar to retention ponds but used in flatter terrain; permeable soils and high rates of evapotranspiration necessary
Sand filters	Remove sediment and pollutants from runoff; filtered outflow is collected rather than infiltrated, then discharged or treated further
Water quality inlet	Treatment inlets modified to control some solids, oil and grease
Grassed swales	Vegetated channels used instead of concrete curbs and gutters. Pollutants are removed through filtration by vegetation
Vegetated filter strip	Vegetated filter strips adjacent to an impervious surface, gradually sloped to allow slow overland flow across vegetation

Table 11.1 (continued)

Practice	Description
Wetlands	Modifications of retention and pond/infiltration ponds to include a broad, shallow shelf periodically inundated by low events
Porous pavements	Modifications to asphalt pavements to allow some infiltration; berms used to trap and contain water and on site.
Nonstructural practices	Included such management practices as street sweeping, educational programs, etc.

Source: From material in Heaney et al. (2002)

dissolved heavy metals and other pollutants—of the materials contained in the stormwater. In the summary of results described in the 2002 report, "overall robustness" for all process ranged from low to moderate.

Flood Water Management

The National Atmospheric and Oceanographic administration annually publishes a list of the flood monetary damage and number of flood related fatalities for the water year that runs from beginning of a winter season in October 1 of a given year to September 30 of the following year. Direct flood damages for Water Year 2014 totaled $2.86 billion, with a total of 55 fatalities. The damage was approximately one-third the adjusted 30-year average of more than $8 billion and an annual average of 95 fatalities. Table 11.2 shows the dollar damages and number of fatalities in the 2014 water year for the most severely hit ten states. Flooding in Michigan was the most costly ($1.8 billion), while flooding in Texas accounted for the most fatalities (15). The August, 2014 floods in Detroit Michigan accounted for more than 60 percent of the total for the water year.

The increasing number of floods and the growing severity of the extreme weather events that result in floods considered a consequence of shifting weather patterns due to climate change. The Detroit flooding occurred after from four to six inches of rain fell in a four-hour period. A similar extreme precipitation event resulted in the 2016 flooding in Louisiana. The problem with establishing a comprehensive system to

Table 11.2 Ten most costly flooding and related deaths in the United States in 2014

Rank	State	Total damages	Fatalities
1	Michigan	$1,807,634,000	0
2	Texas	$214,935,300	15
3	Florida	$195,360,830	3
4	Illinois	$140,693,000	1
5	Ohio	$71,149,000	1
6	Tennessee	$52,225,000	2
7	Iowa	$46,219,800	1
8	Minnesota	$42,660,500	0
9	Alabama	$34,613,460	2
10	Arkansas	$29,883,000	0

Source: NOAA (2015)

manage flooding is the multi-agency, multi-level, mixed federal, state, and local oversight approach to water management that exists in the country. The American Water Resources Association (AWRA) described the difficulties in the existing system in 2013:

Historically, separate federal, state and local agencies have been given responsibilities with very different mandates, authorities, and missions relating to flood or drought management, making coherent flood and drought policy at the watershed level difficult. There is no coordinated, integrated set of assessment and evaluation programs, decision method, and funding mechanisms that work to prioritize actions that affect water resources objectives of flood control, drought mitigation, water quality protection, ecosystem preservation, and more. (AWRA 2013, 5)

Flood management is one arm in a three-process system along with flood mitigation and flood response. Flood management and response describe the actions taken by utilities, first providers, municipalities, states, agencies, and/or organizations to reduce or avoid the impact of a flood. Flood *management* is in large part the planning and administrative collection and ensuring that the needed human and material resources to deal with a flood are in place and available when and where they are needed. *Response* describes the strategy chosen to alleviate the damage. *Mitigation*, on the other hand, describes the actions taken to prevent or lessen the impact of a flood; mitigative actions are taken prior to a flood to lessen or moderate the force or intensity of a flood. Combined, they constitute a process of *proactive flood management*. AWRA defines proactive management as "an all-inclusive term" that includes all three actions when "planning and preparation for extreme conditions *before* difficulties associated with a flood" occurs (AWRA 2013, 6; emphasis in the original).

Four case studies of flood prevention and mitigation and planning activities were described in a 2013 collection of existing proactive flood and drought management systems. Flood cases included in the report were the Chehalis River Basin in Washington state, the Miami Conservancy District in Ohio, the Easton, Pennsylvania, flood prevention planning to 500-year flood level standards, and the Nashville, Tennessee, response to extreme damage from a major flood in 2010. The Chehalis River Basin example case is described here.

Flood Management in the Chehalis River Basin

The Chehalis River Basin is located approximately half way between the two largest pacific Northwest metropolitan areas, Portland, Oregon, and Seattle, Washington. The basin covers three Washington counties, seven municipalities, and two federally recognized Tribes. Interstate 5 (I-5) runs from the Canadian border, through Seattle, crosses the Columbia River border between Washington and Oregon, across Oregon and south through the California Central Valley to Los Angeles, San Diego, and the border between California and Mexico. It is the major economic artery of the tri-state area.

The area subject to flooding includes the Lewis County cities of Chehalis and Centralia along a five-mile stretch of I-5. Floods closed I-5 at Chehalis and Centralia for four days in both February 1996 and December 2007; flooding in January 2009 closed the same stretch for two days. The main stem of the Chehalis River runs west and northwest from the Cascade Mountains to the Pacific Ocean at Gray's Harbor. The Basin is most flat agricultural land that has long been subject to flooding. When floods occur, they inundate the I-5 freeway which is then closed to all traffic, resulting significant economic losses to the region. In

December 2007, the upper river basin flooded to record high, shutting down portions of the freeway, destroying homes, farms, and businesses, causing $938 million damage. Another flood occurred just 14 months later, again shutting down portions of the freeway in January of 2009. The Chehalis Basin Flood Authority was formed to explore flood mitigation alternatives. The story of this agency's was included in the AWRA report because of its remarkable ability to secure cooperation among the many different federal, state, local, and tribal stakeholders in a list of alternative river basin flood management projects. Although complete agreement on all proposed projects was not possible, much of their work was still progressing as this book was being written. Work on protecting the freeway from flood damage was nearly complete.

As part of the 2011 capital budget, the state legislature required the state's Office of Financial Management (OFM) to prepare a report on alternative flood-damage reduction projects and to recommend priority, flood-hazard mitigation projects in the Chehalis River Basin. The OFM report explored a range of alternatives to protect people and communities from flooding, including I-5 protection, constructing a dam for stormwater retention in the upper Chehalis, smaller scale infrastructure protection that included levees, floodplain management, and other projects. The objective was to identify the most cost-effective package of projects that would improve ecological and the natural floodplain function, as well as land-use management, maintain the important salmon habitat, and suggest weigh different approaches to reducing potential flood damages. The Chehalis Basin Flood Mitigation Alternatives Report was made available for public review in July 2012 and finalized in December 2012. Six I-5 protection project alternatives were evaluated.

In addition to six I-5 protection options, a scenario was studied that assumed construction of a dam on the Upper Chehalis River. Hydrologic and hydraulic modeling was undertaken in the Chehalis River Basin which predicted flood levels for a 100-year storm using the assumption that a dam would be constructed. The results of this analysis indicate that a dam would reduce flood elevations throughout much of the upper Chehalis Basin, and in the Centralia and Chehalis area. As modeled, a dam would not fully protect I-5 from flood events like those in 1996, 2007, and 2009, or in a simulated, 100-year flood event, but the duration of I-5 closures in those storm events would reduce significantly. In a simulated 100-year flood event without a dam results indicated that I-5 would be closed for approximately five days. However, with construction of a dam, in a simulated 100-year flood event, results indicated that I-5 would only be closed for approximately one day.

Flood Mitigation

Flood damage reduction projects considered included large- and small-scale capital projects, ecosystem projects, land-use management, and flood warning and preparedness programs. Large scale projects included a dam and reservoir in the upper basin and construction items to protect the I-5 freeway, including raising the highway. Small-scale projects included levee construction, water and wastewater treatment infrastructure protection, and livestock and farm equipment protection.

Ecosystem-based projects included aquatic species enhancement projects, floodplain restoration, riparian and wetland habitat enhancement, and river and stream erosion control projects. Land-use management projects included action of the 128 flood endangered structures for raising or buyout, and assessing the potential for action of additional structures with FEMA guidelines. Flood warning and preparedness projects included a flood data website and additional observation equipment.

Ecology Impact Statement

The Washington State Department of Ecology issued an Environmental impact statement in late September of 2016 that included four options. A fifth option to not do any of the projects introduced by the Flood Authority was not included, but neither was it removed entirely from consideration.

The first alternative, which was recommended by the 2014 Governor's Work Group, includes building a dam on the Chehalis River, airport levee improvements and levees in Aberdeen and Hoquiam. Two options exist for the dam. One called for a dam that lets water flow freely until a big storm approaches, when it would be shut, creating a temporary reservoir. The second dam option would create a closed dam with a permanent reservoir.

The second alternative keeps both levee projects and adds levees along I-5, but does not include a dam or reservoir. The third alternative does not include any large structural, state-funded projects like a dam, but instead focuses on local flood damage reduction projects and aquatic species (primarily salmon) habitat restoration actions, which was also an underlying conditions in all four options. Alternative four includes the state buying some 21,000 acres of riverfront land in the upper basin and conducting restorative work, including planting a substantial greenbelt and creating obstructions in the water to slow its flow. During a storm, water would back up along these portions of the river, and overflow into historic floodplains, reducing flood damage in populated areas downstream and greatly expanding fish habitat. It would also move people out of the floodplain.

In 2016, the state legislature allowed the creation of an Office of the Chehalis Basin, which would direct the implementation of large-scale projects.

Managing Urban Runoff

In cities and other developed areas, paved-over surfaces such as roads and parking lots and roofs prevent precipitation from naturally soaking into the ground. Instead, the water that runs off these impervious surfaces usually moves rapidly into storm drains, sewer systems, drainage ditches and ultimately into rivers, lakes, and streams. This can result in any one or more of the following outcomes:

- Downstream flooding
- Stream bank erosion
- Increased turbidity (muddiness created by stirred up sediment) from erosion

- Habitat destruction
- Combined sewer overflows
- Infrastructure damage
- Contaminated streams, rivers, and coastal water

The NPDES program is a key element of the Federal CWA aimed at controlling and reducing water-borne pollutants discharged from point sources such as wastewater, stormwater, and urban runoff water. In most states, the local state department of ecology has been given jurisdiction for implementing the federal NPDES program. In implementing this program, the state agency issues permits to cover individual facilities or groups of multiple treatment organizations with common activities under a general NPDES permit. These permits require the organizations to meet federal minimum requirements. The NPDES program requires permits for large, medium, and small Municipal Separate Storm Sewer Systems (MS4s) as defined in federal regulations. The Phase I regulations of the MS4 program went into effect in 1990 and applies to medium and large MS4s in cities with populations of more than 100,000.

Working through individual state environment departments, municipal governments and local agencies, the Environmental Protection Agency has implemented a nation-wide sustainable stormwater management program (also called LID or GI). Sustainable stormwater management focuses on reducing runoff and improving water quality; LID practices help maintain natural hydrologic cycles through site grading, vegetation, soils, and natural processes that absorb and filter stormwater onsite. They also help minimize erosion, flooding, and water pollution downstream from developed areas. Some of the GI and LID practices EPA had helped apply on government structures and encourage private and municipal organizations to adopt for reducing harmful stormwater runoff and pollution are:

Green roofs. These are office building, apartment, and industrial facility roofs that are covered with vegetation filters and facilitate evapotranspiration of stored water. A green roof can also reduce the effects of atmospheric pollution, reduce energy costs, decrease the “heat island” effect, and create an attractive environment.

Rain barrels and cisterns. Rain barrels and cisterns harvest rainwater primarily from rooftops for reuse. Rain barrels are placed at roof downspouts, and cisterns store rainwater in larger volumes in tanks for use in non-potable applications such as toilet flushing.

Permeable pavements. Permeable surfaces, unlike impermeable surfaces such as asphalt or concrete, allow stormwater to infiltrate through porous surfaces into the soil and groundwater. EPA parking lots, driveways, or sidewalks include pervious concrete, porous asphalt, pervious interlocking concrete pavers, or grid pavers.

Bioretention areas. Bioretention areas are shallow, landscaped depressions that allow runoff to pond in a designated area, and then filter through soil and vegetation. Small-scale bioretention areas are also known as rain gardens.

Vegetated swales/dry swales. Swales are drainage paths or vegetated channels used to transport water. They can be used in small drainage areas with low runoff instead of underground storm sewers or concrete open channels. Swales help slow runoff, facilitate infiltration, and filter pollutants as runoff flows through the system.

Curb and gutter elimination. Curbs and gutters collect and transport runoff quickly to a stormwater drain without allowing for infiltration or pollutant removal. Eliminating curbs or adding curb cuts allows runoff to be directed into open, unpaved areas and filtered through LID features. Swales can also be used to replace curbs and gutters as a way to convey runoff.

Vegetated filter strips. Planted filter strips are bands of dense vegetation through which runoff is directed. Filter strips may treat runoff from roads and highways, roof downspouts, very small parking lots, and impervious surfaces.

Sand and organic filters. Runoff directed to these filters infiltrates through a sand bed to remove floatables, particulate metals, and pollutants. They are typically used as a component of a treatment train to remove pollution from stormwater before discharge to receiving waters, to groundwater, or for reuse.

Constructed wetlands. Constructed wetlands mimic natural wetlands. They capture and filter stormwater and create diverse wildlife habitat.

They are designed to contain standing water on the surface or water saturated just below the soil surface.

Riparian buffers. A riparian buffer is an area along a shoreline, wetland, or stream where development is restricted or prohibited. The primary function is to physically separate and protect the aquatic area from future disturbance or encroachment. A properly designed buffer can act as a right-of-way during floods, sustaining the integrity of aquatic ecosystems and habitats.

Summary

The mega-trends affecting America's water resources today are making it imperative for water managers take a more holistic view of their water resources. For many, storm, flood, and urban runoff water have become a viable augmentation resource as well as an environmental problem to overcome. For most of the country, augmenting normal surface or groundwater resources has joined with water supply and conservation as a strategy for achieving resource sustainability. It is common in the literature of water management to see stories of how utilities large and small are beginning to include water recycling and reuse, beneficial use of gray water, stormwater for aquifer recharge, and rainwater harvesting in their operational planning. What was once looked upon wastewater has become a valuable resource. This chapter looked at management issues for storm, flood, and urban runoff water.

Stormwater management can be applied in rural areas to harvest precipitation water for livestock watering or irrigation, but is more commonly used in urban areas where runoff cannot be absorbed because the surfaces are impermeable. As used in water management, the term stormwater refers to an abnormally large amount of surface water due to a heavy rain or snow. In urban areas, it may be collected in single-purpose storm drainage systems or in collection systems that are combined with the wastewater system. Stormwater runoff becomes a problem when rain or snowmelt flows over an impervious land surface. The addition of roads, driveways, parking lots, rooftops, and other surfaces that prevent water from soaking into the ground increases the runoff volume created during storms. This runoff then enters local streams, lakes, wetlands, and rivers. Large amounts of swiftly moving water can cause flooding and stream bed erosion. Stormwater runoff also carries with it many different pollutants that are found on paved surfaces such as sediment, nitrogen, phosphorus, bacteria, oil and grease, trash, pesticides, and metals. Stormwater runoff is the number one cause of stream impairment in urban areas.

The United States has a long history of investments in projects to eliminated, control, or mitigate flooding. However, stopping rivers from flooding entirely just is not possible. What can be done is to mitigate and manage the risks that arise from flooding. The US Corps of Engineers and the Bureau of Reclamation have constructed and manage hundreds of dams and other river flood control projects.

Flood management strategies generally involve multiple engineering projects that can fall under one of two categories: (1) construction of artificial structures such as dams designed to prevent a river from flooding and/or store surface water for discharge during dry periods and (2) projects use natural resources and local people's knowledge of the river to reduce the risk posed by a flood, such as floodplain management, repairing riparian ecosystems, and others.

Extreme weather events that result in extremely heavy downpours have increased in frequency and intensity in all parts of the country in the last 50 years. They are expected to become more frequent and intense as global warming continues. As a result, the risk of flooding is likely to increase dramatically across the United States.

The average 100-year flood is projected to increase 45 percent by the year 2100 and damages from flooding are predicted to increase by an average of $750 million every year. Among the types of flooding that will likely become more frequent are localized floods and riverine floods. Localized flooding happens when rainfall overwhelms the capacity of urban drainage systems, while riverine flooding happens when river flows exceed the capacity of the river channel.

Urban runoff consists of water that has drained from man-made nonporous surfaces in densely populated areas. These surfaces consist of roads, freeways, sidewalks, roofed structures, parking lots, airports, and industrial sites, among others. All forms of precipitation can wash away the materials on top of and from which the surfaces are made. Urban surfaces are predominantly impervious (non-porous). They cannot filter or biodegrade contaminants as natural soil does. Suspended sediment is the primary pollutant in urban runoff, but is also contain oil, grease, pesticides, road salts, metals, pet wastes, bacteria, and toxic chemicals from automobiles and trucks.

The threat to human health by urban runoff is not only due to materials scoured from surfaces but also from the infrastructure of the sewer system. Stormwater systems are often combined with sanitary sewer systems. Excessive storm water can cause this combined system to overflow, resulting in contamination of waterways and urban surfaces by sewage. It is common for many urban dwellers to dispose of toxic household chemicals, old pharmaceuticals, used motor oil, and paint directly into storm sewers. Urban runoff collected by single-purpose storm sewers is usually discharged directly into waterways. As a result, many sources of discharge go uncontrolled and untreated. According to the EPA approximately 20 percent of the population is served by combined systems.

Additional Reading

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12

Managing Recycled Water

As the chapters on wastewater and storm, flood, and urban runoff water have shown, recycled water has come to be a valuable resource rather than just a nasty problem that was to be given a minimally acceptable level of treatment and sent on its way down rivers or into the sea. California, severely hurt by prolonged and repeated droughts, has revered this traditional view, officially declaring that not to take advantage of it is wasteful and now illegal: "The State Water Board declares . . . it is a waste and unreasonable use of water for water agencies not to use recycled water when recycled water of adequate quality is available and is not being put to beneficial use . . . the Board shall exercise its authority . . . to the fullest extent possible to enforce the mandates of this paragraph" (California State Water Resources Control Board 2013).

The EPA defines water recycling as "reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge" (2012b). The key point is that recycled or reclaimed wastewater is water than has already been put to a previous use and then processed again to bring it to

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standards fit for a second or more use. Technology now makes it possible to tailor the treatment to meet the water quality requirements of a planned reuse. Categories and classes of recycled/reused water and EPA-approved descriptions of each are included in Table 12.1. EPA standards for recycled water use by levels of treatment are shown in Fig. 12.1.

Federal Recycled Water Policy

Federal water policy includes a wide variety of uses for recycled water that includes reuse in urban and domestic applications for food and non-food crops, or industrial and environmental purposes, and for impoundment and groundwater recharge. Nationwide, the greatest use for reclaimed water remains for agriculture. In 2011, agriculture use comprised nearly 30 percent of the total reuse in the United States. Increasingly, accepted reuses for what was formerly used once and discarded wastewater includes human consumption. However, the treatments required for these different uses differ from use level to level. Recycled water has long been used for landscape irrigation; this use requires less treatment than recycled water for drinking water.

Water reuse involves taking domestic wastewater, giving it a high degree of treatment, and using the resulting high-quality reclaimed water for a new, beneficial purpose. Extensive treatment and disinfection ensure that public health and environmental quality are protected. The percentages of various wastewater uses are shown in Table 12.2, with agriculture leading the list at 29 percent.

Although the value of wastewater as a resource was known for many years, its actual use as a way of augmenting declining potable water supplies has only come to be generally accepted in modern times. The first large-scale use of treated wastewater for recharging a groundwater aquifer occurred when the Whittier Narrows Water Reclamation Plant was built in Rosemead, California, by the Sanitation Districts of Los Angeles Country. The system is located in The San Gabriel River Watershed covers more than 640 square miles and includes portions of

Table 12.1 Categories and classes of water reuse and their applications

Reuse category	Description
Urban reuse	
Unrestricted	The use of reclaimed water for non-potable applications in municipal settings where public access is not restricted
Restricted	The use of reclaimed water for non-potable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction
Agricultural reuse	
Food crops	The use of reclaimed water to irrigate food crops that are intended for human consumption
Nonfood crops and processed food crops	The use of reclaimed water to irrigate crops that are either processed before human consumption or not consumed by humans
Industrial reuse	The use of reclaimed water in industrial applications and facilities, power production, and extraction of fossil fuels
Environmental reuse	The use of reclaimed water to create, enhance, sustain, or augment water bodies, wetlands, aquatic habitats, stream flow
Impoundment use	
Unrestricted	The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities
Restricted	The use of reclaimed water in an impoundment where body contact is restricted
Groundwater recharge: non-potable reuse	The use of reclaimed water to recharge aquifers that are not used as a potable water source
Groundwater recharge: potable reuse (IPR)	Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment (indirect potable recharge)
Direct potable recharge (DPR)	The introduction of reclaimed water (with or without retention in an engineered storage buffer) directly into a water treatment plant, either collocated or remote from the advanced wastewater treatment system (direct potable recharge)

Source: EPA (2012b)

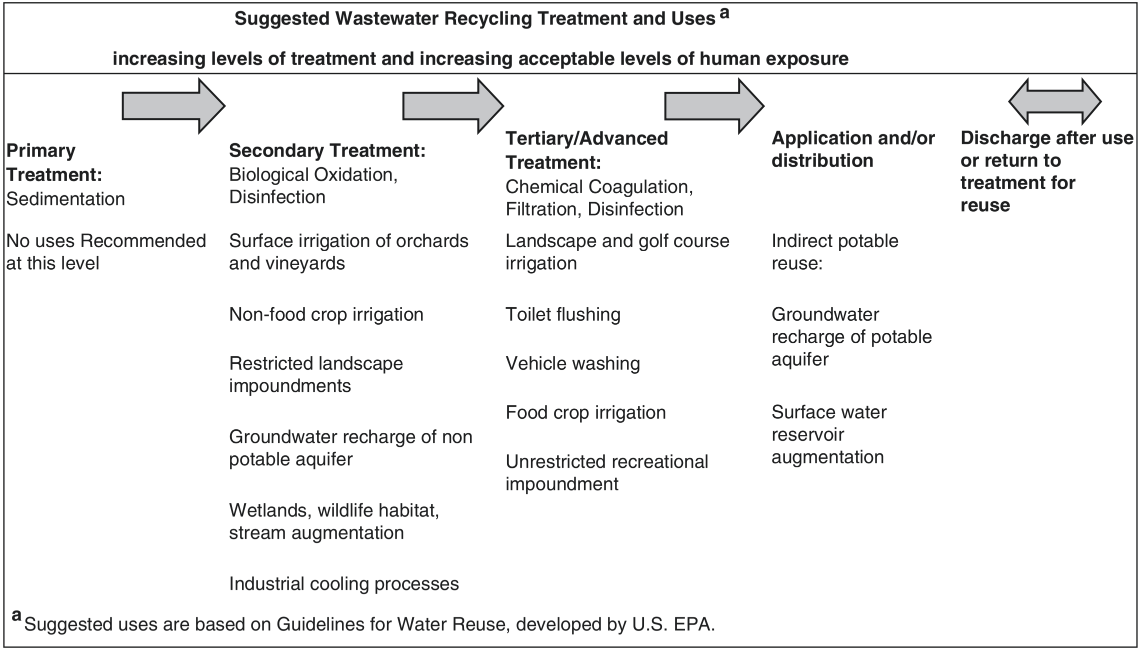

Fig. 12.1 Wastewater treatment levels and suggested uses for recycled water
Source: EPA (2012b)

Table 12.2 Nationwide uses of reclaimed water in 2011

Rank	Type of reuse	Percentage of total reuse
1	Agriculture, including livestock and silviculture	29
2	Landscape and golf course watering	18
3	Seawater barrier	8
4	Commercial and industrial	7
5	Recreational impoundment	7
6	Groundwater recharge	5
7	Natural habitat, wetlands, wildlife habitat restoration	4
8	Geothermal energy generation	2
9	Indirect potable reuse	<1
10	Surface water augmentation	<1
11	All other uses	20

Source: EPA Guidelines for Reclaimed Water Reuse (2012b)

37 cities in Los Angeles and Orange Counties, as well as communities in unincorporated Los Angeles County. More than one-third of the upper watershed falls within the Angeles National Forest, including significant portions of the San Gabriel Mountains.

The original plant began operation on July 26, 1962, to demonstrate the feasibility of large-scale water reclamation. The original plant employed primary and secondary treatment only. A replacement facility in 1978 added tertiary treatment with a capacity of treating 15 million gallons of wastewater per day. All the reclaimed water is reused in the Upper San Gabriel Valley Municipal Water District and as groundwater recharge in the Rio Hondo and San Gabriel Coastal spreading grounds. The recycled water system had grown to include five reclamation treatment plants capable of processing a total of 80 million gallons of wastewater daily.

Spreading grounds, former gravel mining pits, are a very important part of the local water supply infrastructure. These large ponds temporarily hold surface, storm, and reclaimed water long enough for the water to percolate through the bottoms and sides of the ponds to replenish the groundwater basin. The basins are fed by allocated water from the San Gabriel River. Water from the river is derived from different sources, depending on the time of year. During the rainy season, water is derived from storm runoff, both from the mountains and from the urban areas that drain to the river. This is mixed with water from the Water

Reclamation Plants. Between storms and during the dry season, water for groundwater recharge is provided by releasing water held at upstream reservoirs, adding water from the plants, and by imported water bought from the Metropolitan Water District of Southern California (with some nuisance runoff from urban areas). The amount of water being recharged to the basins is carefully controlled. Over a ten-year period an average of 63,000 acre feet of imported water and 47,000 acre-feet of reclaimed water was recharged annually (LACDPW 2006).

Selected examples of the published research on recycle water use in the 1970s focused on the use of recycled water in industrial applications (Vaughn 1971, Kollar and Brewer 1977, Milliken and Trumbly 1979). Vaughn, taking note of the large increase in manufacturing coupled with population growth in the United States since the 1950s, repeated the often-repeated prediction that industrial use of water would soon exceed the available supply and that industrial would have to soon “close the loop” and reuse most of if not all of its water. In 1971, the cost associated with treating recycled water to a point where it could be used in many industrial applications was still to great to make it a common event.

