# 1.0 OVERVIEW

## 1.1 THE IMPORTANCE OF WATER RESOURCES

Is it really necessary to have a chapter on the importance of water resources? How about I simplify this section and get to the point: Without water, there would be no life on this planet. Water is *the* major environmental issue of the 21st century; all other concerns pale in comparison.

We think of Earth as a water world, and it certainly is, with ocean waters covering nearly 71% of Earth's surface. Ninety-eight percent of the water on the planet is in the oceans and therefore unusable for drinking. Of the 2% of the fresh water, the majority is in glaciers and the polar ice caps. Approximately 0.36% is in underground aquifers, and about the same amount makes up our lakes and rivers. (See Figure 1.1.)

But although there is plenty of water on Earth, it is not always in the right place, and it is not always there when we need it. The world's population is expected to expand to over 9.4 billion people by 2050, and scientists are concerned that our water resources will not be able to



**Figure 1.1** *Water is the most important environmental issue of this or any other century. Image courtesy NRCS.*

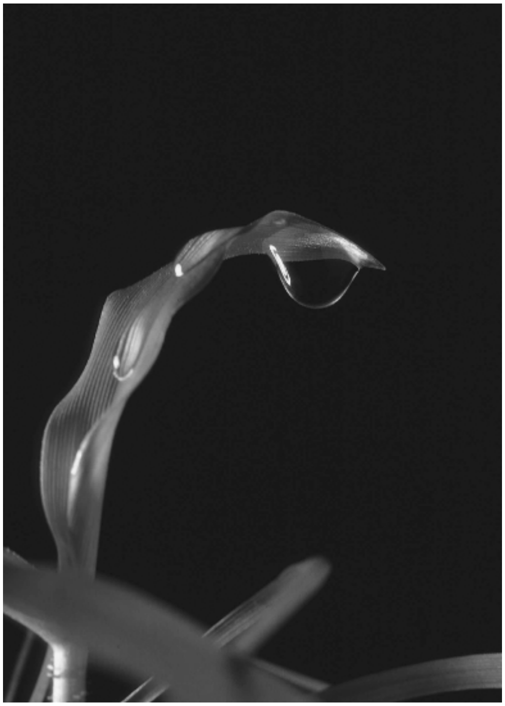

Figure 1.2 *Water is essential for life on this planet. The question is how to protect existing water resources while meeting all the demands for water. Image courtesy NRCS.*

accommodate this mass of people. According to the Stockholm International Water Institute, more than 1 billion people worldwide do not have adequate clean drinking water, and 2.5 billion lack safe sanitation (U.S. Census Bureau).

In most parts of the United States, people take for granted that cheap, clean water will always be available to us. In other parts of the world, tens of millions of people do not have access to safe water. The United Nations calls it a crisis of epic proportion. According to the U.S. Census Bureau, at the beginning of 2000, one-sixth (1.1 billion people) of the world's population was without access to improved water supply and two-fifths (2.4 billion people) lacked access to improved sanitation. The majority of these people live in Africa and Asia.

In recent years, though, even the United States has experienced severe droughts that rival the dust bowl days of the Great Depression. Water is a natural resource that is already in short supply in many parts of the nation, and the situation is only going to get worse. As the population continues to grow, demands for water increase, and climate change mucks up the hydrologic cycle, water will become even scarcer. (See Figure 1.2.)

For example, the state of Georgia is one of the fastest-growing states in the United States. In the past two decades, however, Georgia has experienced the two worst droughts on record. According to the U.S. Army Corps of Engineers, on August 14, 2008, Lake Lanier, which supplies most of the water for the Atlanta metropolitan area, had fallen to 16 feet below full pool. This is a full 9 feet lower than the lake level during the droughts of 2007. Within a matter of days, Atlanta was running out of water.

It is important to point out, though, that the issue is not just about water availability. Water quality is increasingly becoming a major concern. Poor water supply and sanitation have a high health toll. Much of our water is polluted to the point where it