Citing research by the US Water Resources Council, Kollar and Brewer called for greater attention to be paid to the interrelationship between industrial growth and water resources. The growth of the manufacturing sector’s demand of municipally supplied water was projected to be as great or greater than that of the US population served by municipal systems. Hence, the sustainability of such systems needed to be analyzed. Industrial demand was largely centered on withdrawals by 12,000 large manufacturing plants, each of which withdrew or was supplied an average of 27,000 gallons of freshwater each day—a demand not deemed to be sustainable over the 25 years from 1975 to 2000 for processing and cooling purposes. A need to eventually turn to unconventional sources was predicted: “There are a number of reasons to anticipate an increase in recycled wastewater as replacements for new water intake. Industrial expansion of 150 percent in 25 years may overtax available supplies in many of the areas where growth occurs. Allocations and reallocations of water between other expanding uses, such as irrigated agriculture, thermal electric power generation, coal, oil and fuel conversions, may impose artificial limits as may environmental considerations . . . and other federal and state legislation" (Kollar and Brewer 1977, 470).

Writing in 1979, Milliken and Trumbly saw increasing support in for the concept of reusing municipal wastewater, despite what they referred to as the large number of people who continued to view the idea of having treated wastewater "coming through their household water taps with aversion." They added a problem-limiting acceptance of water reuse by municipal water utilities at the time was the need for finding the huge sums needed to pay for the high cost of developing new municipal and industrial water supplies as traditional sources of freshwater dwindle and the equitable apportionment of existing supplies (for residential, industrial, and agricultural users) becomes more difficult. Under the then-existing high cost of treating wastewater and the aversion to including recycled water in with potable supplies, they concluded that for the rest of the twentieth century, use of recycled water was more likely to be adopted by industrial and agricultural water users. Pointing to the approval by the Denver (Colorado) Water Board's 1979 decision to construct a $21.6 million demonstration plant to recycle 3 million gallons of wastewater into safe drinking water per day as an example, they concluded: "Supply agencies will need relatively large-scale funding in order to construct wastewater reclamation facilities, but these costs may amount to less than . . . those required to develop new conventional supply resources" (Milliken and Trumbly 1979, 555). The public would have to be convinced through publicity and education that wastewater is a safe and preferable alternative to other water supply developments before recycling water for extensive augmentation of potable water.

Time and climate change, population growth and urbanization of large amounts of former farmland has seen the public's ultimate acceptance of treated wastewater for many uses, particularly so as a supplemental source of water for agricultural irrigation (Ahmadi and Merkley 2009).

Managing Recycled Water at the State Level

The challenges to acceptance of the idea of wastewater as a valuable resource for use other than industry and agriculture have been addressed in the past decade. The force driving acceptance has been the prolonged priors of severe drought. The change in attitudes has been extant long enough for the use of recycled water to become recognized as a total water resource necessity and an accepted position in the water policies of the United States. Successful programs exist in California, Arizona, and Texas, to the same just several areas where recycled water is helping to meet the water needs of the semi-arid West. Similar programs are being implemented in regions of the country such as Florida and other Southern states where over-use is the problem, not the lack of rainfall. These states lead the Nation in the search for alternative sources of water; these four alone account for 90 percent of all reclaimed water use in the United States. The reclaimed water policies and practices of each of these four states and local examples in each are described in the following.

Reclaiming and Reusing Wastewater in California

California, in the midst of a multi-year drought, issued its latest recycled water policy report in April of 2013 in which it described the foundation for its comprehensive water policy. A partial list of allowed uses at the four main classes of wastewater treatments is shown in Fig. 12.2. At the highest level, disinfected tertiary treatment, the water reclaimed can be used for almost exactly like normal freshwater. More important, there are a number of used possible for treated water at every level of treatment.

Declaring what it termed is "independence from relying on the vagaries" of annual rainfall and the mountain snowpack, the State Water Board warned that the State had to focus on a sustainable water supply that included enhanced water conservation, water reuse and the use of stormwater. Implementation of the revised water policy was expected to enable the state to meet the following four goals:

Example Uses	Disinfected tertiary treatment	Disinfected secondary 2.2 treatment	Disinfected secondary 2.3 treatment	Undisinfected secondary treatment
Irrigation for:				
Food crops, no human contact	All uses allowed	Not allowed	Not allowed	
Parks, playgrounds, freeway landscaping				Not allowed
Food crops, no recycled water contact				
Cemeteries				
Nonedible vegetation		Allowed	Allowed	
Orchards and vineyards, no edible portion				
Ornamental landscaping				Allowed
Impoundment:				
Nonrestricted recreational impoundments			Not allowed	
Restricted recreational impoundments	All uses allowed	Allowed	Not allowed	Not allowed
Landscape impoundments				
Landscape impoundments, no decorative fountains		Allowed		Allowed
Cooling or Air-conditioning:				
Industrial Cooling/AC that creates a mist		Not allowed	Not allowed	Not allowed
Industrial Cooling/AC without mist		Allowed	Allowed	
Other:				
Flushing toilets/urinals				
Car Washes	All uses allowed	Not allowed	Not allowed	Not allowed
Industrial process, no human contact				
Cleaning roads, dust control		Allowed	Allowed	
Flushing Sanitary Sewers				Allowed

Fig. 12.2 Examples of recycled water use allowed in California

Source: California State Water Resources Board

- Increase use of recycled water over 2002 levels by at least one million acre feet per year by 2010, and by at least two million by 2030.
- Increase the beneficial use of stormwater by at least 500,000 acre feet by 2020 and by at least one million acre feet by 2030.
- Increase the amount of municipal and industrial water used by more than 20 percent in 2020 over amounts used in 2007.
- Substitute by 2030 as much recycled water for potable water as possible.

Recycled Water Use

Cities and counties throughout the length of California have embraced the use of recycled water; recycled water approved for reuse is particularly important landscape watering applications and is becoming increasingly used is some agricultural uses. California is among the major players worldwide in water recycling. There are over 250 water recycling plants currently operating in the state, with more planned for the future. According to the California Department of Water Resources, the state recycles anywhere from 450,000 acre-feet to 580,000 acre-feet of wastewater annually, which is almost three times the amount recycled in 1970.

About two-thirds of the state's recycled water is used for irrigation, with about 46 percent used for agriculture and another 21 percent used for landscaping. About 14 percent is used for groundwater recharge, while 19 percent goes to all other uses (ACWA 2016). Examples of successful programs are found in San Diego, Los Angeles County, and San Jose.

Reusing Water in San Diego

To meet future water demands while reducing its dependence on imported water, the City of San Diego has built two water reclamation plants, each of which treat wastewater to a level that is approved for irrigation, manufacturing and other non-drinking, or non-potable purposes. Rules and regulations for the reuse of water in San Diego cover such topes as making sure all pipes, sprinkler heads, meter boxes, and other irrigation equipment are properly marked or color-coded purple and properly labeled signage to distinguish them from potable water supplies (traditionally, recycled water pipelines are generally colored purple everywhere). Approved uses of recycled water include the irrigation of these facilities:

- Parks
- Playgrounds
- School-yards
- Residential landscaping
- Common areas
- Garden nurseries
- Freeway landscaping; and
- Golf courses

Additional approved uses for water recycled at the San Jose treatment plant include recreational water bodies used for fishing and boating and as source water for industrial processing, commercial laundries, and soil compaction.

Recycled Water in Los Angeles County

The West Basin Municipal Water District in Southwest Los Angeles County has solved the problem of gaining greater customer acceptance of the idea of recycled water by custom designing recycled water treatment levels to meet the specific needs of a variety of customers, and in some instances by offering recycled water on long-term contracts. With this customer-centered reuse policy West Basin considered itself having evolved from just a supplier of recycled water to "a business partner, making a concerted effort to understand each customer's operation and culture. This deepens the customer's commitment to recycled water uses and has led West Basin to continually expand recycled water use" (Goldman 2016, 25).

West Basin produces recycled water that has undergone treatment to any one of five different levels of processing desired by its customers. The first level is what is considered to be the standard disinfected tertiary-treated level for wastewater that has been approved for irrigation and similar uses. Other levels include

- Nitrified water is typically recycled wastewater, groundwater, or industrial process water and some surface storm runoff water from which ammonia has been removed, often with the use of detergents of the addition of nitrites and nitrates; this treated water is then used in industrial cooling towers that typically consist of large amounts of copper tubing that is highly sensitive of damage from high concentrations of ammonia.
- Secondary-treated wastewater that has undergone pure reverse osmosis microfiltration and disinfection. This recycled water is used as water in low-pressure steam boilers.
- Ultra-pure reverse-osmosis filtration disinfected reuse water that has undergone a second microfiltration necessary for its use as feedwater for high-pressure steam boilers.
- Water for indirect groundwater recharge that has been pre-treated with microfiltration, received secondary treatment, followed by reverse osmosis filtration and disinfection using hydrogen peroxide and ultraviolet light.

Recycled Water in Burbank

Municipal water systems with 3,000 or more connections or delivering 3,000 acre-feet of water annually are required to prepare an urban Water Management Plan every five years over a 20-year horizon. Burbank's 2015 population was 106,084. The City of Burbank's water utility (BWP) has more than 26,000 water connections and supplies between 15,000 and 19,000 acre feet of potable water annually. BWP's receives surfacewater from the Metropolitan Water District (MWD) and its own groundwater resources. MWD imports water from Northern California by the State Water Project and from the Colorado River by the Colorado River Aqueduct. Wastewater is treated in the Burbank Water Reclamation Plant (BWRP), which in 2015 treated 8.5 million gallons per day. BWRP produces a disinfected tertiary effluent; up to 10,000 acre feet of recycled

Table 12.3 Burbank 2015 recycled water use, 2010 projection for 2015 and actual (MGD)

Use type	2015 projected in 2010	2015 actual use
Agricultural irrigation	0	0
Landscape (excludes golf courses)	975	936
Golf course irrigation	300	222
Commercial use	525	150
Industrial use	1,360	0
Geothermal and other energy production	0	1,155
Seawater intrusion barrier	0	0
Recreational impoundment	0	0
Wetlands or wildlife habitat	0	0
Groundwater recharging	0	0
Surface water augmentation	0	0
Direct potable reuse	0	0
Other	500	0
Total	3,660	2,463

Source: Burbank Water Plan (2016)

water per year is available for reuse in any one of three ways: landscape irrigation at the BWP campus, pumped into an existing recycled water distribution system, or discharged into the Los Angeles River.

Recycled water is used in three general categories within the city: power production, landscape irrigation, and evaporative cooling. The city can provide up to 10,000 gallons of treated recycled water per day. Recycled water has been used in power production since 1967. This use was expanded in 2005 when a 310 MW natural gas fired turbine power plant was constructed in Burbank. The plant uses approximately 1,350 million gallons of recycled water per day for cooling and all other power plant uses, including high-purity boiler feed. Table 12.3 lists all other uses of Burbank's recycled water.

Recycled Water Use in Silicon Valley

South Bay Water Recycling (SBWR) in San Jose in the heart of California's Silicon Valley provides a sustainable, high-quality reclaimed water supply that reduces the region's dependency on imported water while preserving drinking water supplies for current and future generations. Administered by the city, the SBWR system consists of over 130 miles of pipeline, 5 pump stations, and over 690 customers. Recycled water is also available for construction purposes. San Jose has set a goal to recycle or beneficially reuse 100 percent of our wastewater (100 million gallons per day) by 2022.

Reclaiming and Reusing Wastewater in Arizona

Arizona was one of the first states to reuse treated wastewater, installing a water reclamation facility in 1926 that converted wastewater into water safe to use for irrigation and toilets. The City of Phoenix began reclaiming water after treatment for agricultural use in 1932; the first state rules for reclaimed water were issued in 1972 by the Arizona Department of Health; in 1983, reclaimed wastewater was delivered to the Palo Verde Nuclear generating facility for use in cooling. And, in 1984 the state's first full-scale program for reusing reclaimed water from the Tucson Sweetwater facility for recharging a groundwater aquifer. In 2015, Tucson Water, the municipal utility, delivered reclaimed water for irrigation to nearly 1,000 sites, including: 18 golf courses, 50 parks, 65 schools, including the University of Arizona and Pima Community College; and more than 700 single family homes.

The entire state of Arizona has looked to reclaimed water to augment severely limited existing sources at least since 1999, when the Department of Environmental Quality (ADEQ) was granted authority to regulate and issue permits for all water reclaiming in the state. This included setting and monitoring reclaimed water quality standards. Issuing permits for any direct use of reclaimed water, and technical standards for open channels and pipelines. Revisions in 2001 expanded regulatory focus and set approved uses for five classes of reclaimed water, A+ through C as shown in Table 12.4. By the second decade of the new century, 65 percent of all sewage treatment plants in Arizona distributed various classes of treated wastewater for reuse.

A comprehensive narrative of Arizona's water problems and programs was produced by the Arizona Department of Water Resources (ADWR) in 1999 focused on the state's Augmentation and Recharge Program. Since that early work, most cities and many counties in Arizona have either adopted or are

Table 12.4 Classes of reclaimed water and allowed reuses in Arizona

Class	% of permits issued	Definition	Allowed uses
Type A+	72	For reclaimed water for direct reuse where there is a high risk of human exposure to potential pathogens	Same as A but requires advanced treatment and more stringent nitrogen limitations
Type A	2	For reclaimed water for direct reuse where there is a relatively high risk of human exposure to potential pathogens in the reclaimed water	Irrigation of food crops, recreational impoundments, residential and schoolyard landscape irrigation, open access landscapes, toilet and urinal flushing, fire protection systems, spray irrigation of an orchard or vineyard, snowmaking
Type B+	13	For uses where access by general public is controlled but restricted	Same as B but requires advance treatment
Type B	9	For uses where access by general public is controlled but restricted	Surface irrigation of an orchard or vineyard, golf course irrigation. Restricted access landscape irrigation, landscape impoundment (as it water traps, etc.), dust control, pasture for dairy animals, livestock watering and concrete mixing
Type C	3	For reclaimed water reuse where there is little chance of contact by the general public	Pasture for non-dairy animals; livestock watering for non-dairy animals, irrigation of sod farms, irrigation of fiber, seed, forage and similar crops, silviculture

Source: Arizona Department of Environmental Quality (2016)

examining the possibility of augmenting water supplies with reclaimed water. Additional master plans have followed the first master plan.

The ADWR has designated areas in the state where groundwater depletion is most severe as Active Management Areas (AMAs). There are five AMAs: Prescott, Phoenix, Pinal, Tucson, and Santa Cruz. Water withdrawals in the AMAs are regulated according to the Groundwater Code. In the Phoenix, Prescott, Tucson, and Santa Cruz AMAs, the primary management goal is safe-yield by the year 2025. Safe-yield is accomplished when no more groundwater is being withdrawn than is being annually replaced. In the Pinal AMA, where the economy is primarily agricultural, the management goal is to preserve that economy for as long as feasible, while considering the need to preserve groundwater for future non-irrigation uses. Each AMA carries out its programs in a manner consistent with these goals, while considering and incorporating the unique character of each AMA and its water users. Provisions for aquifer recharge programs included in the Groundwater Code allow injection of surface water or treated wastewater into an aquifer for stored for future use.

Reclaiming and Reusing Wastewater in Texas

The Texas 2012 master water plan included a reuse strategy discussion that focused on the need for and accepted reuse of reclaimed or recycled water in the state. The report estimated that the existing supply from reuse of water will reach of 614,000 acre feet (4,787,200 gallons) of water per year by 2060, with new water supplies from water reuse adding another 915,000 acre feet (6,844,200 gallons) of usable water to the 2060 total.

The plan then related the two methods, direct reuse and indirect reuse, of putting reclaimed water to use to the situation in Texas. *Direct reuse* refers to reclaimed water from a water reclamation facility that is introduced directly into pipelines, storage tanks, or other distribution infrastructures. *Indirect reuse* is returning treated and purified wastewater to a water supply source such as a lake, river, or aquifer where it mixes with existing water sources and then withdrawn once again for reuse. Both direct and indirect water can be treated and purified to standards that makes it suitable for human consumption (potable), or to a standard that it is not suitable for human consumption (non-potable). Reclaimed water is thus classified into four separate use-classes that are recognized throughout the United States:

- Direct potable reuse: The use of reclaimed water piped directly from a treatment facility to a drinking water treatment and distributions system.
- Indirect potable use: The use of reclaimed water to augment drinking water supplies by discharging it to a water body, such as groundwater or surface water, which is subsequently treated for potable use.
- Direct non-potable reuse: The use of reclaimed water that is piped directly from a wastewater treatment facility to a site for non-potable uses such as golf courses and landscape irrigation, power plant cooling or manufacturing.
- Indirect non-potable reuse: The use of reclaimed water for non-potable purposes by discharging it to a water body that is a supply source for non-potable use.

All reuse water that is discharged into any waters of the United States must comply with federal and state regulations. Recent legislation and Supreme Court 2015 rejection of the disapproval by Congress greatly expands the scope of waters that now fall under EPA protection. Texas has been an early innovator in the application of direct reclaimed water to the potable water chain of supply. The Colorado River Municipal Water District (CRMWD), established in 1949, was formed to control storm and flood water in the Colorado River basin and to harvest the unappropriated flow of water of the Colorado River and its tributaries. This Colorado River is located in central Texas and is the largest river wholly in the State of Texas. It rises in northern Dawson County flows some 600 miles across the Texas prairie and hill country to Matagorda Bay on the Gulf of Mexico.

The CRMWD distributes water to cities and other agencies for municipal, domestic, and industrial uses. It originally provided water to the cities of Odessa, Big Spring, and Snyder. Its charter was amended in 1961 and 1963 to permit water withdrawals for mining in the secondary recovery of oil (for which it provides low quality water), and to enforce water pollution prevention and water-quality enhancement. In 1981 its service area was expanded to serve the counties in which the three cities were located, as well as 31 other cities in the basin. From its headquarters in Big Spring, the district manages several dams and reservoirs and groundwater well fields.

The district also operates a wastewater treatment plant in the city of Big Spring. This conventional surface water treatment facility can treat approximately 16 million gallons per day and filter 21 million gallons per day. Treated effluent from the treatment plant had been discharged into the Colorado River at the District's E. V. Spence Reservoir. However, since May of 2013, the district's Raw Water Production Facility (RWPF) has been purifying the municipal wastewater effluent to the point where it is now the first direct potable reuse water system in the Nation. That treatment includes microfiltration, reverse osmosis, and an advanced oxidation process consisting of ultraviolet disinfection and added hydrogen peroxide. It is then blended with other raw water supplies and delivered directly to conventional water treatment plants in the service area. The technologies employed produce water that meets or exceeds all primary drinking water quality standards as well as the non-mandatory guidelines set for taste considerations, It is then blended with raw lake water from other sources before being delivered to water treatment plants in Big spring, Stanton, Midland, and Odessa. The Texas Water Development Board and WaterReuse Research Foundation have funded a study of the District's process to evaluate the feasibility of its expansion to other parts of the state (Steinele-Darling et al. 2016).

Reclaiming and Reusing Wastewater in Florida

Although Florida is still only reaching a fraction of potential reuse opportunities, in 2006, Florida's Water Reuse Program was the first recipient of the EPA Water Efficiency Leader Award. The state is continuing to follow an innovative water policy. For example, Senate Bill 536 passed in the 2014 legislative session required the Florida Department of Environmental Protection (FDEP) to conduct a comprehensive study and submit a report on the expansion of use of reclaimed water, stormwater, and excess surface water in this state. This statement by former Secretary of the FEPA Michael W. Sole on the need to expand use of reclaimed water in Florida remains on an undated webpage of the Department: "Reuse is key to the State's water future. Currently, Florida is leading the Nation—

reusing 660 million gallons of reclaimed water each day to conserve freshwater supplies and replenish our rivers, streams, lakes and the aquifers."

Responding to the legislative mandate, the FDEP's Office of Water Policy released its *Report on Expansion of Beneficial Use of Reclaimed Water, Stormwater and Excess Surface Water* in December of 2015. A multi-agency planning workgroup was formed, with representatives from the DEP, the Florida Department of Agriculture and Consumer Services, the Department of Transportation, and from the five major water management districts in the state (WMDs). The study was required to respond to the six broad question areas listed below; selected responses are shown in Table 12.5:

1. Identify factors that prohibit or complicate expansion of the beneficial use of reclaimed water, stormwater, and excess surface water.
2. Identify concepts that could lead to the efficient use of reclaimed water.
3. Identify environmental, engineering, public health and perception, and fiscal constraints to reuse expansion, including utility rate structures for reclaimed water.
4. Identify areas in the state where traditional water supplies are limited and where reclaimed, stormwater and excess surface for irrigation or other purposes is necessary.
5. Recommend permit incentives for all entities that substitute reclaimed water for traditional water sources, and that might be otherwise cost prohibitive.
6. Determine the feasibility, benefit, and cost estimates of the infrastructure needed to construct regional storage facilities for reclaimed water on public or private lands, and for delivery of reclaimed, storm and excess water for such beneficial uses and agricultural irrigation power generation, public water supply, wetland restoration, aquifer recharge, and water body base flow augmentation.

In Florida, close to 90 percent of the state's domestic and public water supply is groundwater. Agricultural runoff, urban stormwater and domestic and industrial discharges percolate back into the ground, as does most stormwater and reclaimed water used in farming, recreational, and landscape applications. Most programs for surface ponds,

Table 12.5 Report on expanding use of reclaimed, storm and excess surface water in Florida

Study mandates	Selected report responses
Factors that prohibit or complicate expansion of the beneficial use of reclaimed water	Federal, state and local regulatory impediments for collection, storage and use of non-traditional water; excessively nutrient-impaired surface water; conflicts with existing basin management plans
Concepts that could lead to the efficient use of reclaimed water	Finite freshwater resources and increasing demand from continuing population growth and high cost of desalination may limit lack of public support for reuse expansion
Environmental, engineering, public health and perception, and fiscal constraints	Lack of knowledge of impact of emerging Substances of Concern (ESOP) in wastewater, including flame retardants, pharmaceuticals, personal care products, endocrine-modulating chemicals, nanoparticles such as plastics, and biological metabolites such as antibiotics, resins, and fuels; partnerships with stakeholder groups will help provide science, engineering and implementation expertise
Areas in the state where traditional water supplies are limited	South Florida is in the middle of one of it's worst-ever droughts; cane sugar growers, nurseries, fruit farmers and golfers, are suffering. Groundwater withdrawals in the Tampa-St. Petersburg area has led to saltwater intrusion and subsidence in the form of sinkhole development and concern about surface-water depletion from lakes in the area
Incentives for all entities that substitute reclaimed water for traditional water sources	Implement mandatory reuse zones; implement tiered reclaimed water rates; focus on industrial and commercial users; promote long-term supply contracts; outreach with stakeholder groups will aid in development of water reuse incentives
Feasibility, benefit and cost estimates of the infrastructure need for storage, collection and delivery of the reuse water	Funding for the needed infrastructure is the greatest problems for extensive expansion of the use of reclaimed, storm and excess surface water

Source: Florida Department of Environmental Protection (2015) infiltration basins, spray fields, and other discharges of treated wastewater effluent also result in reclaimed water returning to groundwater aquifers. All this water then mixes with freshwater before being subjected to treatment and purification in municipal water utility treatment plants. The problem with this picture is that the traditional natural water supplies are being over-used and subjected to continuing drought conditions, and supplies of recycled water are insufficient to take up the slack. In 2015, Florida was using only about 45 percent of the wastewater available.

Managing Recycled Water in Tampa

The City of Tampa is Hillsborough County, which is located in the central portion of the Southwest Florida Water Management District (Fig. 12.3), on the west coast of Florida on Tampa Bay. The population of Tampa in 2015 was estimated by the US Census Bureau to be 369,075, which is nearly 10 percent greater than it was in 2010. The population of Hillsborough Country in 2015 was estimated to be 1,349,050, which is 9.7 percent more than in the 2010 Census Bureau count. Reclaimed water use in the district for 2014 included the following facts:

- More than 44 percent (151 mgd) of wastewater in the district is reused.
- Nine local power plants use reclaimed water as cooling water.
- Nearly 200 area golf courses in the district irrigate with reclaimed water.
- More than 9,000 acres of mostly citrus crops are irrigated with reclaimed water.
- More than 114,000 residential customers in our area irrigate with reclaimed water.

The City of Tampa announced in October of 2016 that it was taking its first steps in implementing a large-scale water-reuse program, The Tampa Augmentation Project (TAP) by evaluating the costs and feasibility of increasing its recycle water reuse program. Reclaimed water from Tampa's Curren Advanced Wastewater Treatment Plant will be

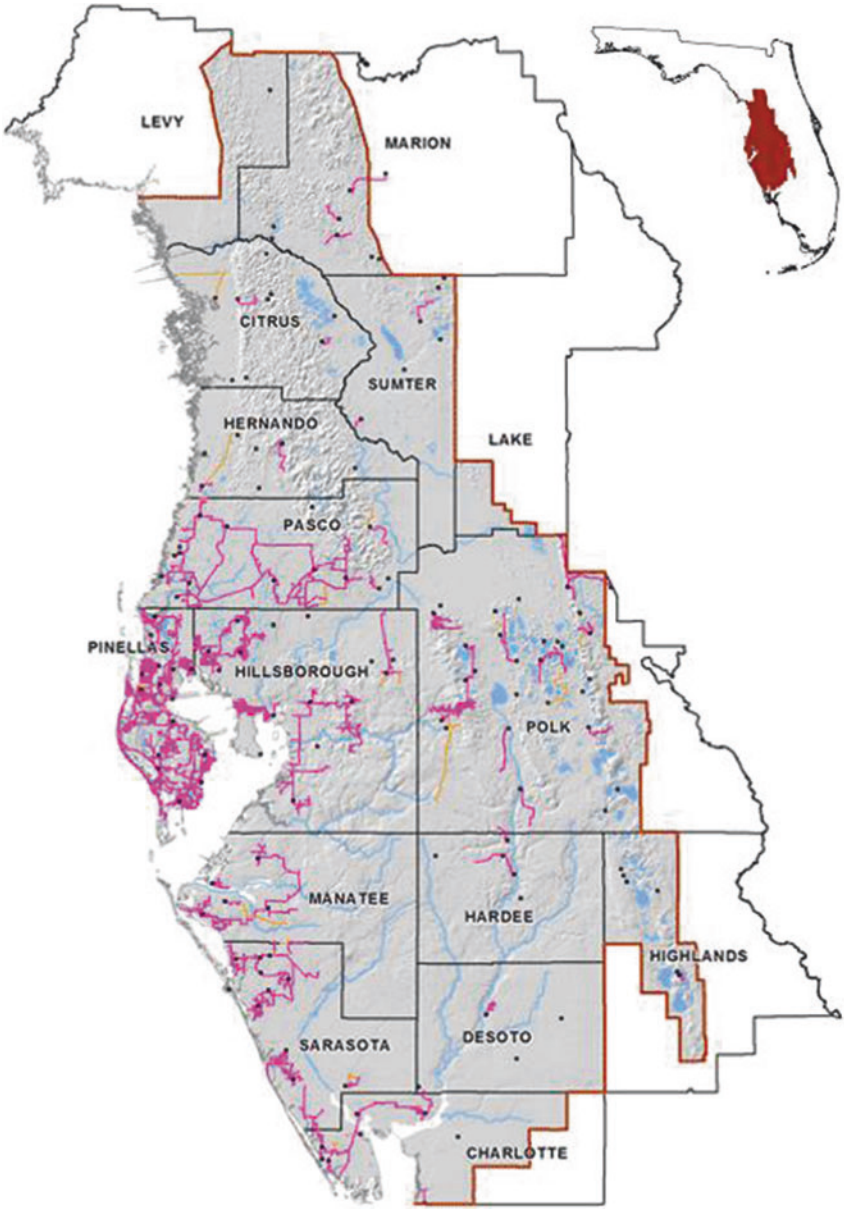

Fig. 12.3 Map of the Southwest Florida Water Management District
Source: Southwest Florida Water Management District (2016)

used to augment regional potable water supplies. The evaluation process will compare two approaches for adding reclaimed water to the existing potable supply. One method is to use natural systems to treat the reclaimed water or to use the Florida aquifer system to augment the groundwater supply by adding reclaimed water for later retrieval and delivery. Tampa is constructing a small wetlands area near the treatment plant to demonstrate the treatment effect of natural infiltration. Data from the 20-month test program will be used to help water managers decide the best way to proceed with expanding the region's recycled water reuse initiative.

Summary

Recycling is the reuse of domestic, industrial, and agricultural water. The most common uses of recycled water are for landscape and some agricultural crop irrigation, for thermoelectric generating plant cooling, and for some industrial processes. A few states are beginning to look upon recycled wastewater as a resource for augmenting potable water supplies. This chapter looked at recycling in the four states that lead the Nation in putting recycled water to beneficial use: California, Arizona, Texas, and Florida.

Beneficial use in California includes the use of recycled water to augment potable water supplied drawn from some groundwater aquifers. The Nation's first large-scale use of recycled water for this purpose occurred in 1962 in Los Angeles County, where treated recycled water was allowed to naturally soak into the ground in the San Gabriel River Watershed.

Also having undergone a multi-year drought and with a rapidly growing population reuse of recycled water has become a necessity in Arizona. The use of recycled water for small-scale agricultural use began in 1932 in Arizona, but it was not until 1999 when the Arizona Department of Environmental Quality received authority to regulate and issue permits for all reclaimed water uses in the state. By 2010, 65 percent of all waste-water treatment plants delivered some classes of recycled water for reuse.

Texas has included two levels of potable water augmentation by recycled wastewater: direct reuse and indirect reuse. Direct reuse entails directly introducing treated reclaimed water directly into some position in the distribution system for potable use. Indirect reuse is returning treated and purified wastewater to a water supply source where it mixes with existing water sources before being withdrawn again for reuse.

Reclaimed water in Texas is classified into four separate use-classes: direct potable reuse, indirect potable reuse, direct non-potable reuse, and indirect non-potable reuse. The direct potable reuses class requires the highest level of sanitation treatment before its reuse.

The need for augmenting the natural supply of potable water with reclaimed water in Florida is an effect more the result of population growth, overdrawing from limited over-allocated surface water resources than drought, although rainfall has been below normal for several years. Growth in its neighboring states has also impacted the groundwater and surface water resources in the state. Like California, Arizona and Texas, Florida included a commitment to greater use of recycled water in its water master plans.

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13

Privatization and Commodification of the Resource

The water industry has four main components: (1) municipal and other publicly owned water supply and sewer treatment utilities; (2) the private domestic and international corporations that serve the same type of municipal and industrial customers as public utilities; (3) the water and wastewater engineering, construction and equipment services industry that supply equipment to all public and private water and wastewater operations; and (4) a commercial bottled water industry that often competes with traditional users for access to the same water resources. In the public utilities sector of the industry, government, quasi-government special district utilities and commercial companies supply most of the nation's water. Private water systems, a very small sector considered a subsector of utilities, are individuals and systems that serve fewer than 15 customers almost exclusively from privately owned wells. Utilities function as retail distributors, supplying water, wastewater or combined services to residential, commercial, and industrial customers.

The general services sector exists to provide materials, equipment, and consulting services to all types of utilities (Beecher 2016). This sector consists mostly of individual professionals and commercial firms that

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supply some portion of general services to all types of utilities. General services include a wide variety of water- and wastewater-related services such as engineering, legal service, laboratory testing, and accounting to utilities on a fee-for-service contract basis.

The utility segment includes municipal systems and commercial public service suppliers, both of which operate as natural monopolies. They are owned and operated by local governments, special districts, or commercial (investor-owned) systems. Government-owned and special public district systems make up the vast majority of the United States water and wastewater utility segment, accounting for between 84 and 89 percent of all recipients of water from community systems.

The utility segment of the combined water industry consists of approximately 53,000 community water systems and approximately 16,000 community wastewater facilities in the United States. There are only a relatively few private water utilities in the United States, and most of them are international corporations with home offices in France, Germany, The United Kingdom, and Japan. The largest of the US-based private companies, American Water, operates 19 state subsidiaries providing water or wastewater services or both to their customer bases (American Water was 130-year-old in 2015; stockholders' return in 2015 was 14.9 percent). These company utilities are generally subject to economic regulation by the public utilities commissions in the states in which they operate. The federal government and the states also regulate environmental, health and safety and water quality matters.

Private Water Systems

This group includes self-supplied users and private water systems. Private groundwater wells supply water to just one or a very few residences, industries, or institutions such as schools, colleges, or universities. Private water users also include wholesale and retail bottled water suppliers as well as small-group systems. Private water systems' supply is usually groundwater acquired from private wells, cisterns, or agricultural supply providers. The supply may also come from private springs, streams, ponds, or shallow wells that were not specifically intended for drinking.

Private water systems serve no more than 25 people at least 60 days of the year in temporary locations such as campgrounds, or they have no more than 15 permanent service connections (varies by state). Each building serviced by the same private water system is considered to be a service connection for that system.

The General Services Segment

The general services segment includes parts and machinery companies, suppliers of management and technical services surrounding the supply of water and wastewater, including engineering, consulting, and sales of water infrastructure and distribution products. These services are provided to water and wastewater utilities and other consumers on a fee-for-service contract basis and are not subject to economic regulation.

Privatization Models

Privatization refers to the private sector's participation in water and wastewater utility ownership, management, or operations. In some respects, privatization can be understood as moving along a continuum of options from "completely public" to "completely private."

The National Academy of Sciences defines *privatization* as it occurs in the water industry as covering a wide variety of water utility operations, management, and governance models (NAS 2002). In practice, privatization can take any one of four different forms: (1) provision of services and supplies such as laboratory work, meter reading, and chemicals; (2) contracting with a private firm for water and/or wastewater utility plant operation and maintenance; (3) contracting with a private firm for the design, construction, and operation of new facilities; and (4) sale of water utility assets to a private company. Options 1 and 2 are referred to as *outsourcing*; option 3 is referred to as *design, build*, and *operate*, or DBO.

The NAS study added that because political, demographic, economic, and physical circumstances vary, no one model of public or private drinking water or wastewater treatment best fits all situations. Contracting with a private firm for management and operations has been more common than the sale of utility assets to private companies. No major US city has sold its utility assets in recent decades, although some smaller water utilities have done so. Some of the more common privatization arrangements are operations assistance, contract management or operations, full-service contracts, turnkey facilities, build-own-transfer and build-own-operate arrangements, concessions, joint ventures, retail operations (billing, etc.), and asset sales. Table 13.1 lists the range of responsibilities expected with a contract manager of a small public special district governance model.

In the United States, municipal ownership remains the predominant organizational structure of water utilities, although most small special

Table 13.1 Selected scope of work items for contract manager of community water system

Item	Description
1	Register with the State Department of Health as the District Water Manager
2	Operate and maintain well pumps, water treatment process and all other parts of the system, includes ordering routine supplies and materials and advising the District on needed overhaul or replacement of equipment
3	Take required water samples and be responsible that all proper tests are performed
4	Inspect the water distribution for visible leaks
5	Respond to water quality and customer service concerns
6	Respond to callouts after normal work hours, be available 24 hours/day or make arrangements for backup manager when unavailable for responding or when assistance is needed
7	Develop and implement a cross connection control program
8	Develop and implement a coliform monitoring program
9	Develop a preventative maintenance program
10	Carry out discontinuation and resumption of water service tasks
11	Operate meter reading operation under separate contract
12	Obtain and maintain certifications as required by law, including Water Distribution Manager II, Cross Connection Control Specialist, and Confined Space Certification

Source: Water district documents

districts contract out for management and operations, with an elected board overseeing the contract. Most cities prefer to maintain control over assets and engage in more limited forms of privatization.

Private or "investor-owned" water utilities account for about 15 percent of total water sales and revenues. Many investor-owned utilities operate multiple water systems. As monopolies, private water systems are subject to economic regulation by the state public utility commission; municipal utilities can usually avoid this. All utilities, regardless of ownership or governance model are subject to the same environmental and public health rules and regulations.

While their numbers are small, private water corporations make a significant contribution to the total value of water supply. The four major multinational water companies with US subsidiaries are European firms. Two are French corporations: Veolia Environment and Suez Lyonnaise des Eaux (Suez Environmental). Suez owns United Water. The two German firms are RWE AG, which controls American Water Works Co., and Siemens, which controls US Filter Corp.

Water System Governance

Of all public services, the governance structure of the water industry may be the most diverse, although most residents of cities with more than 100,000 residents receive their water from systems that are owned and operated by municipally owned utilities. As of 2015, approximately 84 percent of the 155,000 water delivery systems and nearly all wastewater treatment and discharge wastewater utilities in the United States were owned by local or regional government bodies. A closer look at the water industry reveals the nation's water delivery systems fall into four separate classes: (1) systems owned and operated by local governments, (2) independent public service systems, (3) systems that are public/private partnerships, and (4) systems and specific segments of the water supply chain that are entirely privately owned and that operated as pro-profit businesses. This chapter focuses on the last two segments, public/private partnerships and private commercial water enterprises, beginning with a brief review of the extent of private sector involvement in the industry.

Proponents of Privatization

Throughout most of the early nineteenth century, water systems were small and privately owned. Wastewater systems did not exist as such; disposal of sewage and household wastes was a private concern. However, outbreaks of water-borne disease in the increasingly crowded cities forced local governments to construct waste collection systems and eventually, sewage systems. The private or commercial sector involvement in the water services industry slowly gave way in major cities to municipal ownership and operation until by the 1950s, most water and wastewater systems were government owned and operated. This was before the creation of the Environmental Protection Agency (EPA) and adoption of many new as stringent water quality measures. The following statement can be said to summarize the argument used by privatization's proponents: Private sector participation in operation of water and wastewater treatment facilities has growth in the U.S. and globally, "despite the serious political and regulatory risks associated with the (water and wastewater) sector" (Haarmeyer and Coy 2002, 24).

After World War II, population growth and suburban sprawl in many parts of the United States required installation of all public services, including water and wastewater. The huge costs associated with this new infrastructure led many governments to seek other ways to finance their construction. At the same time, many people's attitudes toward private ownership of public services were changing.

Supporters and detractors of privatization began publishing their augments. Many people in and out of government began to believe that privately owned services would be more efficient and, hence lest costly, than government operations. By the 1980s, many local governments were considering contracting with outside firms for constructing, maintaining, and managing power systems, solid waste disposal, public transportation, and water and wastewater utilities. Privatization consultants Robert Poole and Philip Fixler described why so many governments had either privatized some services or were considering the idea in an1987 article in the *Journal of Policy Analysis and Management*. Reasons given included were:

> Many hypotheses might help explain the growth of privatization or why it is prevalent in some areas. These include (1) public officials have heeded the findings of economic theory and research that indicate the superiority of the private sector for some types of service provision; (2) an increasing failure by government in the delivery of some services; (3) a change in the political culture resulting in a greater acceptance of the market as a means of service delivery; and (4) the increasing decline or weakness of unions. (Poole and Fixler 1987, 613)

An unpublished and undated study released by the White House Office of Policy Development at about the same time reported that local governments are more likely to use private delivery of public services when they were either suffering under budgetary constraints and finding it difficult to find other funding, located in a metropolitan area with many smaller jurisdictions, whose administrators were experienced in using private firms for services, or located in the Western part of the country. No reason why the west was more likely that the central or eastern portions of the country were given.

By the turn of the century, privatization of the industry has become common enough to be segmented into five levels of commercial involvement, as follows (Bolard, 2007):

- Private operation of one or more facilities or steps in the treatment and supply system functioning under contract with municipal or county owned water or wastewater systems; this includes design-build-operate contracts and joint ventures.
- Outsourced services such as engineering assistance, laboratory services, quality testing, and the like. This is very common in the thousands of small systems not owned or operated by local governments.
- Contract operation of all functions of a local government-owned utility without any rate-setting authority or control of system finances (contract management or operations).
- Contract operation of all functions of a government-owned system including rate-setting authority and financial requirements (full-service contracts).
- Full permanent ownership of all facilities, service infrastructures, and franchises by a private-sector organization, including rate-setting

> authority and financing responsibility. Like all public water organizations, private sector operations are subject to the same water safety and security regulations. Because they are private monopolies, private water companies are subject to the same economic regulation as private power utilities by state public utility commissions.

Full sale of the utility and installed infrastructure, the last of the five levels of private sector involvement, is uncommon in the water resources and distribution organizations. Commercialization of rights to access water supplies, on the other hand, has grown, again particularly in the Western states. This process is primarily associated with purchasing surface or groundwater rights from farmers and selling the water rights to municipal water suppliers. However, it includes elements of the other four levels as well as the growing phenomenon of bottled water by commercial water service organizations and retail chains.

Despite many reasons given for privatizing their water and/or wastewater systems, by the late 1980s there were only an estimated 100–200 municipal system under private contract (Seidenstat et al. 2000). However, by 1997, this number had increased to more than 1,200 facilities in 44 states and Puerto Rico having privatized some or all of their operations. Growth of the privatization movement declined after the 2008–2010 recession, however (Food and Water Watch 2016).

The Privatized Water Supply Sector

Major commercial water and/or wastewater services companies in the United States include American Water Works, Aqua America, and California Water Service, along with France-based global giants Suez Environment and Veolia Environment, Brazil's SABESP, and the UK's Severn Trent. Four of the ten largest private water companies are based in the United States. The annual revenues of each of the four US firms compared to the annual earnings of the world's largest water firms are shown in Table 13.2.

Table 13.2 Earnings of top US water firms compared to world's largest water companies

World rank	Firms	Services	2009 Revenue
	US firms		**(US$ million)**
3	ITT Environment[a] Services	Water supply, wastewater treatment, supplier of pumps	$10,991
7	American Water Works (60.5% owned by RWE AG of Germany)	Water supply and waste-water management	2,441
8	GE Water	Water treatment, waste-water treatment	2,500
10	Nalco Company	Water treatment	1,628
	French firms		
1	Veolia Environment	Water supply and manage-ment, waste management, 4energy and transport services	49,519
2	Suez Environment	Water supply, wastewater treatment, solid waste management	17,623
	UK firms		
4	United Utilities	Water supply and sewage treatment	3,894
5	Severn Trent	Water supply and sewage management	2,547
6	Thames Water	Water supply and waste-water treatment	2,400
	Japanese firms		
9	Kurita Water Industries	Water and wastewater treatment, reclamation, soil and groundwater remediation	1,926

Source: Modified from data in Various financial reports

[a]In October, 2011 ITT Environment became Xylem, a free-standing water-related services company. Xylem's 2015 revenues were $3,653 million, down from $3,916 in 2014

The size of the global water utility market in 2015 was estimated to be $185 billion, according to S-Network Global Water Indexes. Private-sector operators make up about 20 percent of that market. Though public utilities dominate in the United States, competition among private water management companies is relatively common in major markets in Europe, Asia, Australia, and a few countries outside of North America. The two largest water companies in the world are French, three of the top ten are in Great Britain, and one is a Japanese firm. Veolia environment operates in more than 100 countries and provides water services to 110 million people; suez operates in 130 countries and serves 115 million people, and RWE AG provides water services to more than 70 million people.

The US commercial water and sewer utilities industry includes about 4,900 establishments. This includes both single-location companies and units of multi-location companies. Combined in 2015 they had annual revenue of about $13 billion. The commercial industry is small compared to the US water and sewer services operated by many regional and local governments and independent semi-public water and wastewater districts. The public-supply utility services earned about $120 billion annually.

Opponents of Privatization

As noted earlier, water privatization takes several different forms, ranging from outsourcing parts of the operation or management to electing for private sector operation or maintenance but retaining ownership of the system, and outright transfer of ownership of the complete system to a private firm. There are also a variety of reasons why publically owned utilities opt for privatizing some or all of their operations. Law professor Tony Arnold, an opponent of the process, described five of the reasons for the reasons why public utilities become interested in privatizing, or why private corporations are interested in increasing their share of the large US water market (Arnold 2009):

1. The enormous investment needed to upgrade or replace aging or obsolete infrastructure, or to comply with increasingly strict federal

requirements for water quality. Large multinational corporations have the money to invest in water systems in exchange for ownership or control of the systems.
2. Large international corporate find the US market an attractive investment, without many of the restrictions and costs associated with some foreign markets.
3. Changes in the tax code in 1997 that make it possible for private water companies to compete with public sector operations.
4. The mindset in much of the US electorate in support of greater privatization of government activities, reducing the overall role of government, and increasing private sector involvement in provision of public services.
5. Privatization of public water supplies and infrastructure is a global trend, receiving support by many international organizations such as the World Bank, and serving as a model that managers of US public utilities can follow.

Conflicts and Barriers to Privatization

Although the trend in privatization of water and/or wastewater systems in the United States is slowing, it remains strongly entrenched as an alternative to public ownership and operation of public utilities. The process over the last 20 years or so is replete with program failures and early cancellations. One of the biggest of these failures occurred in Atlanta, Georgia, where rapid growth and urban sprawl was taxing the local water utilities and their supply beyond their ability to pay for needed infrastructure repairs and replacements. Atlanta negotiated a 20 year agreement with United Water, a US subsidiary of Suez Environment, in 2003. The city terminated the contract after just four years. The following description explains the problems that led to the breakdown and early end of the relationship:

> The parties . . . rushed through the bidding process, failed to gather sufficient information, and did not negotiate carefully. Moreover, United ran the Atlanta system poorly, resulting in extensive complaints and widespread

> public and municipal regret over the privatization decision. [United} underbid the highly competitive contract to operate, maintain, and upgrade Atlanta's aging water infrastructure, but blamed the city for allegedly failing to fully disclose the condition of the infrastructure. As United Water cut jobs and training to reduce expenses, it developed backlogs of work orders and delivered poor quality water, often with inadequate pressure. As a result, water ran orange to brown for many customers, tinting clothes laundered in it and hair washed in it, and United Water had to issue numerous "boil water" orders because low pressure or insufficient water treatment made the water unsafe to drink . . . In one example, United did not address a broken main gushing water into the street and washing away pavement for ten days during a severe drought, even though a customer notified United repeatedly. In addition, inefficiencies led to waste, such as failure to bill customers properly, which resulted in millions of dollars of lost revenues to the city of Atlanta (Arnold 2009, 799/800).

Similar problems have resulted in early contract terminations in other parts of the country, as the following examples illustrate. In 2005, the City of Laredo, Texas was forced to terminate a five-year privatized system contract after three years. United Water claimed the costs of operating the system were higher than they had anticipated. The end was allowed only after they paid the city $3 million in exit fees. Residents in Lexington, Kentucky voted to repurchase their water system from Cal-Am, a RWE subsidiary, after water rates increased, service deteriorated, and failures in system management. In 2004, a contract between OMI/CH2M canceled its contract with the city of East Cleveland because OMI could not generate enough income from water and sewer revenues to pay for operating the systems. Also, in 2005, a federal indictment charged a consultant working with OMI with bribing the mayor to get the contract. Charges have been made that political favors to administrators were also took place in influencing water privatization bids in the cities of Birmingham, Atlanta and New Orleans. Orange Country, California water agency rejected a proposal to privatize the Santa Margarita Water district after strong opposition by local residents. A contract between OMI and the City of Santa Paula, California ran into trouble when investigators found the OMI had violated terms of its discharge permit and had apparently filed false water quality reports.

Security Concerns over Privatization

Security of the Nation's essential services, while always a concern, became even more worrisome with the terrorist attack on September 11, 2001 (Copeland 2010). As noted, although they control only a small proportion of the US water service industry, most of the private corporations engaged in supplying water and wastewater services in the United States are European-based corporations. The issue associated with this is how much of a concern is it when foreign-owned and foreign-operated private corporations control public water systems, buy and sell domestic water rights, and hold exclusive control over water resources (Arnold 2009). Opponents of privatization ask whether foreign ownership make the country vulnerable to business decisions that pay insufficient attention to environmental and conservation concerns, and the answer if possibly but not immediately likely. The question is made more problematic when international agreements on foreign trade are taken into consideration. The World Trade Organization and the North American Free Trade Agreement consider water to be a "tradable good or commodity." Bans on international sales could be considered export restrictions that are not allowed by the treaties.

The potential target for terrorist activity against water infrastructure is large. It includes surface and groundwater sources of untreated water for municipal, industrial, agricultural and national needs. It also includes the thousands of dams, reservoirs, aqueducts, and pipes that hold and transport raw water, the treatment facilities that distribute water to users, the systems that collect, treat and discharge wastewater. Ownership and management of various parts of this system and their suppliers is both public and private. It is important to note that only about 15 percent of all drinking water and wastewater utilities, nearly all of which are located in large urban areas, provide water services to more than 75 percent of the US population. The rest of the approximately 16,000 utilities in the United States serve everyone else. All utilities are subject to the same rules and regulations.

The threat of terrorism against all America's essential infrastructure has become a major concern of the Federal government. The Federal

Emergency Management Agency, the Department of Homeland Security, the FBI and other government agencies consider the potential threat to the nation's water supplies to be real, but not critical. Water infrastructure attacks could include introducing chemical, biological or radioactive contaminants into reservoirs or into water distribution systems. However, to be effective, large amounts of the contaminants would be needed, limiting the ability of terrorists to carry out such an attack. Moreover, water treatment would eliminate much of the potential danger before it could take effect. Terrorist activity is more likely to be directed at damage to pumps, distribution equipment, or pipelines—all of which are repairable. More vulnerable are foreign attacks on water utilities' computer systems, actions based outside the nation and with little or no regard for ownership. However, because of the real danger that could occur to the Nation's water supplies, Congress included the entire water industry in the 2002 Public Health, Security, and Bioterrorism Preparedness and Response Act. This legislation requires public water systems to prepare emergency response plans to deal with threats to water supplies, and to periodically send vulnerability assessments of their systems to the EPA.

Slower Growth in Privatization

Private participation in US municipal water markets is poised for expansion, according to an October 8, 2016, press release from Bluefield Research of Boston, MA. Excerpts from that release are included in Box 13.1. private water companies and their US share of the US market are shown in Fig. 13.1.

Box 13.1 Private companies ready to expand participation in the US water industry

Municipalities and local authorities are showing an increasing reliance on investor-owned utilities and private players for the ownership, management, and operations of public water and wastewater systems. The market opportunity is a reflection of the growing water infrastructure investment gap exceeding US$532 billion that will be needed over the next decade.

Municipal utilities are "approaching a breaking point as utility assets reach the end of their useful lives. They must now seek-out alternative solutions for funding and technical expertise," according to Keith Hays, Bluefield Research vice president. "Federal funding for municipal water has declined steadily in the past 40 years to barely 4%, leaving municipalities to finance infrastructure projects locally," he added.

The lion's share of investment activity will be focused on New Jersey, California and Pennsylvania, but increased activity in Illinois, North Carolina, and Virginia highlights a transition toward new markets for growth. "Private ownership of a highly fragmented network of 49,000 systems represents 15 percent of the current market, but recent activity signals a larger role for investor-owned utilities going forward. While American Water and Aqua America have been the most aggressive investor-owned utilities, more than 19 deals totaling US$384 million (completed and pending) are on the books for the first half of this year.

Source: Bluefield Research (2016)

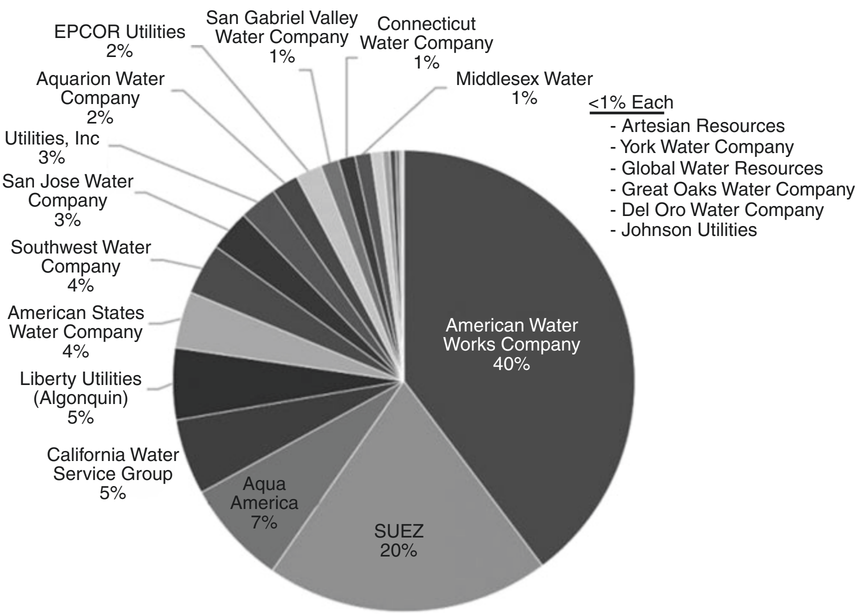

Fig. 13.1 Private water companies and their shares of the market in 2016
Source: Bluefield Research (2016)

The huge cost of the infrastructure problem highlighted in Box 13.1 is not exaggerated. Moreover, neither is difficulty municipal and other water public suppliers face in finding this needed repair, replacement and upgrading of the infrastructure under their control. Still, public water companies speak with pride of the way the public has turned away from their love affair with private ownership. The managers of public water utilities are somewhat more optimistic about the state of industry. In 2016, the Washington, DC-based consumer-rights organization *Food and Water Watch* released a report on the water industry in which it compared water rates and customer services for publicly and privately owned and managed US water utilities. The study analyzed eight years of data from the Federal Drinking Water Information systems.

A major finding of the Food and Water Watch group was that a trend away from private ownership back to public ownership and operation was occurring. A survey of the 500 largest community water systems revealed that private systems charged 59 percent more for water than large publicly owned systems. The numbers of people served and ownership and the numbers of community water systems in 2007 and 2014 are shown, respectively, in Tables 13.3 and 13.4. Other findings reported were:

- Publicly owned utilities serve 87 percent of the population with piped water (excluded private wells).
- Private water companies owned approximately 10 percent of US water systems, most of which served small communities.
- From 2007 to 2014, the portion of people receiving water rom publicly owned companies increased from 83 to 87 percent.

Table 13.3 People served by water companies with different ownership, 2007–2014

Ownership type	Customers in 2007	Customers in 2014	Increase or decrease	Percent change
Public	237,634,535	261,745,966	24,111,431	10
Private	44,459,100	36,338,067	(8,121,033)	(18)
Public/Private	4,357,569	4,511,784	154,215	4
Totals	286,451,204	302,595,817	16,144,613	6

Source: From EPA data in *Food and Water Watch* (2016)

Table 13.4 Numbers of water suppliers with different types of ownership

Ownership type	Systems in 2007	Systems in 2014	Increase or decrease	Percent change
Public	25,671	25,770	99	0
Private	25,081	23,395	(1,686)	(7)
Public/Private	1,358	1,266	(92)	(7)
Totals	52,110	50,531	(1,679)	(3)

Source: From EPA data in *Food and Water Watch* (2016)

- Over the same period, the number of publicly owned systems remained relatively constant, although population growth and urbanization resulted in increases in the number of people served.
- On average private utilities charged households 59 percent more for drinking water than local government utilities.
- In 25 states, private water companies serve less than 10 percent of the population; private companies serve more than 35 percent of the population in four states.
- Only 22.3 percent of privately owned systems are owned by for-profit companies; the remainder are non-profit subsidiaries of organizations whose primary activity is not water.

Commodification of Water

One of the outcomes of privatization is the commodification of water (Arnold 2009). This is the process by which by which water, like undifferentiated consumer products, is assigned economic value. In this way, water becomes a simple consumer commodity without attributes that can be differentiated in the eyes of consumers. Thus, such broader concepts as social rights, ecological damage, watershed protection, stewardships of the resource and fundamental rights, are not addressed in the commercial management of water. The process in turn often results in cost cutting, failure to innovate, and deferred repair and replacement of aged infrastructure. A number of examples of the negative experiences that have occurred as some municipal water utilities' privatized their water operations.

The commodification of water is the process of transforming water from a public good into a tradable commodity or economic good. It does this by taking water out of the control of governments and putting it in the hands of private enterprise. This transformation is supported in the belief that privatization will result in the supply being managed more efficiently, and that price can function as an incentive to conservation of the resource. The commodification of water increased during the late twentieth century in parallel with concerns over climate change, environmental damage, and the need to replace and upgrade failing infrastructure.

Proponents of privatization hold the view that public provision of water and government regulation of environmentally damaging behavior is ineffective and far more costly than its results warrant. By strict enforcement of traditional private property rights over social rights over water and application of market mechanisms, it is argued that water will be allocated more efficiently and, hence, more effectively. An underlying rationale often aired in support of privatization is that this market-based approach is a method of resource regulation that promises economic and environmental objectives can be met at the same time; it is called *market environmentalism*.

Bottled Water Concerns

A number of private bottle water suppliers have been accused of exploitation and overpumping in groundwater aquifers to meet high consumer demand. Globally, this industry had annual sales estimated to be from a low of $50 billion to $100 billion; in 2013, bottle water sales in the United States reached $13.1 billion. Demand has increased by from eight to twenty per cent each year from 1999 to 2009. According to the Internal Bottle Water Association, between 1976 and 2013, bottled water grew at a compounded annual growth rate of 9.5 percent, outdistancing every other beverage category. On a per capita basis, in 1976 Americans each drank 1.6 gallons of bottled water. In 2014 that figure was projected to reach a record 34.2 gallons.

Conflicts are breaking out between competing public and private water supply groups and new and traditional water users as private-based water right holders either fight complying with conservation calls, or struggle with how to do so in a ways consistent with their traditional water rights. The state-administered "water rights system will be stretched, and tested, in new ways. Persistence, creativity, and in some cases strong monetary incentives, will be needed to open the door for meaningful change in a water rights system that was designed for a much different time that we live in today" (Hayes 2003, 24).

The large-scale withdrawal of groundwater for bottled water and irrigated agriculture. The thermoelectric generation industry and irrigated agriculture are the two largest user of water in the United States. This has resulted in what may be irreplaceable drawdowns in many local and regional aquifers. These excessive withdrawals result in increased contamination, salt-water intrusion in coastal areas, harm to many surface water systems and associated ecosystems, as well as harm to local communities. All bottled water in the United States is processed and distributed by privately owned companies, including some of the largest food and beverage companies in the world.

Summary

The water industry includes four major components: municipal or publicly owned and managed community water service utilities, general services and material suppliers, commercial bottled water suppliers, and privately owned water service suppliers. All major metropolitan areas and from 80 to 90 percent of the population who received pipe water do so from publically owned utilities. Privately owned provide water from 40 to 50 percent of all small municipal systems.

Privatization takes several different forms, ranging from services such as laboratory testing of water samples for all classes of water service providers, to outright ownership of the gathering, treating, and distributing infrastructure of a water utility. The largest privately owned water suppliers in the United States are subsidiaries of very large European corporations that operate around the globe. Privatization became a viable alternative after World War II. The movement to privatization of all or part of municipal water utilities took off in the 1970s and 1980s, but the trend has shifted from growth to decline since 2010. From 2007 to 2014, private water supply utilities lost more than 2 million customers to public utilities.

The privatization trend grew as municipalities found it difficult to finance need expansion of services to meet the needs of new urban and suburban families and industrial growth while at the same time repair and replace old and outdated infrastructure. At the same time, a change in attitudes toward what was seen as "big government" took place; public administration was thought to be less efficient as private industry, and as a consequence, more costly. A spate of poor management practices and failures to meet contract specifications contributed to a reverse in attitudes again, this time against privatization. However, smaller municipal systems continue to find the practice a popular way to cut expenditures and lower taxes.

The vulnerability of much of the Nation's water infrastructure to terrorist activity extends to the concern over foreign ownership of water resources. The controversy over commodification of water and commercial purchase of private water rights are issues that flare up periodically. Demonstrations against the practice of using purchased rights to scarce water resources for growing animal feed crops in the California desert that are then exported to water-scarce foreign countries are an example of the alleged mismanagement of the resource.

The bottled water industry continues to grow, however, despite concerns over waste plastic containers and the excessive pumping of groundwater. Problems arising from poor water quality and health hazards such as those experienced by the municipal water utility Flint, Michigan in 2015, along with water shortages in the Western United States have resulted in even faster growth in bottled water sales. As earlier chapters have noted, climate change, physical and cyber terrorism, population growth and greater urbanization of the country may have helped slow the growth in privatization of the water resource, but the high cost of vitally needed replacement and upgrading of water infrastructure that is 70 years old or older suggests that renewed growth in the need for more private capital can be expected in the years to come.

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14

Integrated Water Resource Management

As discussed in earlier chapters, in the United States, water management is divided between the federal government, the individual states, and a large number of public and private organizations. The federal government does not own any water, but is heavily involved in much of the infrastructure constructed to manage water flows, provide for flood control and water reservoirs for hydroelectric power generation, and for projects for protecting and enhancing navigation. In addition, the US Reclamation Bureau is the Nation's largest wholesale supplier of water.

The basis for the federal government's interest in water lies in three main sources: power to resolve conflicts arising between states awarded to US Supreme Court by the Constitution; authority over navigable waters established in the Constitution's Commerce Clause; and Congressional authority to manage most of the nation's largest water resource projects. The states are given responsibility for ensuring that local water resources are managed according to federally established rules, regulations, and standards. Individual's and organizations authority rests in ownership of water rights, which in the United States are generally considered to be property rights.

D.E. McNabb, *Water Resource Management*,
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Federal authority over water management is administered in a wide variety of separate agencies, ranging from the Environmental Protection Agency (EPA), the Public Health Service, the departments of Agriculture and Interior, the US Army Corps of Engineers (USACE), and many other sections of department agencies. Direction for agency actions is guided by both the executive and the legislative branches, both of which are dependent upon judicial determination of their Constitutional authority. Each individual state operates its own versions of these federal agencies. To make a coordinated approach even more difficult is the differences in water rights systems and their application that exists across the Nation. As a result, this polycentric management system often results in paralyzing passage of important water legislation as diverse stakeholders fight to defend the interests of their particular stakeholder group. The overly complex nature of water resource management is one of the driving forces behind the movement to replace the nation's piecemeal approach to water management with an Integrated Water Resource Management (IWRM) approach. This chapter will describe that approach.

End of the Piecemeal Approach to Water Management

The future of water management is more complex today than it has ever been. That is because today water management involves not only local water supply, but also the economic, social, and ecological environments affected by water, together with the interests and concerns of all water users, and a new level of water resource management planning by state and local agencies cooperating with the traditional federal water managers. Sheer began a journal editorial with this view of the state of management of the resource:

> Water is an increasingly precious but still poorly managed resource. There is no need to repeat the litany of ways in which water is vital to the survival of human society and the ecosystems on which we depend. Nor is it

> necessary to describe in detail how the needs for water both real and perceived, have changed dramatically, particularly over the course of the last century. Yet the practice of water resources management falls abysmally short of the start of the art. (Sheer 2010, 1)

The need to do a better job of managing this critical resource, particularly in light of the effects of climate change on water supply, has led to a number of proposals to change the way the United States manages its water resource. This chapter looks at the IWRM approach increasingly promoted by the United Nations. The next chapter reviews the latest in a series of water management tools being followed by water delivery organizations: the Total Water Management approach.

Integrated Water Resource Management

This much broader approach to managing the water resource is known as IWRM or simply Integrated Water Management (IWM). An example of the IWM program in California's Silicon Valley is shown in Box 14.1. Other modifications of the approach include integrated watershed management, integrated river basin management, integrated urban water management, and adaptive water management (Furlong et al. 2015). Foremost among the global organizations supporting the IWM approach are the United Nations and the Global Water Partnership. Their actions have led to the development of a resource management model that can be implemented in a variety different situations and circumstances, although most of the published research on this model focuses of its application in lesser developed nations.

Box 14.1 Silicon Valley's integrated water system

Located just to the south of San Francisco Bay, Santa Clara County (Silicon Valley) has a land area of 1,315 square miles. As of April 1, 2015, the county's estimated population was approximately 1,918,044 million, 7.7 percent greater than the 2010 census of 1,781,642 million. It is the largest of the Bay Area counties, and the fifth most populous county in California.

It contains two distinct geographic sections: the North Valley is extensively urbanized, with thirteen of the county's fifteen cities, with over 88 percent of the county's residents. Gilroy and Morgan Hill, with approximately 5 percent of the county's population, are located in the rural South Valley. San Jose is the largest incorporated city.

The Santa Clara Valley Water District (SCVWD) manages a county-wide integrated water system that includes surface water, artificial aquifer recharge, groundwater, imported water, flood control, conservation, habitat restoration and public education activities.

In 2010, the water system included 10 surface water reservoirs with storage capacity of 210 million cubic meters (m^3), or 170,249.8 acre feet, and underground storage estimated to contain as much as three times as much as the surface reservoirs. Treatment of imported water occurs at three water treatment plant prior to distribution to either customers or underground storage. The district operates four wastewater treatment plants with a total annual capacity of 21 million cubic meters (m^3) or 17,014 acre feet. Processed water is used for irrigation or environmental uses.

In 2008, the district's total water use was 470 million m^3 (381,035 acre feet), of which 282 million m^3 (228,621 acre feet) was imported water from the California State Water Project, 100 million m^3 (81,071.3 acre feet) was groundwater, 68 million m^3 (55,128.5 acre feet) was local surface water, and 20 million m^3 (16,214.3 acre feet) was from miscellaneous sources including trades.

The Santa Clara Valley Urban Runoff Pollution Prevention program is an association of 13 cities and town is the valley. The Santa Clara water district, along with other member agencies, are joint holders of the National Pollution Discharge Elimination System (NPDES) permit required for all stormwater discharge into San Francisco Bay.

Source: Narasimhan (2010) and miscellaneous county, state and federal materials

The IWRM model is not a single blueprint for water management, but rather a flexible system of concerns that are designed to help local communities solve their own water resource problems in ways that best meet their particular needs. The recommendations are based in four fundamental principles that shape the water environment. These principles were the product of international discussions on water problems that culminated in an International conference on water and the environment held in Dublin in 1992. The principles were intended to remain flexible and altered as time and events dictated; they were to serve as a guide upon which subsequent developments in water management were to be developed. This chapter describes the process in greater detail. The four Dublin Principles and their explanations are included the excerpt from the United Nations document in Box 14.2.

Box 14.2 Principles in the Dublin statement on water and sustainable development

Concerted action is needed to reverse the present trends of overconsumption, pollution, and rising threats from drought and floods. Recommendations for action at local, national and international levels, are based on these four guiding principles:

Principle No. 1: Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment. Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer.

Principle No. 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels. The participatory approach involves raising awareness of the importance of water among policy-makers and the general public. It means that decisions are taken at the lowest appropriate level, with full public consultation and involvement of users in the planning and implementation of water projects.

Principle No. 3: Women play a central part in the provision, management and safeguarding of water. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation, in ways defined by them.

Principle No. 4: Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

Source: UN Documents (1992)

The Technical Advisory Committee of the Global Water Partnership (GWP) included this definition for the integrated management process: "IWRM is a process, which promotes the coordinated development and management of water, land and related resources in order to minimize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". IWRM is thus one of the important tools water planners can employ in seeking to influence government water policy and for planning how to manage the resource as the water environment undergoes changes brought on by climate change. A general definition for the broader version of the approach is a management process with the goal of achieving an outcome that is balanced among three core dimensions of sustainability: economic efficiency, social equity, and environmental sustainability (Gallego-Ayala 2013). A model of the components that are included in the recommended implementation of the IWRM process is shown in Fig. 14.1.

Although introduced by the United Nations (UN) for managing water resources on a global scale, under many different names the principle of integrating social and ecological concerns with economic needs in water management has caught on at a local scale as well. A 1979 UN report on the organization's role in water resource development emphasized the need for local involvement and contained this prescription for water managers:

> Water management and use should be based on an overall water policy based on an assessment of all available resources and of all needs. The water policy needs to be an integral part of an overall socio-economic development plan in which various sectoral objectives have been weighed against each other, and against the costs and benefits involved in their complete or partial realization. Problems of water management and use generally arise from local conditions under which the resource is developed, and from the specific purposes for which it is used. Their solution is, thus, primarily a matter for local, regional or national action. (United Nations 1979, 474)

The IWM approach has influenced water planning and management for more than 40 years, having first appeared in its present form since

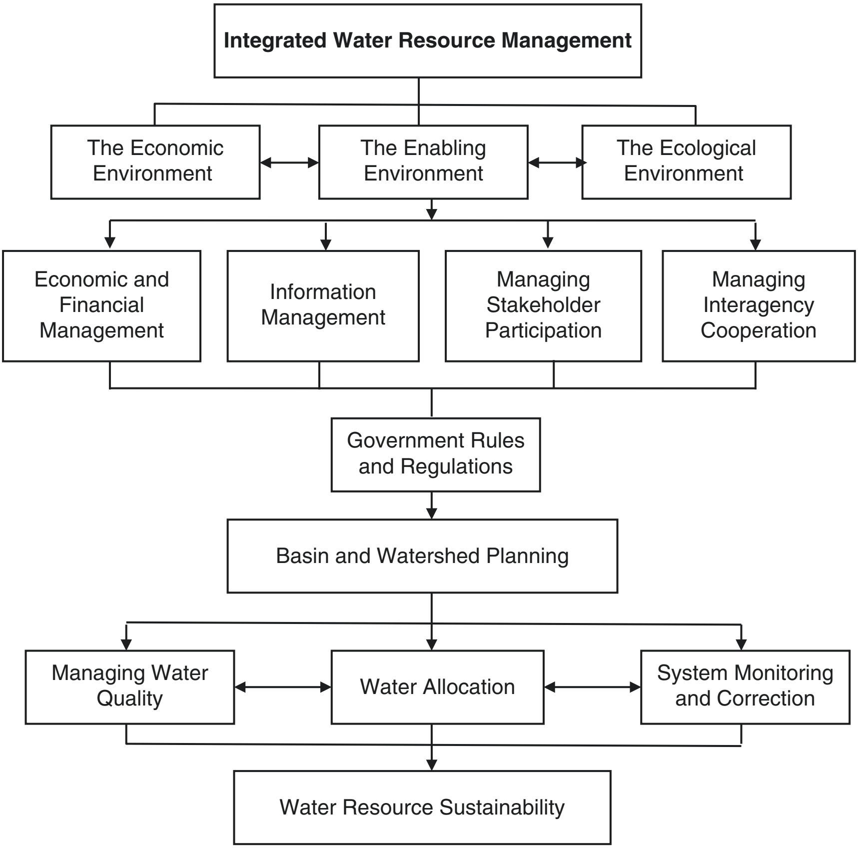

Fig 14.1 Selected components in an integrated water management model
Source: United Nations 2014 and others

becoming the focus of the 1977 UN Conference on Water (Furlong et al. 2015), although the term itself was first used by the UN in the 1950s as an element in a broader theme of integrated resource management. By 2015, Furlong and his team of researchers found that the IWM concept had appeared under a minimum of 26 different names.

A core principle of IWM planning, therefore, is the need for broadening involvement to include of all sectors of society affected by the water system in the planning and management of the system. Another is recognizing that water problems occur at more than just a local supply system, and therefore requires planning on a national, regional, watershed, and river basin focus. The objective of IWRM is incorporating the effects global warming-influenced changes on all segments of the socio-ecological system and the ability of a water system to survive such “stresses and shocks” as droughts, hurricanes and tornados, heavier rainstorms, reduced snow packs, floods, pollution resulting from human activity, loss of species diversity, and geographic modification. Water planners must go beyond just monitoring indications of changes in water supply and/or quality; they must also “try to assess the major social, ecological and economical drivers, possible [weather] ‘surprises’, and provide rough estimates” for the” longer term changes to entire freshwater systems. For “without a thorough understanding of these dynamics, conventional monitoring activities could miss the increasing risk that the water system is becoming more vulnerable to the impacts of climate variability and change . . . towards a threshold that is difficult or impossible to reverse” (Galaz 2007, 2–3).

Adaptive Water Management

Water management standards may be made in Washington, DC, but they must be continually revised and updated to ensure they follow the latest improvements in the field and be adjusted to meet local needs and conditions. One of the many versions of IWRM developed to cope with these shifting aspects of water management is the Adaptive Water Management (AWM) model (Furlong et al. 2015). The proponents of AWM approach are convinced that the one-size-fits all water management models cannot work for every basin, every watershed, every water use, particularly in light of the tremendous changes occurring as a result of climate change and global warming. Rather, what is needed are location and conditions-specific water management plans that can be applied in neighborhoods, farmlands, and industrial and commercial regions of each state.

The problem with the current system is that there is no one single agency responsible for managing water supplies and water distribution. Rather, supplies are management by a host of federal agencies while managing distribution is generally left to state and local government agencies (the polycentric governance model). A coherent water management policy must include both, as the following statement by Hickey notes: "A municipal water supply system cannot service its customers unless there is a continuous supply of water to meet domestic consumption needs in the broadest sense and water needs for structural fire protection. Water sources need to be selected carefully to make sure that this fundamental requirement is met. Two main factors that affect water supply selection are quantity of water and quality of water" (Hickey 2008, 2).

Integrated Urban Water Management (IUWM)

The GWP has supported implementation of an IWM program specifically designed for urbanized areas. Under the water cycle common in many urban areas, current Urban Water Management (UWM) practices import freshwater from natural water bodies that are further and further away from urban areas. The main objectives of that Urban Water Cycle system are to supply high water quality for all uses, and to remove stormwater and wastewater efficiently, with little coordination between the two responsibilities. The IUWM approach, on the other hand, calls for the coordinating all future urban development with watershed and river basin management to include achieving sustainability in economic, social, and environmental goals. Accordingly, it brings together water supply, wastewater treatment and discharge, storm- and flood water management and meshes these with regional land use planning and economic development goals. The IUWM approach integrates water sector planning with other urban issues such as land, housing, energy, and transport development in order to eliminate fragmentation and duplication. With IUWM, a common working culture, collective goals, and benefits are better identified, differences in power and resources become negotiable (Bahri 2012). The IUWM approach is based on the following principles:

- Include all alternative water sources.
- Match water quality with water use.
- Integrate water storage, distribution, treatment, recycling, and disposal.

- Protect, conserve and exploit water resources at their source.
- Account for non-urban users, including local agriculture.
- Recognize and seek to align formal and informal institutions and practices.
- Recognize relationships among water, land use, and energy.
- Pursue efficiency, equity and sustainability.
- Encourage participation by all stakeholders.

IUWM Economic Issues

Under IUWM, water prices and allocations reflect the costs of developing and delivering water supplies and maintaining the system. In this way, price is an indication of the true value of water. With development of integrated urban water management strategy, full pricing of water is expected to encourage domestic, industrial, and agricultural users to manage water wisely. In addition, graded tariffs based on water quality can urge users to reduce surface water or groundwater use in favor of reclaimed water. Prices, taxes, and subsidies can be used to distribute benefits fairly without reducing the sustainability of water resources.

Bahri added that pricing instruments can also be designed so users pay more for higher levels of consumption or quality. Financial incentives such as rebates, subsidized retrofits, water audits, and seasonal and zone pricing can also be used. Schemes under the "polluter pays" principle, in which charges relate to the effluent that users generate, can improve the cost-effectiveness of treatment and reuse. They can even fund the construction of new infrastructure. However, he also emphasized that the social needs of the urban community must also be considered when setting prices.

> While water prices that reflect water scarcity conditions and the true costs of developing and delivering water supplies can encourage more efficient water management by all water users, water pricing must also continue to account for the role of water as social good. This needs to be kept in mind when planning water tariffs, so that the rights of vulnerable groups are protected. (Bahri 2012, 66)

Water Management for Sustainability

Two of the variety of external forces are influencing the application of an IWM policy in the United States: the effects of climate change on supply and the crucial need to repair and replace aging infrastructure. To accomplish the many tasks needed to ensure that there is sufficient water of sufficient quality available when and where needed, the many federal, state, and local agencies that shape and implement water policy in the United States must suborn their own selfish interests to a develop a water policy that will give the Nation a sustainable supply of freshwater throughout the twenty-first century and beyond. A number of scientific papers, government agency studies and books have clearly identified the problem with America's water supply resulting from the consequences of our changing in climate: some areas of the country can expect to have too much water while others will not have enough. We cannot change the atmospheric conditions that hare influencing the weather change, but we can and must do a better job of managing what we have.

Sustainable Resource Management

Immediate changes in both water demand and supply called for in the IWM approach must be addressed in a new sustainable water management program. Otherwise, the country will see more lead poisoning in municipal water supplies, more toxic algae blooms in our lakes and rivers, and more abandoned farms for which irrigation water is no longer available. Our Nation's water policy must be one that aims to alleviate the discrepancy between water supply and demand and eliminates long-obsolete water rights system that benefit a few at the expense of the many. Americans must become more efficient in our use of the existing supply and adopt new and better ways of augmenting the national supply.

Repairing and Replacing Infrastructure

The US Environmental Protection Agency estimates that utilities in the United States need to spend $633 billion over the next two decades to supply water and to treat sewage. Others think the bill will be higher: A 2012 report by the American Water Works Association, for example, predicts that restoring and expanding water systems over the next 25 years could cost $US1 trillion. Without federal help, local water suppliers cannot come up with the funds needed to accomplish this daunting task.

The nation's water and wastewater utilities are forced to deal with the effects of weather trends that are increasingly severe and damaging to existing infrastructure. Warren B. Causey reminded us in 2011 that what the United States cannot ignore is that there is just so much freshwater available in the world and supplies nearly everywhere are already under strain. Added to the supply problem is that much of the country's water and wastewater infrastructure is from one hundred to several hundred years old and buried under community streets and buildings. In the United States, for example, many of the major mains serving cities and towns east of the Mississippi River were constructed in the nineteenth century. In Europe and Asia, many systems are even older. Much of that infrastructure is beginning to fail at the same time that supplies are reaching or have already reached the point where their use is no longer sustainable.

Integrated Water Management Principles

Passage of the Water Resources Development Act (WRDA) in 2007 instructed the Secretary of the Army to develop a new set of principles, requirements, and guidelines (PR&Gs) for the USACE. This section follows the Whitehouse announcement of the action that led to the change. In 2009, the Obama Administration began the process of updating the PR&G for Federal agencies engaged in water resources planning. These eight agencies involved included the USACE, EPA, Department of Agriculture, Department of the Interior, National Oceanic and Atmospheric Administration, Tennessee Valley Authority, Federal Emergency Management Agency, and Office of Management and Budget.

The final set of PR&Gs released in December 2013 provides a good guide to understanding US water management policy in the second decade of the twenty-first century and beyond. These policy principles were designed to guide all future federal investments in water and wastewater projects, The stated objective of the modernized PR&G was to "help accelerate project approvals, reduce costs, and support water infrastructure projects with the greatest economic and community benefits. They will also allow agencies to better consider the full range of long-term economic benefits of protecting communities against future storm damage, promoting recreational opportunities that fuel local business, and supporting other locally driven priorities. They allow communities more flexibility to pursue local priorities; take a more comprehensive approach to water projects that maximizes economic, environmental, and recreational benefits; promote more transparent and informed decision-making across the federal government; and ensure responsible taxpayer investment through smart front-end planning so that projects proceed more quickly, stay on budget, and perform better." Moreover, they emphasized that all new water resources projects should maximize economic development, avoid the unwise use of floodplains, and protect and restore natural ecosystems. Released for public review and comment occurred in December 2009 the bill was finalized in March 2013.

The policy principles were first spelled out in the Water Resources Planning Act IN 1965, the same law that established the Water Resources Council and led to two exhaustive assessments of the nation's water resources. These guidelines were intended to provide an analysis framework that government organizations and local individuals and groups were to employ before receiving Federal assistance and investments for water-related projects. Initially, they were restricted to just four agencies: the US Corps of Engineers, the Bureau of Reclamation, the Tennessee Valley Authority, and the Natural Resources Conservation Service. It was believed that following the same guidelines would increase consistency and comparability when comparing water resource federal investment decisions. Not long afterward, the guidelines were expanded to apply to similar federal investment decisions on projects undertaken by the EPA, and the departments Commerce, Interior, Agriculture and Homeland Security's Federal Emergency Management Agency (FEMA). The types of water-related projects covered by the P&Rs included projects related to these four classes of federal programs:

1. Federal grants, including for assistance activities under as the Endangered Species Act, Coastal Zone Management Act, Coastal Wetlands Planning Protection and Restoration Act, Consolidated Farm and the Rural Development Act. In addition to these programs, projects associated with such programs as Sport Fish Restoration, Wildlife Restoration, National Coastal Wetlands Conservation, North American Wetlands Conservation, Hazard Mitigation, and Assistance and Public Assistance programs.
2. Funding programs, such as the Pacific Coastal Salmon Recovery Fund, Safe Drinking Water Act State Revolving Fund, Clean Water Act State Revolving Fund, Federal Financing Bank Guaranteed Loan Program, and the Renewable Loan Program.
3. Project studies or investigations for construction of infrastructure such as new or modernization of facilities, dam safety or operational modifications, and ecosystem protection and restoration projects.
4. Proposals and plans that affect the management of such government assets as National Wildlife Refuges, National Parks, National Forests, and National Grasslands.

Three Aims of the WRDA

The aims of the nation's twenty-first-century water management approach were set forth in the 2007 WRDA. From that time on, the federal water management was to follow a three-pronged policy for funding investments in the nation's water resources. First, all such action had to reflect national priorities. Second, in addition to any water-related objectives, all new projects had to encourage economic development. Third, carrying out any action had to ensure that the implementation would protect the environment in the broadest of terms.

A set of six principles were included in the WRDA to ensure decisions followed these three broad policy guidelines. The principles are listed in no special priority or order, and all were to carry an equal weight. Each of the guiding principles are discussed below.

Maximize Sustainable Economic Development

Federal investments in enhancements to water resources and their management should contribute to the economic and environmental sustainability of society while also ensuring the well-being of the present and future generations; sustainability in this sense means creating and maintaining conditions under which humans and nature can coexist.

Avoid Unwise Use of Floodplains

Floodplains are the regions that connect land and water ecosystems in which a high degree of important biodiversit6y exists and should be maintained. Federal investments in water should not allow the unwise use of floodplains and flood-prone areas. "Unwise" use of floodplains is defined as any action or change that has an unreasonable adverse effect on public health a safety, or an action that is incompatible with or adversely affects one or more floodplain functions that lead to a floodplain that is no longer self-sustaining. At the same time, it is recognized that Federal action is often necessary to reduce regional vulnerability to floods and storms.

Protect and Restore Natural Ecosystems

Water projects with federal investments should protect and restore wherever possible the ecosystems and lessen any damage to the systems. Important features of natural ecosystems are their ability to respond to natural changes, including climate change, and to contribute to and enhance biodiversity. Specifications and requirements included in the

National Environmental Policy Act of 1969 and its several amendments. Requests for Federal funding of water-related projects are required to follow a common framework; use the best available scientific data, analytical techniques, procedures, models and tools in hydrology, engineering, economics, biology, ecology, risk, and other fields to the degree to which funding is available; and quantify the effects of water resource projects; collaborate with other affected federal agencies, with Tribal, regional, state, local, and non-governmental entities, community groups, academia, and private land owners; identify and clearly and understandably identify all risks and uncertainties—quantified if possible—related to climate change, future land use, and scientific-based adaptive management.

Follow a Total Watershed Approach

Watersheds are land areas that drain to a common water body. Following a pattern that was emphasized in the 1965 Water Resources Planning Act, the federal government promotes a watershed approach to analysis and decision-making on a wide range of potential solutions to water problems. Moreover, this suggests that federal support is more likely to be given to projects that represent the best means to achieve goals over the entire watershed and benefit a wide range of stakeholders within and around the watershed. The watershed approach enables consideration of both upstream and downstream conditions, effects, needs, and potential impacts of proposed actions.

Ensure Minority Involvement in Planning and Implementation

Environmental justice refers to the requirement for the fair treatment and meaningful involvement of all persons, regardless of race, color, regional origin, or income. Federal agencies are instructed to ensure that their water-related actions bring to light any disproportionately high adverse impact on public safety, human health, or environmental burden of projects on any minority population. Efforts must also be made to provide opportunities for participation by minority, Tribal, or low-income communities to participate in the planning and decision process. The water management policy should also ensure minority involvement in planning and implementation.

Avoid Unwise Use of Floodplains and Flood-Prone Areas

The use of floodplains for any action or change that has an unreasonable adverse effect on public health and safety, or an action that is incompatible with or adversely affects one or more floodplain functions that lead to a floodplain that is no longer self-sustaining. What this means is: do not build housing on land subject to flooding. Or, if you must, be sure you prepare for the heavy loss of life and cost of private property that will ensue if it can. Floods happen now, and in many parts of the country climate change-related extreme weather events are expected to cause even greater flooding in the future.

Protect Human Safety

Planning for federal water and wastewater investments must include assessing existing and future conditions that threaten loss of life and injury. Thus, structural and nonstructural elements of alternative solutions must avoid, reduce and lessen risks and include plans to manage and communicate residual risks from any action taken by a federal agency. Under this policy, all water-related projects in which any Federal agency is involved are in addition to all previously enacted rules and regulations (unless replaced or removed) is responsible. Other requirements agencies must follow when proposing federal investments in water projects include the availability and efficient use of water resources, including consideration of multiple uses and competing demands on the same resource, as well as considerations on water quality; consideration of nonstructural or alternative solutions that include changes to public policy, regulatory policy, pricing policy, and such management practices as green infrastructure; federal water resources investments must also consider treaty and other international obligations, including international consultations with relevant foreign governments; alternative plans, strategies and actions must also be considered, with assurance that a final solution has evaluated alternatives (the environmentally preferred alternative, where required, must be included in the final analysis); transparency in decision-making in the planning and implementation process for federal investments in water resources is also a requirement when preparing a proposal and selecting a final plan of action.

Integrated Water Management in Action

The High Plains aquifer (also called the Great Plaines or the Ogallala aquifer) underlies about 174,000 square miles across the high plains portions of eight states: South Dakota, Wyoming, Nebraska, Kansas, Colorado, New Mexico, Oklahoma, and Texas. "The Ogallala Aquifer, whose total water storage is about equal to that of Lake Huron in the Midwest, is the single most important source of water in the High Plains region, providing nearly all the water for residential, industrial, and agricultural use. Extensive use of irrigated agriculture results in farming accounting for 94 percent of the groundwater use. Irrigated agriculture forms the base of the regional economy. It supports nearly one-fifth of the wheat, corn, cotton, and cattle produced in the United States. Crops provide grains and hay for confined feeding of cattle and hogs and for dairies. The cattle feedlots support a large meatpacking industry. Without irrigation from the Ogallala Aquifer, there would be a much smaller regional population and far less economic activity" (WaterEncyclopedia.com).

A variety of federal, state agencies, and local districts soil and conservation districts have been charged with regulatory oversight of the aquifer. However, until recently, they has been little cooperative action at play, resulting in confusion and conflict over authority to address aquifer depletion and groundwater pollution. Nebraska, the state with the largest percentage of land overriding the aquifer, began to address this problem in 1969 by consolidating the many single-issue agencies into integrated natural resource management districts. Box 14.3 describes the development of that system.

Box 14.3 Innovative water management integration in Great Plains

"The Great Plains region of the United States produces significant quantities of food and fiber for U.S. and international markets, yet its natural [surface and ground water] resources are being taxed by problems such as drought, overpumping of aquifers [for irrigated agriculture], and contamination from agricultural inputs [predominantly fertilizers and animal wastes generated at a large number of cattle feedlots]. From an economic development perspective, irrigated agriculture has allowed the region to enjoy enormous economic growth. The growth of this . . . system has come with resource, environmental and social costs, however. With relatively low natural recharge rates, a semi-arid climate, and the dramatic increase in the use of groundwater throughout the region, declining water levels have plagued the region since the 1940s. Today, with some parts of the aquifer showing declines of more than 50 percent, concern about the health of the aquifer remains acute."

"By the 1960s, Nebraska had established watershed planning boards, rural water districts, and flood control districts in addition to soil and water conservation and irrigation districts [formed following the 1930s Dust Bowl disasters]. With overlapping functions, authorities, and boundaries, there often was confusion about who had responsibility for what issues and coordination at the state level was extremely difficult. To better manage its natural resources, the Nebraska legislature consolidated the 154 existing resource-related districts into 23 Nebraska Natural Resources Districts (NRDs), local agencies with broad authority to research, regulate and manage natural resource use in the state. . . . NRDs, with their authority over all [water] resource related issues, allow integrated resource analysis, planning and management . . . in a coordinated and efficient manner."

Source: David W. Cash (2003), from sections in pps. 8–13

Call for a New Management Approach

Juliet Christian-Smith and Peter H. Gleick, two of the water field's most prolific writers and among their generation's respected water scientists, with other editors and water research contributors, Heather Cooley, Lucy Allen, Amy Vanderwarker and Kate A. Berry, published their *A Twenty-first Century US Water Policy* in 2016. They made the following recommendations for a new approach to water management that is designed to preserve and protect the nation's water supply:

1. Combine and coordinate fragmented water agencies and programs.
2. Revive river basin commissions and require river basin planning on rivers shared by two or more states.
3. Task a national water commission or council with guiding river basin plans and reviewing water-related budgets and priorities.
4. Support an improved understanding of water supply, use, and flows.
5. Use innovative economic strategies as a tool to encourage sustainable water practices; increase local cost share for federal grants; continue or expand current levels of funding for state revolving funds; use proper prices to improve cost recovery and build reserves for infrastructure maintenance and improvements.
6. Integrate the risks of climate change into all water facility planning, design, and operation.
7. Update current federal water laws and expand monitoring and enforcement.
8. Develop federal policies to encourage demand management and alternative approaches to expanding water supplies; promote new supply approaches; increase water-use efficiency; build the capacity of community-based organizations.
9. Integrate US water policy with other federal resource policies; manage water and energy together; link water and agricultural policies.
10. Apply environmental justice principles comprehensively in federal water policies.

Summary

Climate change, population growth and a history of over-used, over-allocated, and over-regulated water has resulted in a complex challenge for managing America's most vital resource, water. The United States faces water problems in all regions and in all sources of supply—this is despite the fact that the Nation has been blessed with what has long been believed to be a sufficient, sustainable supply of clean freshwater.

Conditions today and for decades to come have made the traditional way of managing the resource obsolete. The polycentric model of water management has to be replaced with one that is constructed from a position of respect for all stakeholders, all users, and all environments. One of these new water management models is the Integrated Water Resource Management approach.

Canadian university professor Keith W. Hipel and his team of fellow researchers described the scope of the management model necessary to successfully achieve water resource sustainability position water managers are in this way: "Virtually all water resources and environmental management problems involve multiple stakeholders, who have different objectives and value systems . . . recent scientific studies on the effects of rapid climate change on global warming strongly indicate that as climate systems are becoming increasingly susceptible to technological and man-made stresses, future mitigation measures required to diminish the risk of further deterioration in these climate systems have to be highly adaptive in addition to integrative" (Hipel et al. 2008, 52–53). This means that water managers ought not follow a single all-stakeholder approach to managing the resource, but that different management models that are designed with local needs and restrictions in included are necessary for local success to be achieved.

Additional Reading

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Total Water Management

As early as the 1990s, government and private water managers began to recognize the piecemeal approach to managing the Nation's water resource was not going to achieve the goal of sustainability talked about for decades. Two holistic ways of managing the resource emerged to rectify this problem. One was discussed in the last chapter: integrated water management. This chapter looks at the second recommended solution: the total water management (TWM) approach. Each these management models has been proposed as a way of cutting through this iron curtain of single-purpose business model focus and replacing water providers' self-interest with collective and collaborative innovation.

As the twentieth century was coming to a close, dealing with water supply and sanitation problems in light of global warming, increased population and urban growth had become recognized a global problem, one that impact developed as well as developing regions. In 2005, UNESCO published a comprehensive volume on *Water Resources Systems Planning and Management* that began with this statement calling for government and water industry leaders around the world to exert greater effort to come up with innovative and coordinated solutions to

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the water resource management challenges facing the changing water management organizations and governments:

> Throughout history much of the world has witnessed ever-greater demands for reliable, high-quality and inexpensive water supplies for domestic consumption, agriculture and industry. In recent decades there have also been increasing demands for hydrological regimes that support healthy and diverse ecosystems, provide for water-based recreational activities, reduce if not prevent floods and droughts, and in some cases, provide for the production of hydropower and ensure water levels adequate for ship navigation. Water managers are challenged to meet these multiple and often conflicting demands . . . Added to all these management challenges are the uncertainties of natural water supplies and demands due to changes in our climate, changes in people's standards of living, changes in watershed land uses and changes in technology. How can managers develop, or redevelop and restore, and then manage water resources systems—systems ranging from small watersheds to those encompassing large river basins and coastal zones—in a way that meets society's changing objectives and goals? In other words, how can water resources systems become more integrated and sustainable? (Loucks and van Beek 2005, 1)

The call aired by the UN applied to the United States as much as it did to the rest of the world. American's have not always done a good job of managing this critical natural resource. The national press regularly contains stories about the problems and pitfalls resulting from poor or misdirected water management (Sheer 2010).

The many challenges facing America's water resources in this era of heightened urbanization, population growth, deterioration of much of the water sector's aging infrastructure, and the stresses placed on the resource by climate change are have brought water managers to recognize that a need existed for taking a more comprehensive, watershed-wide water management approach. The TWM approach was recommended as a way to help water managers plan and implement programs designed to assure resource sustainability despite those challenges. O'Connor et al. (2010a) saw TWM as an approach that would guide water managers to looking at their water supplies and distribution systems in an interconnected manner, rather than only a focusing on just one district-centered problem at a time. Traditionally, water managers had dealt with just one or two goals, such as reducing water demands, increasing water recycling, repairing or replacing failing infrastructure, controlling stormwater and other urban runoff problems, or the like. A fundamental aim of TWM was to match water quality to all possible sources and end-use needs while achieving managing the resource to meet environmental goals, public health, and organizational sustainability.

TWM Defined

The American Water Works Association's research foundation provided this broad definition of TWM in 1996: TWM is "the exercise of stewardship of water resources for the greatest good of society and the environment," thereby associating TWM with the concept of the "triple bottom line." The Merriam-Webster online dictionary relates the stewardship concept to caring for water and other natural resources in its definition: "The conducting, supervising, or managing of something; especially the careful and responsible management of something entrusted to one's care, [such as the] stewardship of natural resources." By including the private business sector in its online website, the World Wide Fund for Nature took note of the broad stakeholder responsibility in its definition of stewardship: Water resource stewardship goes beyond being an efficient water supplier or water user. It is includes the private sector collaborating with the public sector, governments, other businesses, NGOs [non-government organizations], communities, the public and other stakeholders in ways that assures sustainable shared water resources. The role of both the private and public sectors must work together in advocating, supporting and promoting better watershed and river basin governance for the benefit of all the people and the natural environment.

In a report on a national parks research project dealing with water management, EPA described the TWM concept as a way of improving the sustainability of a water supply by including water in all its forms in a water management system. TWM helps water supply managers and municipal, industrial, and agricultural water users shape and operate programs to become more efficient their use water. This occurs when the stakeholders achieve in breaking down institutional barriers that designate water as a distinct type based on its source and/or characteristic: potable, waste, or runoff. By including all types of water in management plans, waste streams become water sources instead of traditional utility water management operations. Utilities do more than only provide consumers potable water that will be used once and then discharged by consumers to a wastewater utility or septic system.

In a more detailed description of what the TWM approach can do for water managers, an EPA-sponsored report on the City of Los Angeles, California, explained that it is a valuable approach to water management because it is based on a holistic view of a water supplier's water resource system because it is founded upon principles of sustainability. Another advantage is the flexibility of the process. It can be used to increase water resources efficiency and enhance overall benefits. This is because of its commitment to taking an interconnected view of all water forms and sources, thereby reducing demand for the limited supply of freshwater by including recycled wastewater, stormwater, urban-area runoff, while improving management of unavoidable floodwater. In this way, TWM considers all water as a valuable resource that undergoes a distinct cycle. Moreover, all those cycles can be managed in a fully integrated manner. Figure 15.1 is a model of a traditional, once-through water management

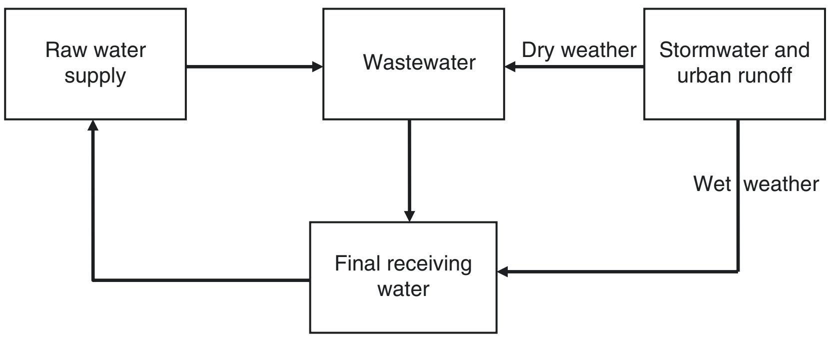

Fig. 15.1 Non-integrated water resource management system
Source: From material in Rodrigo et al. 2012

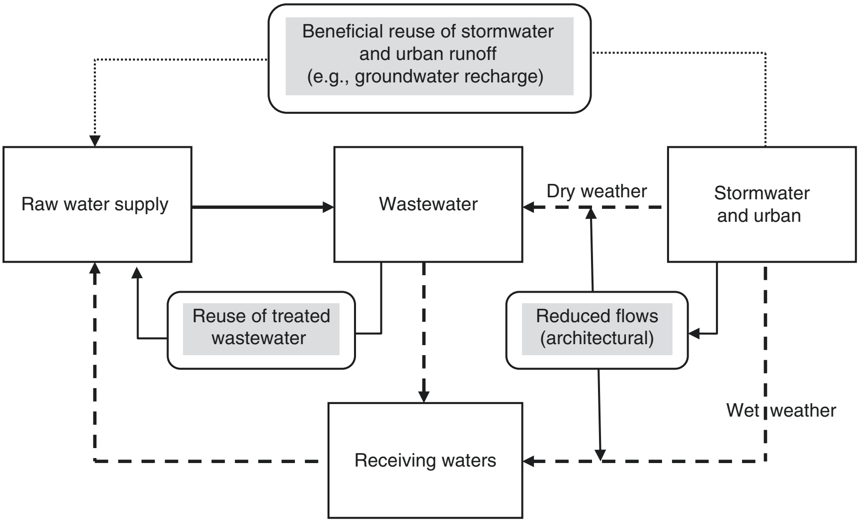

Fig. 15.2 Total water management with integrated water resources system
Source: From material in Rodrigo et al. 2012

systems; the model in Fig. 15.2 illustrates how a TWM approach results in including an integrated water source system into a water supply.

The traditional approach focused on the supplier's capacity to locate, collect, and protect water sources, treat that water, and provide customers with clean, safe drinking water through a distinct functional system of pipes. Other nearby providers were not included in this focus. In the waste stream, where system individuality is also extant, separate service providers must provide significant infrastructure to collect, treat, and protect the public from water-borne diseases—with little or no cost recovery of water. Many water utilities and municipalities are moving to a TWM strategy to protect source waters and recover cost on treated effluent by providing consumers multiple grades of water.

Barriers to Greater Adoption

Although adopting a TWM approach has been shown to make a beneficial contribution to the water management process, wider application of the process faces difficulties. Sustainability of the water resource everywhere faces challenges springing from a variety of large and small internal and external problems, it is not a single devastating enemy calling for the immediate mustering an army to conquer. For most Americans, the water crisis is something that affects other people in other countries. It is a phenomenon they hear or read about, something that is growing slowly in intensity and, therefore, easy to ignore in the short term. A sea rise of an inch a year, for example, is hardly noticeable by anyone. It is not a massive, sudden crisis such as Hurricane Katrina that enlisted thousands of volunteers and an outpouring of contributions and political support.

Water managers must work with a large number of stakeholders including citizen groups, government administrators, regulators, and private customers. The shared challenge of water managers, therefore, is to provide management services for a sustainable water resource while maintaining the economic stability and environmental quality that underlies health of the Nation. Sustainability requires balanced water supplies for people, businesses and industries, farmers, and the environment. At the same time, they must follow practices that ensure the protection of water sources. Water scarcity in many parts of the country requires new technologies for water efficiency, while in other areas they must cope with extreme weather events that result in more and more severe flooding and urban runoff.

TWM and Watershed Water Management

The concept of TWM requires planning for a watershed as well as for water in all its forms and uses. The TWM approach was originally seen as applicable primarily to an urban environment, but as TWM has achieved greater acceptance, it now includes all watersheds associated with a water system. In TWM, management of water at different stages of the water cycle does not consider classes of water as independent "types" of water, such as raw water, potable water, wastewater, and runoff. Rather, "water, regardless of form, is considered one resource that undergoes a cycle that can be managed holistically. Nor are pollutants are seen as attributes of a specific type of water. Instead, they are seen as elements that all water will transport once they are introduced in the water cycle. That introduction can occur at many different locations, and as a result of specific human activities and practices and as process of nature. In TWM, managers track pollutants from where they are introduced in the water cycle and how they are transformed and removed from it, what is their ultimate fate and how managing decisions can impact that fate and transport" (EPA 2009).

O'Conner et al. (2012) assert that the TWM watershed approach makes necessary adopting a holistic view of the resource instead of the piecemeal approach that often characterized past water management actions. Water managers must plan for and manage all functions, including purchasing or withdrawing, storing, treating, distributing water services. Today this includes all types and quality levels of the resource. Planning must now be done on a watershed level. A partial list of the tasks that may be involved in the exercise of TWM in addition to the traditional supply and delivery tasks of utilities includes the following:

- Water conservation
- Wastewater reuse
- Gray water reuse
- Stormwater catchment and productive use
- Rain water harvesting
- Dryweather runoff treatment
- Separate plumbing for potable and non-potable supplies
- Separate distribution systems for fire protection
- Multi-purpose water/wastewater infrastructure
- Variable water quality levels for varied uses
- Green roof and urban surface catchment and aquifer recharging facilities
- Low-impact development

TWM integrates the management of watershed issues, water supply sources, land-use practices, and related resource in the effort to ensure sustainable supplies while considering economic and social considerations and promoting a healthy ecosystem in a "triple bottom line" approach to resource management (Ffolliott et al. 2003, Jeffcoat et al. 2009, *The Economist* 2009). Originating in a 1994 recommendation of British business consultant John Elkington, the triple bottom line planning system called for organizations to prepare three different bottom lines when preparing annual plans: the traditional economic measure, the organization's level of responsibility to society, and one on its achievements in environmental responsibility.

TWM and Watershed and River Basin Management

The TWM process requires looking beyond the specific source of water and the receiving waters into which water eventually returns; it looks at the total watershed of the resource. A watershed approach does the same for the entire area drained by a stream system or a protected area from which surface or groundwater is received and which itself receives water from an upstream source or from natural precipitation. Management of a watershed is in the hands of a hydrological response unit, a physical biological unit, or a political unit, or more likely, a combination of any of three. The region is most often a smaller geographic area that is part of a larger river basin, although smaller, independent watersheds may exist as well.

Holistic watershed TWM includes the interrelationships that exist among soil, surface and groundwater water supplies, and land use as well as the links between upstream and downstream regions. This includes the connections between the effects of precipitation, weather, and human actions on stream channel and aquifer characteristics. The triple bottom line planning in watershed management considers socioeconomic and human-institutions as well as the biophysical relationships. Ffolliott et al. (2003) point out that watershed management planning in a TWM system may have any of the following or other objectives:

- Rehabilitating degraded land areas,
- Protection of water and/or soil resources on lands used for producing food, fiber, forage, forests, recreation, or other purposes,
- Improvement of human environments, such as landscaping,

- Enhancement of water quality and quantity,
- Flood control and water transportation improvements,
- And any combination of these and more.

River basins are the larger view of watersheds; they have been defined as a "watershed on a larger scale" (Ffolliott et al. 2003, 1). Examples include the Columbia River Basin, the Colorado River Basin, the Ohio River Basin, and the Mississippi River Basin. River basins include all the tributaries and their tributaries that flow into the major rivers for which the basins are named. Water management at this level is far beyond the scope of this text; aspects of the state of the resource in many of the nation's major river basin were addressed in Chap. 1.

A Texas Example of the Watershed Management Approach

The Texas Water office, a unit of the College of Geosciences at Texas A&M University, promotes a Watershed Water Management (WWM) approach that is similar to the TWM program of integrated water resource planning. They define WQM as "a holistic approach to managing water resources for quantity and quality within a watershed." The steps involved in watershed approach to water management are shown in Fig. 15.3. By including whole watersheds in resource planning, water supply managers are able to evaluate all the sources of supply and pollution that may be affecting water quality and quantity.

As the figure illustrates, the watershed approach is a continuous cycle of tasks: setting standards for surface water quality, taking measurements of the conditions, assessing the data and identifying the impairments including establishing priorities, verifying the pollution sources and developing plans for restoring water quality, and implementing pollution source controls. Pollution source controls can be things such as permits, rules, and nonpoint source management practices. Setting standards, developing strategies, and implementing controls are included below.

Fig. 15.3 Processes in the watershed approach to water quality management
Source: Persyn, Griffin, Williams and Wolfe (2014)

The Texas Surface Water Quality Standards identify four general categories for water use: (1) *aquatic life use:* The standards associated with aquatic life use are designed to protect plant and animal species that live in and around the water. They establish optimal conditions for the support of aquatic life and define indicators used to measure whether these conditions are met; (2) *contact recreation*: The standard associated with contact recreation measures the level of certain bacteria in water to estimate the relative risk of swimming or other water sports involving direct contact with the water; (3) *public water supply*: Standards associated with public water supply indicate whether water from a lake or river is suitable for use as a source for a public water supply system; and (4) *fish consumption*: The standards associated with fish consumption are designed to protect the public from consuming fish or shellfish that may be contaminated by pollutants in the water.

Strategy Development and Setting Goals

The next step in the watershed management approach is strategy development. This phase involves the development of goals and strategies to maintain, or achieve water quality standards and meet future demands.

Setting and prioritizing goals is the key step at which stakeholders, both direct and indirect, become key players in identifying strategies and designing the actual

Implementing Goals and Strategies

To fit their watershed's needs, stakeholders and decision makers may customize the tools that exist for putting watershed management plans into practice. Three of those tools are permits, best management practices (BMPs) and educational programming. Each watershed management plan will have site-specific needs requiring different combinations of these three tools.

Total Water Management Examples

Including supplies of all classes of water, from source water to wastewater and stormwater treatment, reuse, and flows in the natural water cycle, in the water management task is a second principle of TWM. Three examples of how water managers have adopted a TWM approach are described in the following sections. The first example explains the how the City of Los Angeles, California, included a comprehensive view of how all water sources were to be included in its state-mandated water plans (Rodrigo et al., 2012). The second example explains how the Clayton County Water Authority (CCWA), Georgia, has implemented a TWM plan for its water system (Jeffcoat et al. 2009). The third example is TWM as it has been employed in Arizona.

TWM in Los Angeles, California

The service area and urban watershed of the City of Los Angeles, California, and its immediate environs stretches from the San Fernando Valley, the core central city, west side Pacific Ocean beach areas, east to the San Gabriel mountains, and south in a narrow corridor to one of the Nation's busiest ports at San Pedro.

Potable Water Supplies

The City's main water supply sources are (1) the Los Angeles aqueducts (LAA), (2) local groundwater, and (3) water purchased from the Metropolitan Water District of Southern California (MWI). The City relies on imported water for 85 percent of its needs. Half of the imported water via the LAA originates in the Sierra Nevada Mountains via the Owens Valley and Mono Basin. The MWI supplies 35 percent of the City's supply from both the State Water Project (SWP) from the Sacramento River basin and the Colorado River. Local groundwater contributes 15 percent of the City's supply; this has increased to 30 percent in times of severe state-wide drought. Approximately 86 percent of this supply is pumped from the Upper Los Angeles River groundwater basins, with the primary of supply coming from the San Fernando Valley Basin.

The County of Los Angeles receives its water supplies from the same local and regional sources as the City, but also includes surface water from the San Gabriel and Rio Hondo rivers and groundwater from the San Gabriel River Basin. The San Gabriel Valley sits atop an underground gravel-filled storage basin that is three miles deep in places, and maintains excellent groundwater storage capabilities. Freshwater is augmented by tertiary-treated wastewater that is allowed to naturally augment the aquifer from abandoned gravel mines converted to deep pit surface spreading grounds.

Wastewater Services

The City provides wastewater collection, treatment and disposal. The collection system includes some 6,500 miles of major interceptors and mainline sewer lines, 46 pumping stations, 4 wastewater treatment plants, 2 water reclamation plants with tertiary treatment capability, handling an average dry weather flow of 543 million gallons per day. Additional collection system capacity and treatment facilities are projected to be needed by 2020. Secondary-treated effluent that is not further treated for recycling uses is discharged into Santa Monica Bay via a 5-mile ocean outfall.

Recycled Wastewater

Although Los Angeles has a long history of using recycled water, it remains committed to a small portion of the system's overall demands. The City began supplying recycled water to irrigate in the large Griffith Park area in 1979. Since then, deliveries of recycled water has expanded to now include water for freeway landscaping, golf courses, environmental enhancement, and for some non-governmental industrial and commercial users. Some recycled water is also sold to the West Basin Municipal Water District for landscape and similar uses. The City has also been expanding its recycled water processing capabilities for other non-potable uses by advanced treatment of recycled water for groundwater aquifer recharge.

TWM in Clark County, Georgia

The Clayton Country (Georgia) Water Authority (CCWA) describes itself as "the county's one-stop-shop for water, sewer and stormwater services." The utility provide serves 78,500 customer accounts in Clayton Country and portions of adjoining counties, maintains five raw water reservoirs that can produce up to 42 million gallons per day of potable water and treat up to 38.4 million gallons of wastewater every day. The facility's water supplies are impacted by the ongoing water war between Georgia, Alabama, and Florida over surface water (discussed in Chap. 8). The CCWA manages approximately 1,500 miles of water distribution pipes, 1,300 miles of sewer conveyance pipes and 500 miles of stormwater infrastructure. CCWA is one of the few metropolitan water utilities in the country using its own constructed treatment wetlands to recharge its groundwater supply.

The CCWA service area is located on the south side of metropolitan Atlanta. The entire region has experienced rapid population growth and urbanization. As a result, all water suppliers in the metropolitan area have encountered difficulties finding and establishing alternative water supplies to meet the increasing demand. These challenges were included in its decision to use the TWM approach in its 2007–2008 water plan.

Despite having limited surface water or groundwater supplies available, the Water Authority has developed a sustainable water supply by development of an extensive system natural treatment wetlands for the recycling of treated wastewater. During the second worst drought on record in 2007 when many utilities in north Georgia were in danger of running out of water, the Authority was recycling of over 10 million gallons per day of reuse water.

Water Supply Stresses

In early September of 2016, the Georgia Environmental Protection Division declared a Level 1 drought response was required for 53 Georgia counties, including Clayton County. While this declaration does not require additional outdoor watering restrictions, the state's permanent year-round outdoor watering restrictions allow outdoor watering any day of the week between 4 p.m. and 10 a.m. Conditions worsened in October of 2016, resulting in forced implementation of more severe restrictions in the northern part of the state. North Georgia's drought forced Haralson County, 35 miles west of downtown Atlanta, to impose drought conditions Level 3, the state's harshest water use restrictions: No outdoor watering allowed (except for irrigation of family food plots), no car washes, football fields must remain dry, and similar household water use restrictions apply. The Tallapoosa River was so low that the county water authority dismantled beaver dams. Long-time residents said they had not seen such conditions since 1925.

Haralson was the first Georgia county to announce a need for Level 3 drought restrictions. However, 50 counties across North Georgia were experiencing, at least, an "extreme" drought, according to the U.S. Drought Monitor. Atlanta's rainfall shortfall since March 1, 2016, was almost 11 inches. Rome, north of Haralson County, is a foot below average rainfall. Lake Lanier, the region's main water source, was seven feet below full pool. Residents were warned: "If you don't need to use water, don't use it. We're asking everybody to conserve" (Chapman 2016).

Drought conditions similar to the 2016 drought were behind the decision to use the TWM model in developing their water plan. By implementing what they considered to be an "aggressive water supply plan" that would include a description of how the Authority would ensure it could meet the water demands of a growing population without compromising on water quality in the watershed or in the distribution system during the severest of drought conditions.

The Authority's TWM approach included expansion of its constructed wetlands treatment system to a capacity of 26 million gallons per day. The goal was to create a "drought proof" water supply system.

TWM Begins in Arizona

The State of Arizona continues to be hit by two unrelated external forces that are making it increasingly difficult for water suppliers to be assured of being able to meet present and future demand. The state has undergone population growth at an alarming pace, while at the same having to deal with water scarcity (Hill et al. 2007). With no access to the sea for a potential source for desalinated water, the state must rely on non-renewable groundwater supplies and limited surface water supplies to meet the water needs of its people. Supplies of surface come from the over-allocated Colorado River that is itself declining in flow due to climate change is expected to decline even more as Southwestern U.S. droughts occur more often, the temperatures are increasing, and droughts last for longer period.

Water planners in the state agree that with the uncertainty of water supplies growing ever more present, recycled water may be the only water source that is increasing in availability. Recycled water is already commonly in use to irrigate Arizona's public spaces such as parks and golf courses. Recycled water is also extensively used for certain classes of agriculture. Use for augmenting potable water sources is only lately becoming more plausible. Planning for future water demands has made application of TWM principles a necessity. Yet, the state was slow to adopt the idea. For example, the Arizona Drought Preparedness Plan issued in 2004, gave little notice to recycled water, as this following statement in that plan attests:

> Effluent, or treated wastewater, can be treated to a quality that can be used for purposes such as agricultural irrigation, turf grass watering, industrial cooling, or maintenance of riparian areas. Effluent has the potential to replace a portable water supply when potable water quality is not necessary for the use. (Arizona Drought Preparedness Plan 2004)

Despite the apparent slowness of the state to embrace recycled water as a valuable element in a TWM program, some Arizona cities have taken on the task themselves. For example, in 2008 the City of Tucson, AZ, adopted an ordinance requiring that:

- All new single family and duplex residential dwelling units shall include either a separate multiple pipe outlet or a diverter valve, and outside "stub-out" installation on clothes washing machine hook-ups, to allow separate discharge of gray water for direct irrigation.
- All new single family residential dwelling units shall include a building drain or drains for lavatories, showers, and bathtubs, segregated from drains for all other plumbing fixtures, and connected a minimum three (3) feet from the limits of the foundation, to allow for future installation of a distributed gray water system
- All gray water systems shall be designed and operated according to the provisions of the applicable permit authorized by ADEQ under the Arizona Administrative Code, Title 18, Chap. 9.

In 2014, the Tucson Water utility announced that it had completed a master plan for the development of recycled water as a future drinking water source. In Tucson's Recycled Water Master Plan, the water supplier was charged with preparing a phased multi-year implementation plan for the new indirect potable reuse (IDR) program included in the Plan. IDR uses advanced treatment and aquifer recharge before recovering the water and blending it with other potable supplies.

Flagstaff, Arizona's Limited Water Management

The City of Flagstaff's wastewater treatment operations produces high-quality recycled or reclaimed water to offset the use of drinking water by meeting regulations for landscape irrigation and industrial use, but not for as a potable water resource in a TWM scheme. The range of Flagstaff's applications of reclaimed water includes irrigation of parks and golf courses, industrial use, toilet flushing, residential lawn and garden watering, snow making and habitat along the Rio de Flag. Reclaimed water quality is closely regulated by the Arizona Department of Environmental Quality and the Environmental Protection Agency. Reclaimed water is one of the City's most significant water conservation tools. Over 2,000 acre-feet of reclaimed water is directly used each year.

High-quality Class A+ reclaimed water is produced by the City's Rio de Flag Water Reclamation Plant. Treated effluent from the Rio Plant supplies most public schools and parks, cemeteries, public landscapes, and residences. The City's Wildcat Hill Wastewater Treatment Plant (WWTP) has delivered reclaimed water to the Continental County Club's golf courses for decades. The Wildcat Hill WWTP currently is permitted to deliver Class A reclaimed water.

Meeting the Sustainability Challenge

Water utilities in the United States and elsewhere in the world are facing massive challenges, many of which are attributable to some climate change already under way from long-time natural forces that may or may not have anything to do with the current warnings about global warming. Arid areas such as the Western United States have become more arid and population growth is beginning to tax limited water supplies in many regions. In many areas, freshwater resources are already under strain. Parts of the United States are undergoing a long-term drought, one for which no end is in sight. As we have seen in the book's earlier chapters, drought conditions are spreading to regions that have long enjoyed seemingly unlimited supplies of freshwater. Water resource managers throughout the United States must now deal with the effects of the mega-trends that will affect the water resource throughout the rest of the century.

As Warren B. Causey reminded us in 2011, what cannot be ignored is that there is just so much freshwater available in the world and supplies nearly everywhere are already under strain. Added to the supply problem is that much of the country's water and wastewater infrastructure is one to several hundred years old and buried under community streets and buildings. In the United States, for example, many of the major mains serving cities and towns east of the Mississippi River were constructed in the nineteenth century. In Europe and Asia, many are even older. Much of that infrastructure is beginning to fail at the same time that supplies are reaching or have already reached the point where their use is no longer sustainable.

A list of some of the issues and challenges facing large and small water utilities today and which should be addressed include the following:

1. Infrastructure disintegration.
2. The impact on freshwater supplies by continued global warming and the predicted acceleration of the phenomena predicted in the near future.
3. Population growth and how it affects water supply and distribution infrastructure.
4. Settlement patterns that see migration toward warmer and drier regions of the country.
5. Changing trends in industrialization and industry's use and misuse of freshwater supplies, together with restrictions on factory location and water use.
6. Increasingly rigorous national, regional and local environmental policies.
7. Drought and desertification of many parts of the country.
8. Agricultural extension and intensive water use for certain crops.
9. Impact of drought conditions on hydroelectric energy production.
10. Unequal water distribution and efforts to share resources.
11. Political pressures for use permitting, quotas, metering, reuse and recycling.
12. Security and stability of supply, distribution systems, and records.

Small and rural water and combined water and wastewater sectors of the public utilities industry are facing an increasingly complex and challenging future without the resources to take on all the problems they must deal with. They are stretching their available resources for meeting these challenges to the breaking point. Meeting government-mandated health, efficiency, and other factor requirements add to the small systems' difficulty in maintaining their service commitments. To meet their mandate of serving their publics, managers and operators of these small and rural utilities struggle to keep up-to-date on the issues and trends that affect all aspects of their operations. They must innovate in order to survive. Taking a holistic view of the resource and the water problems facing the country with such management tools as integrated water resource management and TWM are reflection of the industry's recognition of the need to change.

TWM and Innovation and Collaboration

Regardless of size or ownership, water suppliers all provide the same public service. All are also heavily regulated and monitored by federal, state, and local environmental and public service agencies. They are either departments of municipal organizations or private firms operating as quasi-government organizations. They are also similar in their search for innovative solutions to all types of managerial and operation problems.

The search for innovative management solutions may be the greatest challenge facing all utilities in the remaining years of the twenty-first century. Aging infrastructure, changing weather conditions, heightened security concerns, rapidly changing technology, and the difficulty finding and retaining qualified professional personnel all demand new and better ways of operating. This means embracing the willingness to adapt water management operations to changing conditions and to accept innovative ways of dealing with the problems resulting from those changes.

As the commitment to innovative and holistic management of the water resource continues to grow, the willingness to embrace open innovation through inter-organizational collaboration and cooperation. It is happening in all sectors of the utility industry and all sizes of organizations. And, it is not happening just in the United States: innovation at all levels of government is now a global phenomenon. Collaboration in seeking and applying innovative solutions to problems has become increasingly the norm among organizations providing public services. Innovation begets transformational change in all types of organizations.

Planning tools such as integrated water resource management and TWM provide models for managing water resources on a sustainable basis. The water crisis is not going way, although it is often easy to ignore in the short term. Water managers must work together to manage the resource. They must also work with regulators and citizens. We all—suppliers, regulators, and consumers of water—share in the need to ensure a sustainable water supply remains available for this and future generations. Sustainability requires balanced water supplies for humans and the environment, protection of water sources, and resolution of local and regional water conflicts.

Collaboration in the Lower Colorado Basin

The conflict in the West over water from the important Colorado River Basin may be entering a far less contentious stage (King 2016). Publication of the State of Colorado's Water Plan in November, 2015 suggests the states and other stakeholders that depend on Colorado River water may be entering upon a trend reflective of greater cooperation and collaboration and less battling over their shares of the over-allocated resource. Allocations established under the 1922 Colorado River Compact negotiated between the seven Western states and divided the region into an Upper and a Lower Basin was negotiated during an uncommonly wet period. When the river regions reverted to their more normal dry climate, allocations could not be sustained.

The Lower Basin's water allocations were not accepted by the states involved. Moreover, the allocations ignored other groups with an interest in the resources: Mexico and a number of Indian Tribes had no say in the Compact. Environmental concerns were also ignored. Agreement had to wait until the 1963 U.S. Supreme Court apportioned the water between Arizona, Colorado and Nevada. Further resolution had to wait until 2012 when an agreement was reached between the United States and Mexico on what share would be allowed to cross into Mexico.

Another sign that cooperation is supplanting litigation is the negotiations underway in 2916 between Arizona, California and Nevada, affected Tribes and other stakeholders to agree on a Drought Contingency Proposal for sharing cuts during shortages and to raise the level of water stored in Lake Mead.

Security Collaboration

The Pacific Northwest Partnership for Regional Infrastructure Security (PNPRIS) is another example of a successful cooperative arrangement. One of the training exercises sponsored by PNPRIS involved a disaster scenario devised by representatives from the Bonneville Power Center; telecommunications companies Telus, Verizon, and Qwest; the Federal Emergency Management Agency; the British Columbia Provisional Emergency Program; and the Canadian Office of Critical Infrastructure Protection and Emergency Preparedness. The scenario theme was a disruption to the Northwest's electric power grid. It also included terrorist and nonterrorist disruptions of natural gas transmission and distribution systems, municipal water systems, regional ports, and telecommunications systems. Disruptions of those critical public services affected other independent infrastructures, including transportation systems, emergency services, public safety services, hospitals, and cross-border cooperation. A chief result of the training session was that many participants discovered that their organizations' contingency plans were negated by the cross-border interdependencies that exist among the region's public services.

Water managers have their work cut out for them. They have to think about and plan for more severe weather events, changing weather patterns, aging and failing infrastructure, and in large sections of the country, declining resources and increasing demand for their product.

As population grows, urbanization and current water management operations put different stresses on the environment and on urban infrastructure, there is a need for urban water managers to take a more holistic view of their water resource systems. In this urbanizing world, water managers need to develop new planning and management frameworks in or for municipalities to meet challenges, such as limited freshwater supplies, degradation of receiving water quality, increasing regulatory requirements, flood management, aging infrastructure, rising energy and therefore utility costs, population dynamics and climate change (Rodrigo et al. 2012).

Summary

TWM is a management tool developed to assist managers of urban water systems in developing holistic water management plans and operations. The core concept of the process is the comprehensive consideration of all forms of water and all stakeholders while projecting future demand and supply in light of the effects of the need for infrastructure replacement and expansion, climate warming, resource sustainability, population growth, urbanization, degradation of receiving water quality, flood management, and regulatory constraints. As the chapters in this book indicate, the process means an end to the traditional once-pass through view of the resource and recognition that what was once wastewater is rather, a valuable resource.

Although seeming to focus more on the supply side of water management, the total WWM introduced in Texas appeared to take the a water resource management task a step farther by including elements of the integration principle of TWM and the adaptive management element of the integrated water management approach.

The EPA considers TWM to be an interconnected approach that can reduce demands for freshwater, increase recognition and acceptance of recycling and reuse of wastewater, conversion of storm, flood and urban runoff from problems to be channeled away from the city to instead be collected and converted to safe augmentation of groundwater aquifers. In the past, urban water management focused on sorting a municipality's water resources into distinct classes of potable water, wastewater, and urban runoff. TWM refuses to acknowledge the differences, instead looking upon all forms of water as a resource which, with the necessary

level of treatment, contributes to a sustainable water cycle that can be managed for the benefit of all stakeholders.

The conclusion readers should take from the stories of water managers' willingness to try new and innovative approaches to management is a reassuring signal they are committed to making the changes necessary to meet the demands on the sustainability of their water services brought on by stresses on overdrawn water resources, climate change, population increases, shifts and urbanization, changes in precipitation patterns, more and more severe extreme weather events including floods and droughts, and the need for infrastructure repair and replacement.

Additional Reading

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Pacheco, Elizabeth and June Eding. (2011), *The Water Book: A Users Guide to Understanding, Protecting, and Preserving Earth's Most Precious Resource*, Hobart, NY: Hatherleigh.

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Appendix A

Water Measurement Conversions

Quantity

1 acre foot	325,851 US gallons
1 acre foot	42,560 cubic feet
1 acre foot	1.233.45 cubic meters
1 million gallons	3.07 acre feet
7.48 gallons	1 cubic foot

Flow

1 million gallons per day (mgd)	694.4 gallons per minute
1 mgd	1.55 cubic feet per second
1 mgd	1.120 acre feet per year
1 billion gallons per day (bgd)	1.12 million acre feet per year
1 cubic foot per second	1.98 acre feet per day

Metric Conversions

1 US pint (16 fluid ounces)	0.473 liter
1 US quart (2 pints; 32 fl. oz.)	0.946353 liter
1 US gallon (4 quarts)	3.7854 liters

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Appendix B

Acronyms

ACF	Apalachicola–Chattahoochee–Flint River Basin
ACT	Alabama–Coosa–Tallapoosa River Basin
ADPP	Arizona Drought Preparedness Plan
ADWR	Arizona Department of Water Resources
AKART	All known, available and reasonable methods of prevention, control and treatment
AER	Alberta Energy Regulator
AMA	Active Management Areas
AMC	Asset Management Committee
ANSI	American national Standards Institute
ASR	Aquifer Storage and Recovery
AWM	Adaptive Water Management
AWWA	American Water Works Association
BMP	Best Management Practice
CCC	Civilian Conservation Corps
CCL	Contaminant Candidate List
CCWA	Clayton Country Water Authority (Georgia)
CDC	Centers for Disease Control and Prevention
CDWAC	Creeks, Drainage Water and Wastewater Authority Committee

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CDWR	California Department of Water Resources
CEQ	Council on Environmental Quality
CRA	Congressional Review Act
CRC	Colorado River Compact
CRMWD	Colorado River Municipal Water District
CRT	Columbia River Treaty
CSWP	California State Water Project
CVA	Central Valley Authority
CWP	**Center for Watershed Protection**
CWS	Community Water Systems
DHHS	Department of Health and Human Services
DPR	Direct Potable Reuse
DWSPC	Division of Water Supply and Pollution Control
EHSB	Environmental Health Services Branch (CDC)
EO	Executive Order
EPA	US Environmental Protection Agency
EPDES	Environmental Pollutant Discharge Elimination System
EPWU	El Paso Water Utilities
ERTS	Environmental Response Tracking System
ESD	Environmental Site Design
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standards
FPC	Federal Power Commission
FWQA	Federal Water Quality Administration
GAO	Government Accountability Office
GEMI	**Global Environmental Management Initiative**
GI	**Green Infrastructure**
GIS	Geographic Information System
GWP	Global Water Partnership
HAZWOPER	Hazardous Waste Operations and Emergency Response
IBWA	Internal Bottle Water Association
IBWC	International Boundary and Water Commission
IDDE	Illicit Connection and Discharge Detection and Elimination
IFPT	Integrated Federal Permit Training

IPCC	Intergovernmental Panel on Climate Change
IPR	Indirect Potable Reuse
IWRM	Water Resources Management
JARPA	Joint Aquatic Resources Permit Application
LAA	Los Angeles Aqueducts
LCRB	Lower Colorado River Basin
LID	Low Impact Development
MDA	Metropolitan Water District (Los Angeles)
MEP	Maximum Extent Practicable
MS3	Municipal separate storm sewer
MS4	Municipal separate storm sewer system
MTCA	Model Toxics Control Act
MWDSC	Metropolitan Water District of Southern California
NAFTA	North American Free Trade Agreement
NDS	Natural Drainage System
NGO	Non-Government Organization
NIFA	National Institute of Food and Agriculture
NOI	Notice of Intent
NOV	Notice of Violation
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPDWRs	National Primary Drinking Water Regulations
NRDC	Natural Resources Defense Council
NTNCWS	Non-Transient Non-Community Water System
NWQP	National Water Quality Program
O&M	Operations and Maintenance
OIRA	Office of Information and Regulatory Affairs
OMB	Office of Management and Budget
OSMRE	Office of Surface Mining Reclamation and Enforcement
PASV	Pre-Application Site Visit
PCHB	Pollution Control Hearings Board
PHSBPRA	Public Health Security and Bioterrorism Preparedness and Response Act
QA/QC	Quality Assurance/Quality Control
RIB	Rapid Infiltration Basin (wastewater effluent)

RWPF	Raw Water Production Facility
SBWR	South Bay Water Recycling
SC	Source (water pollution) Control
SCADA	Digital Supervisory Control and Data Acquisition
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SEPA	State Environmental Policy Act
SFPUC	San Francisco Public Utility Commission
SKIP	Spill Kit Incentive Program
SSCP	Structural Stormwater Control Program
SSJBS	Sacramento and San Joaquin Basins Study
SWMP	Stormwater Management Program
SWPPP	Stormwater Pollution Prevention Plan
TDL	Temporary Diversion License
TESC	Temporary erosion and sediment control
TMDL	Total Maximum Daily Load
TNCWS	Transient Non-Community Water System
TSS	Total Suspended Solids
TWM	Total Water Management
UCOL	Upper Colorado River Basin
USACE	U.S. Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	U.S. Department of Agriculture
USDOI	U.S. Department of the Interior
USGS	U.S. Geological Survey
UWMP	Urban Water Management Plan
WQM	Watershed Quality Management
WRC	Water Resources Council
WRPA	Water Resources Planning Act
WTO	World Trade Organization
WWF	Wet-Weather Flow
WWFN	Worldwide Fund for Nature
WWM	Watershed Water Management
WWTP	Wastewater Treatment Plant

Appendix C

Glossary

This glossary consists of selections from a compilation of terms previously defined in published USGS reports; hence, all definitions have been approved for publication and are in the public domain. The terms herein are not necessarily the only valid definitions for these terms. Available at http://water.usgs.gov/water-basics_glossary.html

A

Absorption: The process by which substances in gaseous, liquid, or solid form are assimilated or taken up by other substances.

Acid: Has a pH of water less than 5.5; pH modifier used in the US Fish and Wildlife wetland classification system, acidic water has a pH less than 7.

Acre-foot (acre-ft.): The volume of water needed to cover an acre of land to a depth of one foot; equivalent to 43,560 cubic feet or 325,851 gallons.

Adaptive management: The deliberate scientific based process of designing, implementing, monitoring and adjusting an action,

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measure, or project to address changing circumstances and outcomes, reduce uncertainty, and maximize one or more goals over time.

Aerobic: Pertaining to, taking place in, or caused by the presence of oxygen.

Algae: Chlorophyll-bearing nonvascular, primarily aquatic species that have no true roots, stems, or leaves; most algae are microscopic.

Algal bloom: The rapid proliferation of passively floating, simple plant life, such as blue-green algae, in and on a body of water.

Alkaline: Has a pH greater than 7; in the common US usage, a pH of water greater than 7.4.

Alluvial aquifer: A water-bearing deposit of unconsolidated material (sand and gravel) left behind by a river or other flowing water.

Ammonia: A compound of nitrogen and hydrogen (NH_3) that is a common byproduct of animal waste. Ammonia readily converts to nitrate in soils and streams.

Anaerobic: Pertaining to, taking place in, or caused by the absence of oxygen.

Aquaculture: The science of farming organisms that live in water, such as fish, shellfish, and algae.

Aquatic: Living or growing in or on water.

Aquatic guidelines: Levels of water quality which, if reached, may adversely affect aquatic life; the non-enforceable guidelines issued by a governmental agency or other institution.

Aquatic-life criteria: Water-quality guidelines for protection of aquatic life. Commonly refers to criteria established by the US Environmental Protection Agency.

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient permeable material to yield significant quantities of water to springs and wells.

Arroyo: A small, deep, flat-floored channel or gully of an intermittent stream, usually with nearly vertical banks cut, into unconsolidated material. A term commonly used in the arid and semiarid regions of the Southwestern United States.

Artificial recharge: Augmentation of natural replenishment of groundwater storage by construction, spreading of water, or by pumping water directly into an aquifer.

Average discharge: As used by the US Geological Survey, the arithmetic average of all complete water years of record of surface water discharge whether consecutive or not. The term "average" generally is reserved for average of record and "mean" is used for averages of shorter periods, namely, daily, monthly, or annual mean discharges.

B

Background concentration: A concentration of a substance in a particular environment that is indicative of minimal influence by human (anthropogenic) sources.

Backwater: A body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide.

Bacteria: Single-celled microscopic organisms.

Bank storage: The change in the amount of water stored in an aquifer adjacent to a surface water body resulting from a change in stage of the surface water body.

Barrier bar: An elongated offshore ridge, submerged at least at high tide, built up by the action of waves or currents.

Barrier beach: A narrow, elongated sandy ridge rising slightly above the high-tide level and extending generally parallel with the mainland shore, but separated from it by a lagoon.

Base flow: The sustained low flow of a stream, usually groundwater inflow to the stream channel.

Basic: The opposite of acidic; water that has a pH of greater than 7.

Basin and Range physiography: A region characterized by a series of generally north-trending mountain ranges separated by alluvial valleys.

Bed material: Sediment composing the streambed.

Bed sediment: The material that temporarily is stationary in the bottom of a stream or other watercourse.

Best management practice (BMP): An agricultural practice that has been determined to be an effective, practical means of preventing or reducing pollution.

bgd: billion gallons per day.

Bioaccumulation: The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium; the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

Biochemical: Refers to chemical processes that occur inside or are mediated by living organisms.

Biochemical process: A process characterized by, produced by, or involving chemical reactions in living organisms.

Biochemical-oxygen demand (BOD): The amount of oxygen, expressed in milligrams per liter that is removed from aquatic environments by the life processes of micro-organisms.

Biodegradation: Transformation of a substance into new compounds through biochemical reactions or the actions of microorganisms such as bacteria.

Biomass: The amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight-per-unit area.

Biota: All living organisms of an area.

Bog: A nutrient-poor, acidic wetland dominated by a waterlogged, spongy mat of sphagum moss that ultimately forms a thick layer of acidic peat; generally has no inflow or outflow; fed primarily by rain water.

Bolson: An extensive, flat, saucer-shaped, alluvium-floored basin or depression, almost or completely surrounded by mountains and from which drainage has no surface outlet; a term used in the desert regions of the Southwestern United States.

Boreal: A climatic zone having a definite winter with snow and a short summer that is generally hot, and which is characterized by a large annual range of temperature.

Bosque: A dense growth of trees and underbrush.

Brackish water: Water with a salinity intermediate between seawater and freshwater (containing from 1,000 to 10,000 milligrams per liter of dissolved solids).

Braided stream: A stream characterized by an interlacing or tangled network of several small branching and reuniting shallow channels.

Brine: Water that contains more than 35,000 milligrams per liter of dissolved solids.

C

Calcareous: A rock or substance formed of calcium carbonate or magnesium carbonate by biological deposition or inorganic precipitation, or containing those minerals in sufficient quantities to effervesce when treated with cold hydrochloric acid.

Canopy angle: Generally, a measure of the openness of a stream to sunlight. Specifically, the angle formed by an imaginary line from the highest structure (e.g., tree, shrub, or bluff) on one bank to eye level at mid-channel to the highest structure on the other bank.

Capillary fringe: The zone above the water table in which water is held by surface tension. Water in the capillary fringe is under a pressure less than atmospheric.

Carbonate rocks: Rocks (such as limestone or dolostone) that are composed primarily of minerals (such as calcite and dolomite) containing the carbonate ion (CO_3^{2-}).

Center pivot irrigation: An automated sprinkler system involving a rotating pipe or boom that supplies water to a circular area of an agricultural field through sprinkler heads or nozzles.

Channel scour: Erosion by flowing water and sediment on a stream channel; results in removal of mud, silt, and sand on the outside curve of a stream bend and the bed material of a stream channel.

Chlorinated solvent: A volatile organic compound containing chlorine. Some common solvents are trichloroethylene, tetrachloroethylene, and carbon tetrachloride.

Chlorofluorocarbons: A class of volatile compounds consisting of carbon, chlorine, and fluorine. Commonly called freons, which have been in refrigeration mechanisms, as blowing agents in the fabrication of flexible and rigid foams, and, until banned from use as propellants in spray cans.

Cienaga: A marshy area where the ground is wet due to the presence of seepage or springs.

Circumneutral: Said of water with a pH between 5.5 and 7.4.

Cirque: A deep, steep-walled, half-bowlike recess or hollow situated high on the side of a mountain and commonly at the head of a glacial valley; and produced by the erosive activity of mountain glaciers.

Climate: The sum total of the meteorological elements that characterize the average and extreme conditions of the atmosphere over a long period of time at any one place or region of the Earth's surface.

Combined sewer overflow: A discharge of untreated sewage and stormwater to a stream when the capacity of a combined storm/sanitary sewer system is exceeded by storm runoff.

Commercial withdrawals: Water for use by motels, hotels, restaurants, office buildings, commercial facilities, and civilian and military institutions. The water may be obtained from a public supplier or it may be self-supplied.

Confined aquifer (artesian aquifer): An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the movement of water.

Consumptive use: The quantity of water that is not available for immediate reuse because it has been evaporated, transpired, or incorporated into products, plant tissue, or animal tissue; also referred to as "water consumption."

Contamination: Degradation of water quality compared to original or natural conditions due to human activity.

Contributing area: The area in a drainage basin that contributes water to stream flow or recharge to an aquifer.

Coral reef: A ridge of limestone, composed chiefly of coral, coral sands, and solid limestone resulting from organic secretion of calcium carbonate; occur along continents and islands where the temperature is generally above 18°C.

Core sample: A sample of rock, soil, or other material obtained by driving a hollow tube into the undisturbed medium and withdrawing it with its contained sample.

Criterion: A standard rule or test on which a judgment or decision can be based.

Cubic foot per second (ft^3/s, or cfs): Rate of water discharge representing a volume of 1 cubic foot passing a given point during 1 s, equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meter per second. In a stream channel, a discharge of 1 cubic foot per second is equal to the discharge at a rectangular cross section, 1 foot wide and 1 foot deep, flowing at an average velocity of 1 foot per second.

Cyclone: An area of low pressure around which winds rotate counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

D

DDT: Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States.

Deciduous: Refers to plants that shed foliage at the end of the growing season.

Deepwater habitat: Permanently flooded lands lying below the deep-water boundary of wetlands.

Degraded: Condition of the quality of water that has been made unfit for some specified purpose.

Delta: The low, nearly flat tract of land at or near the mouth of a river, resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, or currents. Commonly a triangular or fan-shaped plain.

Denitrification: A process by which oxidized forms of nitrogen such as nitrate (NO_3^-) are reduced to form nitrites, nitrogen oxides, ammonia, or free nitrogen: commonly brought about by the action of denitrifying bacteria and usually resulting in the escape of nitrogen to the air.

Diatoms: Single-celled, colonial, or filamentous algae with siliceous cell walls constructed of two overlapping parts.

Direct runoff: The runoff entering stream channels promptly after rainfall or snowmelt.

Discharge: The volume of fluid passing a point per unit of time, commonly expressed in cubic feet per second, million gallons per day, gallons per minute, or seconds per minute per day.

Discharge area (groundwater): Area where subsurface water is discharged to the land surface, to surface water, or to the atmosphere.

Dispersion: The extent to which a liquid substance introduced into a ground-water system spreads as it moves through the system.

Dissolved oxygen: Oxygen dissolved in water; one of the most important indicators of the condition of a water body. Dissolved oxygen is necessary for the life of fish and most other aquatic organisms.

Dissolved solids: Minerals and organic matter dissolved in water.

Diversion: A turning aside or alteration of the natural course of a flow of water, normally considered physically to leave the natural channel. In some states, this can be a consumptive use direct from another stream, such as by livestock watering. In other States, a diversion must consist of such actions as taking water through a canal, pipe, or conduit.

Domestic withdrawals: Water used for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. The water may be obtained from a public supplier or may be self-supplied. Also called residential water use.

Drainage area: The drainage area of a stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide.

Drainage basin: The land area drained by a river or stream.

Drainage divide: Boundary between adjoining drainage basins.

Drawdown: The difference between the water level in a well before pumping and the water level in the well during pumping. Also, for flowing wells, the reduction of the pressure head as a result of the discharge of water.

Drinking-water standard or guideline: A threshold concentration for a constituent or compound in a public drinking-water supply, designed to protect human health. As defined here, standards are US Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Drip irrigation: An irrigation system in which water is applied directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, or perforated pipe) operated under low pressure. The applicators can be placed on or below the surface of the ground or can be suspended from supports.

Drought: A prolonged period of less-than-normal precipitation such that the lack of water causes a serious hydrologic imbalance.

E

Ecoregion: An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Ecosystem: A community of organisms considered together with the non-living factors of its environment; the dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a system.

Effluent: Outflow from a particular source, such as a stream that flows from a lake or liquid waste that flows from a factory or sewage-treatment plant.

Endangered species: A species that is in imminent danger of becoming extinct.

Endocrine system: The collection of ductless glands in animals that secrete hormones, which influence growth, gender, and sexual maturity.

Environment: The sum of all conditions and influences affecting the life of organisms.

Environmental framework: Natural and human-related features of the land and hydrologic system, such as geology, land use, and habitat, that provide a unifying framework for making comparative assessments of the factors that govern water quality conditions.

Environmental setting: Land area characterized by a unique combination of natural and human-related factors, such as row-crop cultivation or glacial-till soils.

Ephemeral stream: A stream or part of a stream that flows only in direct response to precipitation; it receives little or no water from springs, melting snow, or other sources; its channel is at all times above the water table.

EPT richness index: An index based on the sum of the number of taxa in three insect orders, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), that are composed primarily of species considered to be relatively intolerant to environmental alterations.

Erosion: The process whereby materials of the Earth's crust are loosened, dissolved, or worn away and simultaneously moved from one place to another.

Estuarine wetlands: Tidal wetlands in low-wave-energy environments where the salinity of the water is greater than 0.5 part per thousand and is variable owing to evaporation and the mixing of seawater and freshwater; tidal wetlands of coastal rivers and embayments, salty tidal marshes, mangrove swamps, and tidal flats.

Estuary: Area where the current of a stream meets the ocean and where tidal effects are evident; an arm of the ocean at the lower end of a river.

Eutrophication: The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Evaporation: The process by which water is changed to gas or vapor; occurs directly from water surfaces and from the soil.

Evaporation (net): limited to evaporation from manmade reservoirs that have more than 5,000 acre feet usable for storage capacity and from farm and stock ponds, if rainfall exceeds evaporation, the value is zero.

Evaporite minerals (deposits): Minerals or deposits of minerals formed by evaporation of water containing salts. These deposits are common in arid climates.

Excess surface water: Water that could be available for withdrawal from rivers, lakes, or other water bodies that is in excess of the amount needed to sustain healthy ecological conditions in the water body and downstream waters.

F

Fall line: Imaginary line marking the boundary between the ancient, resistant crystalline rocks of the Piedmont province of the Appalachian Mountains, and the younger, softer sediments of the Atlantic Coastal Plain province in the Eastern United States. Along rivers, this line commonly is reflected by waterfalls.

Fallow: Cropland, tilled or untilled, allowed to remain idle during the whole or greater part of the growing season.

Fecal bacteria: Microscopic single-celled organisms (primarily fecal coliforms and fecal streptococci) found in the wastes of warm-blooded animals. Their presence in water is used to assess the sanitary quality of water for body-contact recreation or for consumption. Their presence indicates contamination by the wastes of warm-blooded animals and the possible presence of pathogenic (disease producing) organisms.

FDA action level: A regulatory level recommended by the US Environmental Protection Agency for enforcement by the Food and Drug Administration (FDA) when pesticide residues occur in food commodities for reasons other than the direct application of the pesticide. Action levels are set for inadvertent pesticide residues resulting from previous legal use or accidental contamination; applies to edible portions of fish and shellfish in interstate commerce.

Fen: Peat-accumulating wetland that generally receives water from surface runoff and (or) seepage from mineral soils in addition to direct precipitation; generally alkaline; or slightly acid.

Fertilizer: Any of a large number of natural or synthetic materials, including manure and nitrogen, phosphorus, and potassium compounds, spread on or worked into soil to increase its fertility.

Flood: Any relatively high stream flow that overflows the natural or artificial banks of a stream.

Flood irrigation: The application of irrigation water whereby the entire surface of the soil is covered by ponded water.

Flood plain: A strip of relatively flat land bordering a stream channel that is inundated at times of high water.

Flowpath: An underground route for groundwater movement, extending from a recharge (intake) zone to a discharge (output) zone such as a shallow stream.

Fluvial: Pertaining to a river or stream.

Fluvial deposit: A sedimentary deposit consisting of material transported by suspension or laid down by a river or stream.

Freshwater: Water that contains less than 1,000 milligrams per liter of dissolved solids.

Freshwater chronic criteria: The highest concentration of a contaminant that freshwater aquatic organisms can be exposed to for an extended period of time (4 days) without adverse effects.

Functional water use: category of offstream use of water, such as domestic, commercial, manufacturing, agriculture, steam electric generation, minerals and petroleum mining.

Furrow irrigation: A type of surface irrigation whereby water is applied at the upper (higher) end of a field and flows in furrows to the lower end.

G

Gaging station: A particular site on a stream, canal, lake, or reservoir where systematic observations of hydrologic data are obtained.

Gcd: gallons per capita per day.

Geomorphic: Pertaining to the form or general configuration of the Earth or of its surface features.

Geothermal: Relating to the Earth's internal heat; commonly applied to springs or vents discharging hot water or steam.

Glacial: Of or relating to the presence and activities of ice or glaciers.

Glacial lake: A lake that derives its water, or much of its water, from the melting of glacial ice; also a lake that occupies a basin produced by glacial erosion.

Glacial outwash: Stratified detritus (chiefly sand and gravel) "washed out" from a glacier by meltwater streams and deposited beyond the end moraine or the margin of an active glacier.

Gray Water: Untreated household water from sinks, showers, and baths; not considered the same as reclaimed water.

Groundwater: In the broadest sense, all subsurface water; more commonly that part of the subsurface water in the saturated zone.

Groundwater flow system: The underground pathway by which ground water moves from areas of recharge to areas of discharge.

Groundwater overdraft: Tthat part of the groundwater withdrawals which exceed recharge; sometimes referred to as ground-water mining.

Growing season: The frost-free period of the year.

H

Hardness: A property of water that causes the formation of an insoluble residue when the water is used with soap and a scale in vessels in which water has been allowed to evaporate. It is due primarily to the presence of ions of calcium and magnesium. Generally expressed as milligrams per liter as calcium carbonate ($CaCO_3$).

Headwaters: The source and upper part of a stream.

Health advisory: Nonregulatory levels of contaminants in drinking water that may be used as guidance in the absence of regulatory limits. Advisories consist of estimates of concentrations that would result in no known or anticipated health effects (for carcinogens, a specified cancer risk) determined for a child or for an adult for various exposure periods.

Herbaceous: With characteristics of an herb; a plant with no persistent woody stem above ground.

Herbicide: A type of pesticide designed to kill plants.

Human health advisory: Guidance provided by US Environmental Protection Agency, State agencies or scientific organizations, in the absence of regulatory limits, to describe acceptable contaminant levels in drinking water or edible fish.

Hydrograph: Graph showing variation of water elevation, velocity, stream flow, or other property of water with respect to time.

Hydrologic cycle: The circulation of water from the sea, through the atmosphere, to the land, and thence back to the sea by overland and subterranean routes.

Hydrologic unit: A geographic area representing part or all of a surface drainage basin or distinct hydrologic feature as delineated by the U. S. Geological Survey on State Hydrologic Unit Maps. Each hydrologic unit is assigned a hierarchical hydrologic unit code consisting of two digits for each successively smaller drainage basin unit.

Hydrologic regime: The characteristic behavior and total quantity of water involved in a drainage basin.

Hydrology: The science that deals with water as it occurs in the atmosphere, on the surface of the ground, and underground.

Hydrophobic: Not capable of uniting with or absorbing water.

Hydrostatic pressure: The pressure exerted by the water at any given point in a body of water at rest.

I

Impaired: Condition of the quality of water that has been adversely affected for a specific use by contamination or pollution.

Index of Biotic Integrity (IBI): An aggregated number, or index, based on several attributes or metrics of a fish community that provides an assessment of biological conditions.

Indicator sites: Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions; most indicator-site basins have drainage areas ranging from 20 to 200 square miles.

Industrial withdrawals: Water withdrawn for or used for thermoelectric power (electric utility generation) and other industrial and manufacturing uses such as steel, chemical and allied products, paper and allied products, mining, and petroleum refining. The water may be obtained from a public supplier or may be self-supplied.

Infiltration: The downward movement of water from the atmosphere into soil or porous rock.

Inorganic soil: Soil with less than 20 percent organic matter in the upper 16 inches.

Insecticide: A substance or mixture of substances intended to destroy or repel insects.

Instantaneous discharge: The volume of water that passes a point at a particular instant of time.

Instream use: Water use taking place within the stream channel for such purposes as hydroelectric power generation, navigation, water-quality improvement, fish propagation, and recreation. Sometimes called non-withdrawal use or in-channel use.

Integrated drainage: Drainage developed during geomorphic maturity in an arid region, characterized by coalescence of drainage basins as a result of erosion in the lower basins or spilling over from the upper basins.

Integrator or Mixed-use site: Stream sampling site located at an outlet of a drainage basin that contains multiple environmental settings. Most integrator sites are on major streams with relatively large drainage areas.

Interface: In hydrology, the contact zone between two fluids of different chemical or physical makeup.

Intermittent stream: A stream that flows only when it receives water from rainfall runoff or springs, or from some surface source such as melting snow.

Intermontane: Situated between or surrounded by mountains, mountain ranges, or mountainous regions.

Internal drainage: Surface drainage whereby the water does not reach the ocean, such as drainage toward the lowermost or central part of an interior basin or closed depression.

Intertidal: Alternately flooded and exposed by tides.

Intolerant organisms: Organisms that are not adaptable to human alterations to the environment and thus decline in numbers where alterations occur.

Irrigation: Controlled application of water to arable land to supply requirements of crops not satisfied by rainfall.

Irrigation district: In the United States, a cooperative, self-governing public corporation set up as a subdivision of the state, with definite geographic boundaries, organized to obtain and distribute water for irrigation of lands within the district; created under authority of the State legislature with the consent of a designated fraction of the land owners or citizens and the taxing power.

Irrigation return flow: The part of irrigation applied to the surface that is not consumed by evapotranspiration or uptake by plants and that migrates to an aquifer or surface-water body.

Irrigation withdrawals: Withdrawals of water for application on land to assist in the growing of crops and pastures or to maintain recreational lands.

K

Kettle: A steep-sided hole or depression, commonly without surface drainage, formed by the melting of a large detached block of stagnant ice that had been buried in a glacial drift.

Kettle lake: A body of water occupying a kettle, as in a glacier outwash plain or in a kettle moraine.

Kill: Dutch term for stream or creek.

L

Lacustrine: Pertaining to, produced by, or formed in a lake.

Lacustrine wetlands: Wetlands within a lake or reservoir greater than 20 acres or within a lake or reservoir less than 20 acres if the water is greater than two meters deep in the deepest part of the basin; ocean-derived salinity is less than 0.5 part per thousand.

Lagoon: A shallow stretch of seawater (or lakewater) near or communicating with the sea (or lake) and partly or completely separated from it by a low, narrow, elongate strip of land.

Latent heat: The amount of heat given up or absorbed when a substance changes from one state to another, such as from a liquid to a solid.

Leachate: A liquid that has percolated through soil containing soluble substances and that contains certain amounts of these substances in solution.

Leaching: The removal of materials in solution from soil or rock; also refers to movement of pesticides or nutrients from land surface to ground water.

Life zone: Major area of plant and animal life; region characterized by particular plants and animals and distinguished by temperature differences.

Limnetic: The deepwater zone (greater than two meters deep); a subsystem of the Lacustrine System of the US Fish and Wildlife Service wetland classification system.

Littoral: The shallow-water zone (less than 2 meters deep); a subsystem of the Lacustrine classification system.

Load: Material that is moved or carried by streams, reported as weight of material transported during a specified time period, such as tons per year.

Loess: A widespread, homogeneous, commonly nonstratified, porous, slightly coherent, fine-grained blanket deposit of wind-blown and wind-deposited silt and fine sand.

M

Main stem: The principal trunk of a river or a stream.

Marine wetland: Wetlands that are exposed to waves and currents of the open ocean and to water having a salinity greater than 30 parts per thousand; present along the coastlines of the open ocean.

Marsh: A water-saturated, poorly drained area, intermittently or permanently water covered, having aquatic and grass-like vegetation.

Maturity (stream): The stage in the development of a stream at which it has reached its maximum efficiency, when velocity is just sufficient to carry the sediment delivered to it by tributaries; characterized by a broad, open, flat-floored valley having a moderate gradient and gentle slope.

Maximum contaminant level (MCL): Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the US Environmental Protection Agency.

Mean discharge: The arithmetic mean of individual daily mean discharges of a stream during a specific period, usually daily, monthly, or annually.

Mesophyte: Any plant growing where moisture and aeration conditions lie between the extremes of “wet” and “dry.”

Method detection limit: The minimum concentration of a substance that can be accurately identified and measured with current laboratory technologies.

Mgd: million gallons per day.

Micrograms per liter (μg/L): A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most streamwater and ground water. One thousand micrograms per liter equals one milligram per liter.

Milligram (mg): A mass equal to 10^{-3} grams.

Milligrams per liter (mg/L): A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water.

Minimum reporting level (MRL): The smallest measured concentration of a constituent that may be reliably reported using a given analytical method. In many cases, the MRL is used when documentation for the method detection limit is not available.

Mitigation: Actions taken to avoid, reduce, or compensate for the effects of human-induced environmental damage.

Monitoring well: A well designed for measuring water levels and testing ground-water quality.

Muck: Dark, finely divided, well-decomposed, organic matter forming a surface deposit in some poorly drained areas.

N

National Academy of Sciences/National Academy of Engineering (NAS/NAE) recommended maximum concentration in water: Numerical guidelines recommended by two joint NAS/NAE committees for the protection of freshwater and marine aquatic life, respectively. These guidelines were based on results of aquatic toxicity studies that were available in 1972, and were considered preliminary at the time.

National Geodetic Vertical Datum of 1929: Geodetic datum derived from a general adjustment of first: order level nets of the United States and Canada; formerly called "Sea Level Datum of 1929."

National Water-Quality Assessment (NAWQA) Program: The long term USGS program, begun in 1991, to assess the occurrence and distribution of water-quality conditions nationwide.

Natural levee: A long, broad, low ridge built by a stream on its flood plain along one or both banks of its channel in time of flood.

Navigable water: In the context of the Clean Water Act, all surface water.

Nitrate: An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Noncontact water recreation: Recreational activities, such as fishing or boating, that do not include direct contact with the water.

Nonpoint-source contaminant: A substance that pollutes or degrades water that comes from lawn or cropland runoff, the atmosphere, roadways, and other diffuse sources.

Nonpoint-source water pollution: Water contamination that originates from a broad area (such as leaching of agricultural chemicals from crop land) and enters the water resource diffusely over a large area.

Nonselective herbicide: Kills or significantly retards growth of most higher plant species.

O

Occurrence and distribution assessment: A component of the USGS that entails characterization of broad-scale spatial and temporal distributions of water-quality conditions in relation to major contaminant sources and background conditions for surface water and ground water.

Offstream use: Water withdrawn or diverted from a ground- or surface-water source for use. *See also* Withdrawal.

Organic: Containing carbon, but possibly also containing hydrogen, oxygen, chlorine, nitrogen, and other elements.

Organic detritus: Any loose organic material in streams: such as leaves, bark, or twigs: removed and transported by mechanical means, such as disintegration or abrasion.

Organochlorine compound: Synthetic organic compounds containing chlorine. As generally used, term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents.

Organochlorine insecticide: A class of organic insecticides containing a high percentage of chlorine. Includes dichlorodiphenylethanes (such as DDT), chlorinated cyclodienes (such as chlordane), and chlorinated benzenes (such as lindane). Most organochlorine insecticides were banned from use in the United States because of their carcinogenicity, tendency to bioaccumulate, and toxicity to wildlife.

Organonitrogen herbicides: A group of herbicides consisting of a nitrogen ring with associated functional groups and including such classes as triazines and acetanilides. Examples include atrazine, cyanazine, alachlor, and metolachlor.

Organophosphate insecticides: A class of insecticides derived from phosphoric acid. They tend to have high acute toxicity to vertebrates. Although readily metabolized by vertebrates, some metabolic products are more toxic than the parent compound.

Organophosphorus insecticides: Insecticides derived from phosphoric acid and generally the most toxic of all pesticides to vertebrate animals.

Outwash: Soil material washed down a hillside by rainwater and deposited upon more gently sloping land.

Overland flow: The flow of rainwater or snowmelt over the land surface toward stream channels.

Oxbow: A bow-shaped lake formed in an abandoned meander of a river.

P

Paleohydrology: Study of hydrologic processes and events, using geological, botanical, and cultural evidence, that occurred before the beginning of the systematic collection of hydrologic data and observations.

Palustrine wetlands: Freshwater wetlands including open water bodies of less than 20 acres in which water is less than 2 meters deep; includes marshes, wet meadows, fens, playas, potholes, pocosins, bogs, swamps, and shallow ponds; most wetlands are in the Palustrine system.

Part per million (ppm): Unit of concentration equal to one milligram per kilogram or one milligram per liter.

Pathogen: Any living organism that causes disease.

Peak stage: Maximum height of a water surface above an established datum plane. Same as peak gage height.

Percent stream flow exceedance: a statistical estimate of probability of flow. For example, a 5 percent exceedance flow will be exceeded only in about five years of a 100-year period and represents a year with very high stream flow. A 95 percent exceedance flow will be exceeded in about 95 years of a 100-year period and represents a year with very low stream flow.

Perched groundwater: Unconfined ground water separated from an underlying main body of ground water by an unsaturated zone.

Percolation: The movement of water through interstices of a rock or soil (except the movement through large openings such as caves).

Perennial stream: A stream that normally has water in its channel at all times.

Periphyton: Micro-organisms that coat rocks, plants, and other surfaces on lake bottoms.

Permeability: The capacity of a rock for transmitting a fluid; a measure of the relative ease with which a porous medium can transmit a liquid.

pH: A measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral.

Phenols: A class of organic compounds containing phenol (C_6H_5OH) and its derivatives. Used to make resins, weed killers, and as a solvent, disinfectant, and chemical intermediate. Some phenols occur naturally in the environment.

Phosphorus: A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Phthalates: A class of organic compounds containing phthalic acid esters [$C_6H_4(COOR)_2$] and derivatives. Used as plasticizers in plastics. Also used in many other products (such as detergents, cosmetics) and industrial processes (such as defoaming agents in paper and paperboard manufacture, and dielectrics in capacitors).

Physiographic province: A region in which the landforms are distinctive and differ significantly from those of adjacent regions.

Picocurie (pCi): One trillionth (10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7×10^{10} radioactive disintegrations per second (dps). A picocurie yields 2.22 disintegrations per minute (dpm) or 0.037 dps.

Pioneer plant: Herbaceous annual and perennial seedling plants that colonize bare areas as a first stage in secondary succession.

Piping: Erosion by percolating water in a layer of subsoil, resulting in caving and in the formation of narrow conduits, tunnels, or "pipes" through which soluble or granular soil material is removed.

Plankton: Floating or weakly swimming organisms at the mercy of the waves and currents. Animals of the group are called zooplankton and the plants are called phytoplankton.

Playa: A dry, flat area at the lowest part of an un-drained desert basin in which water accumulates and is quickly evaporated; underlain by stratified clay, silt, or sand and commonly by soluble salts; term used in Southwestern United States.

Playa lake: A shallow, temporary lake in an arid or semi-arid region, covering or occupying a playa in the wet season but drying up in summer; temporary lake that upon evaporation leaves or forms a playa.

Pocosin: A local term along the Atlantic coastal plain, from Virginia south, for a shrub-scrub wetland located on a relatively flat terrain, commonly between streams.

Point source: Originating at any discrete source.

Point-source contaminant: Any substance that degrades water quality and originates from discrete locations such as discharge pipes, drainage ditches, wells, concentrated livestock operations, or floating craft.

Pollutant: Any substance that, when present in a hydrologic system at sufficient concentration, degrades water quality in ways that are or could become harmful to human and/or ecological health or that impair the use of water for recreation, agriculture, industry, commerce, or domestic purposes.

Polychlorinated biphenyls (PCBs): A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Polycyclic aromatic hydrocarbon (PAH): A class of organic compounds with a fused-ring aromatic structure. PAHs result from incomplete combustion of organic carbon (including wood), municipal solid waste, and fossil fuels, as well as from natural or anthropogenic introduction of incomplete combustion of coal and oil.

Postemergence herbicide: Herbicide applied to foliage after the crop has sprouted to kill or significantly retard the growth of weeds.

Potable water: Water that is safe and palatable for human consumption.

Potential evapotranspiration: The amount of moisture which, if available, would be removed from a given land area by evapotranspiration; expressed in units of water depth.

Potentiometric surface: An imaginary surface in an aquifer. It represents the height above which the water level stands in tightly cased wells that penetrate the aquifer.

Prairie pothole: A shallow depression, generally containing wetlands, occurring in an outwash plain, a recessional moraine, or a till plain; usually the result of melted blocks of covered glacial ice; occur most commonly in the North-Central United States and in States west of the Great Lakes from Wisconsin to eastern Montana.

Precipitation: Any or all forms of water particles that fall from the atmosphere, such as rain, snow, hail, and sleet. The act or process of producing a solid phase within a liquid medium.

Pre-emergence herbicide: Herbicide applied to bare ground after planting the crop but prior to the crop sprouting above ground to kill or significantly retard the growth of weed seedlings.

Primary treatment: physical processes such as screening and settling to remove particulate matter from wastewater.

Pristine: The earliest condition of the quality of a water body; unaffected by human activities.

Public-supply withdrawals: Water withdrawn by public and private water suppliers for use within a general community. Water is used for a variety of purposes such as domestic, commercial, industrial, and public water use.

Q

Quality assurance: Evaluation of quality-control data to allow quantitative determination of the quality of chemical data collected during a study. Techniques used to collect, process, and analyze water samples are evaluated.

R

Radon: A naturally occurring, colorless, odorless, radioactive gas formed by the disintegration of the element radium; damaging to human lungs when inhaled.

Rain shadow: A dry region on the lee side of a topographic obstacle, usually a mountain range, where rainfall is noticeably less than on the windward side.

Reach: A continuous part of a stream between two specified points.

Reaeration: The replenishment of oxygen in water from which oxygen has been removed.

Real-time data: Data collected by automated instrumentation and telemetered and analyzed quickly enough to influence a decision that affects the monitored system.

Recessional moraine: An end moraine built during a temporary but significant pause in the final retreat of a glacier.

Recharge (ground water): The process involved in the absorption and addition of water to the zone of saturation; also, the amount of water added. Also called managed infiltration.

Recharge area (ground water): An area within which water infiltrates the ground and reaches the zone of saturation.

Reclaimed water: Water that has received at least secondary treatment and basic disinfection and is reused after flowing out of a domestic wastewater treatment facility.

Recurrence interval: The average interval of time within which the magnitude of a given event, such as a storm or flood, will be equaled or exceeded once.

Reference site: A sampling site selected for its relatively undisturbed conditions.

Regulation (of a stream): Artificial manipulation of the flow of a stream.

Relative abundance: The number of organisms of a particular kind present in a sample relative to the total number of organisms in the sample.

Residential water use: Domestic water withdrawals.

Return flow: That part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water.

Riffle: A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Riparian: Pertaining to or situated on the bank of a natural body of flowing water.

Riparian rights: A concept of water law under which authorization to use water in a stream is based on ownership of the land adjacent to the stream.

Riparian zone: Pertaining to or located on the bank of a body of water, especially a stream.

Riverine wetlands: Wetlands within river and stream channels; ocean-derived salinity is less than 0.5 part per thousand.

Runoff: That part of precipitation or snowmelt that appears in streams or surface-water bodies.

Rural withdrawals: Water used in suburban or farm areas for domestic and livestock needs. The water generally is self-supplied and includes domestic use, drinking water for livestock, and other uses such as dairy sanitation, evaporation from stock-watering ponds, and cleaning and waste disposal.

S

Saline water: Water that is considered unsuitable for human consumption or for irrigation because of its high content of dissolved solids; generally expressed as milligrams per liter (mg/L) of dissolved solids; seawater is generally considered to contain more than 35,000 mg/L of dissolved solids.

Saturated zone: A subsurface zone in which all the interstices or voids are filled with water under pressure greater than that of the atmosphere.

Sea level: Long-term average position of the sea surface. Sea level varies from place to place and with the time period for which the average is calculated.

Secondary maximum contaminant level (SMCL): The maximum level of a contaminant or undesirable constituent in public water systems that, in the judgment of the US Environmental Protection Agency (USEPA), is required to protect the public welfare. SMCLs are secondary (non-enforceable) drinking water regulations established by the USEPA for contaminants that may adversely affect the odor or appearance of such water.

Secondary treatment: Biological processes in treatment during which time microbiological degradation of organic wastewater; usually followed by settling, gravity filtration, and disinfection of effluent before discharge.

Sediment: Particles, derived from rocks or biological materials that have been transported by a fluid or other natural process, suspended or settled in water.

Sediment guideline: Threshold concentration above which there is a high probability of adverse affects on aquatic life from sediment contamination, determined using modified EPA procedures.

Seep: A small area where water percolates slowly to the land surface.

Seiche: A sudden oscillation of the water in a moderate-size body of water, caused by wind.

Selective herbicide: A compound that kills or significantly retards growth of an unwanted plant species without significantly damaging desired plant species.

Semi-permeable membrane device (SPMD): A long strip of low-density, polyethylene tubing filled with a thin film of purified lipid such as triolein that simulates the exposure to and passive uptake of highly lipid-soluble organic compounds by biological membranes.

Shallows: A term applied to a shallow place or area in a body of water.

Shoal: A relatively shallow place in a stream, lake, or sea.

Short-wave trough (meteorlogical): A wave of low atmospheric pressure in the form of a trough that has a wave length of 600–1,500 miles and moves progressively through the lower troposphere in the same direction as that of the prevailing current of air motion.

Sideslope gradient: The representative change in elevation in a given horizontal distance (usually about 300 yards) perpendicular to a stream; the valley slope along a line perpendicular to the stream (near a water-quality or biological sampling point).

Siltation: The deposition or accumulation of silt (or small-grained material) in a body of water.

Sinkhole: A depression in an area underlain by limestone; its drainage is subterranean.

Sinuosity: The ratio of the channel length between two points on a channel to the straight-line distance between the same two points; a measure of stream meandering.

Slough: A small marshy tract lying in a swale or other local shallow, undrained depression; a sluggish creek or channel in a wetland.

Soil moisture: Water occurring in the pore spaces between the soil particles in the unsaturated zone from which water is discharged by the transpiration of plants or by evaporation from the soil.

Sole-source aquifer: As defined by the US Environmental Protection Agency, an aquifer that supplies 50 percent or more of the drinking water of an area.

Solid-phase extraction: A procedure to isolate specific organic compounds onto a bonded silica extraction column.

Solution: Formed when a solid, gas, or another liquid in contact with a liquid becomes dispersed homogeneously throughout the liquid. The substance, called a solute, is said to dissolve. The liquid is called the solvent.

Sorption: General term for the interaction (binding or association) of a solute ion or molecule with a solid.

Specific capacity: The yield of a well per unit of drawdown.

Specific conductance: A measure of the ability of a liquid to conduct an electrical current.

Specific yield: The ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock.

Spring: Place where a concentrated discharge of ground water flows at the ground surface.

Stage: Height of the water surface, such as in a river above a predetermined point that may (or may not) be at the channel floor.

Storm surge: An abnormal and sudden rise of the sea along a shore as a result of the winds of a storm.

Stormwater: The flow of water that results from and which occurs immediately following a rainfall event and which is normally captured in ponds, swales, or similar areas for water quality treatment or flood control.

Stratification: Subdivision of the environmental framework; divided into subareas that exhibit reasonably homogeneous environmental conditions, as determined by both natural and human influences.

Stream–aquifer interactions: Relations of water flow and chemistry between streams and aquifers that are hydraulically connected.

Stream mile: A distance of 1 mile along a line connecting the midpoints of the channel of a stream.

Stream order: A ranking of the relative sizes of streams within a watershed based on the nature of their tributaries. The smallest unbranched tributary is called first order, the stream receiving the tributary is called second order, and so on.

Stream reach: A continuous part of a stream between two specified points.

Stream flow: The discharge of water in a natural channel.

Streamline: A line on a map that is parallel to the direction of fluid flow and shows flow patterns.

Study-Unit Survey: Broad assessment of the water-quality conditions of the major aquifer systems of each unit. The Study-Unit Survey relies primarily on sampling existing wells and, wherever possible, on data collected by other agencies and programs. Typically, 20 to 30 wells are sampled in each of three to five aquifer subunits.

Subtropical anticyclone: A semi-permanent anticyclone located, on the average, over oceans near 30 ° N. and 30 ° S. latitude.

Surface runoff: Runoff that travels over the land surface to the nearest stream channel.

Surface water: An open body of water such as a lake, river, or stream.

Suspended sediment: Sediment that is transported in suspension by a stream.

Suspended-sediment concentration: The velocity-weighted concentration of suspended sediment in the sampled zone (from the water surface to a point approximately 0.3 foot above the bed); expressed as milligrams of dry sediment per liter of water-sediment mixture (mg/L).

Swale: A slight soil depression sometimes filled with water, in the midst of generally level land.

Swamp: An area intermittently or permanently covered with water, and having trees and shrubs.

Synoptic sites: Sites sampled during a short-term investigation of specific water-quality conditions during selected seasonal or hydrologic conditions, to provide improved spatial resolution for critical water-quality conditions.

T

Tarn: A relatively small and deep, steep-sided lake or pool occupying an ice-gouged basin amid glaciated mountains.

Taxon (plural taxa): Any identifiable group of taxonomically related organisms.

Tectonic activity: Movement of the Earth's crust resulting in the formation of ocean basins, continents, plateaus, and mountain ranges.

Terminal moraine: The end moraine extending across a glacial plain or valley as a crescent ridge that marks the farthest advance or maximum extent of a glacier.

Tertiary-treated sewage: The third phase of treating sewage that removes nitrogen and phosphorus before it is discharged; chemical treatment of secondary treated effluent by advanced oxidation processes, pressure filtration, and other technologies.

Thermal loading: Amount of waste heat discharged to a water body.

Thermoelectric power: Electrical power generated by use of fossil-fuel (coal, oil, or natural gas), geothermal, or nuclear energy.

Tidal flat: An extensive, nearly horizontal, tract of land that is alternately covered and uncovered by the tide and consists of unconsolidated sediment.

Tier 1 sediment guideline: Threshold concentration above which there is a high probability of adverse effects on aquatic life from sediment contamination, determined using modified US Environmental Protection Agency (1996) procedures.

Tile drain: A buried perforated pipe designed to remove excess water from soils.

Till: Predominantly unsorted and un-stratified drift, deposited directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel, and boulders.

Tinaja: A pocket of water developed below a waterfall; a term used in the Southwestern United States; used loosely to mean a temporary pool.

Total head: The height above a datum plane of a column of water. In a groundwater system, it is composed of elevation head and pressure head.

Trace element: A chemical element that is present in minute quantities in a substance.

Tracer: A stable, easily detected substance or a radioisotope added to a material to follow the location of the substance in the environment or to detect any physical or chemical changes that it undergoes.

Trade winds: A system of easterly winds that dominate most of the tropics. A major component of the general circulation of the atmosphere.

Tranmissivity: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.

Transpiration: The process by which water passes through living organisms, primarily plants, into the atmosphere.

Triazine herbicide: A class of herbicides containing a symmetrical triazine ring (a nitrogen-heterocyclic ring composed of three nitrogens and three carbons in an alternating sequence). Examples include atrazine, propazine, and simazine.

Tributary: A river or stream flowing into a larger river, stream, or lake.

Tritium: A radioactive form of hydrogen with atoms of three times the mass of ordinary hydrogen; can be used to determine the age of water.

Tropical cyclone: A cyclone that originates over the tropical oceans. Tropical cyclones are classified according to their intensity and wind speed and, when fully mature, are characterized by extremely high-speed winds and torrential rains. In the United States, tropical cyclones that have wind speeds greater than 40 miles per hour are classified as tropical storms, and tropical cyclones that have wind speeds of 74 miles per hour or more are classified as hurricanes. *See also* Cyclone.

Troposphere: Lowest 6–12 miles of the atmosphere, characterized by a general decrease in temperature with height, appreciable water content, and active weather processes.

Trough (ground water): An elongated depression.

Trough (meteorological): An elongated area of relatively low atmospheric pressure; the opposite of a ridge. This term commonly is used to distinguish a feature from the closed circulation of a low (or cyclone). A large trough, however, may include one or more lows, and an upper-air trough may be associated with a lower-level low.

Tundra: A vast, nearly level, treeless plain of the arctic and subarctic regions. It usually has a marshy surface which supports mosses, lichens, and low shrubs, underlain by mucky soils and permafrost.

Turbidity: The state, condition, or quality of opaqueness or reduced clarity of a fluid due to the presence of suspended matter.

U

Unconfined aquifer: An aquifer whose upper surface is a water table free to fluctuate under atmospheric pressure.

Unconsolidated deposit: Deposit of loosely bound sediment that typically fills topographically low areas.

Underground water: Subsurface water in the unsaturated and saturated zones.

Un-ionized ammonia: The neutral form of ammonia-nitrogen in water, usually occurring as NH_4OH. Un-ionized ammonia is the principal form of ammonia that is toxic to aquatic life. The relative proportion of un-ionized to ionized ammonia (NH^{4+}) is controlled by water temperature and pH. At temperatures and pH values typical of most natural waters, the ionized form is dominant.

Unsaturated zone: A subsurface zone above the water table in which the pore spaces may contain a combination of air and water.

Upland: A general term for non-wetland; elevated land above low areas along streams or between hills; any elevated region from which rivers gather drainage.

Uranium (U): A heavy silvery-white metallic element, highly radioactive and easily oxidized. Of the 14 known isotopes of uranium, U238 is the most abundant in nature.

Urban site: A site that has greater than 50 percent urbanized and less than 25 percent agricultural area.

V

Vernal pool: A small lake or pond that is filled with water for only a short time during the spring.

Volatile organic compounds (VOCs): Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some byproducts of chlorine disinfection.

W

Wasteway: A waterway used to drain excess irrigation water dumped from the irrigation delivery system.

Water budget: An accounting of the inflow to, outflow from, and storage changes of water.

Water column: An imaginary column extending through a water body from its floor to its surface.

Water column studies: Investigations of physical and chemical characteristics of surface water, which include suspended sediment, dissolved solids, major ions, and metals, nutrients, organic carbon, and dissolved pesticides, in relation to hydrologic conditions, sources, and transport.

Water content of snow: Amount of liquid water in the snow at the time of observation.

Water demand: Water requirements for a particular purpose, such as irrigation, power, municipal supply, plant transpiration, or storage.

Water exports: Artificial transfer (by pipes or canals) of freshwater from one region or subregion to another.

Water gap: A deep, narrow pass in a mountain ridge through which a stream flows.

Water imports: Artificial transfer (by pipes or canals) of freshwater to one region or subregion from another.

Water rights: Legal rights to the use of water.

Water-quality criteria: Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to criteria established by the US Environmental Protection Agency. Water-quality criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water-quality guidelines: Specific levels of water quality which, if reached, may adversely affect human health or aquatic life. These are non-enforceable guidelines issued by a governmental agency or other institution.

Water-quality standards: State-adopted and US Environmental Protection Agency-approved ambient standards for water bodies.

Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

Water table: The top water surface of an unconfined aquifer at atmospheric pressure.

Water year: A continuous 12-month period selected to present data relative to hydrologic or meteorological phenomena during which a complete annual hydrologic cycle normally occurs. The water year used by the US Geological Survey runs from October 1 through September 30, and is designated by the year in which it ends.

Water-resources region: Natural drainage basin or hydrologic area that contains either the drainage area of a major river or the combined areas of a series of rivers. In the United States, there are 21 regions of which 18 are in the conterminous United States, and one each in Alaska, Hawaii, and the Caribbean.

Water-resources subregion: Subdivision of a water-resources region. The 21 water-resources regions of the United States are subdivided into 222 subregions. Each subregion includes that area drained by a river system, a reach of a river and its tributaries in that reach, a closed basin(s), or a group of streams forming a coastal drainage area.

Weather: State of the atmosphere at any particular time and place.

Weathering: Process whereby earthy or rocky materials are changed in color, texture, composition, or form (with little or no transportation) by exposure to atmospheric agents.

Wetland function: A process or series of processes that take place within a wetland that are beneficial to the wetland itself, the surrounding ecosystems, and people.

Wetlands: Ecosystems whose soil is saturated for long periods seasonally or continuously, including marshes, swamps, and ephemeral ponds.

Withdrawal: Water removed from the ground or diverted from a surface water source for use. Also refers to the use itself; for example, public-supply withdrawals or public-supply use.

X

Xerophyte: A plant adapted for growth under dry conditions.

Y

Yield: The mass of material or constituent transported by a river in a specified period of time divided by the drainage area of the river basin.

Z

Zooplankton: *See* plankton.

Sources of terms and definitions included in this glossary include:

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Appendix D

Table of Regulated Drinking Water Contaminants

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Microorganisms				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Cryptosporidium	Zero	TT[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste
Giardia lamblia	Zero	TT[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste
Heterotrophic plate count (HPC)	n/a	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment
Legionella	Zero	TT[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and E. coli)	Zero	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste

Turbidity	n/a	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (such as whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Viruses (enteric)	zero	TT[3]	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)	Human and animal fecal waste

Disinfection Byproducts				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Bromate	zero	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	0.8	1.0	Anemia; infants and young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5)	n/a[6]	0.060	Increased risk of cancer	Byproduct of drinking water disinfection
Total Trihalomethanes (TTHMs)	–> n/a[6]	========–>–> 0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection

Disinfectants				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Chloramines (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2)	MRDLG=0.8[1]	MRDL=0.8[1]	Anemia; infants and young children: nervous system effects	Water additive used to control microbes

Inorganic Chemicals				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass and electronics production wastes
Asbestos (fiber > 10 μm)	7 million fibers per liter (MFL)	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints

Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	Zero	TT[7]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands

(*continued*)

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Inorganic Chemicals				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Organic Chemicals				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Acrylamide	Zero	TT[8]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	Zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	Zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(*a*)pyrene (PAHs)	Zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	Zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	Zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories

(*continued*)

(continued)

Organic Chemicals				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP)	Zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	Zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1,1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	Zero	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories

1,2-Dichloropropane	Zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	0.4	Weight loss, liver problems, or possible reproductive difficulties.	Discharge from chemical factories
Di(2-ethylhexyl) phthalate	Zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD)	Zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	Zero	TT[8]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	Zero	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use

(*continued*)

(continued)

Organic Chemicals				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Heptachlor	Zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	Zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	Zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	Zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals

Pentachlorophenol	Zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	Zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Toxaphene	Zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	Zero	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	Zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

Radionuclides				
Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Alpha particles	None[7] ———- zero	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation
Beta particles and photon emitters	None[7] ———- zero	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation
Radium 226 and Radium 228 (combined)	None[7] ———- zero	5 pCi/L	Increased risk of cancer	Erosion of natural deposits
Uranium	Zero	30 ug/L as of 12/08/03	**Increased risk of cancer, kidney toxicity**	Erosion of natural deposits

Notes:
[1]Definitions:

- Maximum Contaminant Level Goal (MCLG)—The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL)—The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

- Maximum Residual Disinfectant Level Goal (MRDLG)—The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Treatment Technique (TT)—A required process intended to reduce the level of a contaminant in drinking water.
- Maximum Residual Disinfectant Level (MRDL)—The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

[2]Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (PPM).

[3]EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to

a. Disinfect their water, and
b. Filter their water, or
c. Meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- *Cryptosporidium*: Unfiltered systems are required to include *Cryptosporidium* in their existing watershed control provisions
- *Giardia lamblia*: 99.9% removal/inactivation.
- Viruses: 99.99% removal/inactivation.
- *Legionella*: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, according to the treatment techniques in the Surface Water Treatment Rule, *Legionella* will also be controlled.
- Turbidity: For systems that use conventional or direct filtration, at no time can turbidity (cloudiness of water) go higher than 1 Nephelometric Turbidity Unit (NTU), and samples for turbidity must be less than or equal to 0.3 NTUs in at least 95 percent of the samples in any month. Systems that use filtration other than the conventional or direct filtration must follow state limits, which must include turbidity at no time exceeding 5 NTUs.
- Heterotrophic Plate Count (HPC): No more than 500 bacterial colonies per milliliter.
- Long-Term 1 Enhanced Surface Water Treatment: Surface water systems or groundwater under the direct influence (GWUDI) systems serving fewer than 10,000 people must comply with the applicable Long-Term 1 Enhanced Surface Water Treatment Rule provisions (such as turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).
- Long-Term 2 Enhanced Surface Water Treatment Rule: This rule applies to all surface water systems or ground water systems under the direct influence of surface water. The rule targets additional *Cryptosporidium* treatment requirements for higher risk systems and includes provisions to reduce risks from uncovered finished water storage facilities and to

ensure that the systems maintain microbial protection as they take steps to reduce the formation of disinfection byproducts.

- Filter Backwash Recycling: This rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

[4]No more than 5.0% samples total coliform-positive (TC-positive) in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E.coli* fecal coliforms, system has an acute MCL violaton.

[5]Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.

[6]Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:

- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L): chloroform (0.07 mg/L).
- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.02 mg/L); monochloroacetic acid (0.07 mg/L). Bromoacetic acid and dibromoacetic acid are regulated with this group but have no MCLGs.

[7]Lead and copper are regulated by a treatment technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

[8]Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows:

- Acrylamide = 0.05% dosed at 1 mg/L (or equivalent)
- Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent)

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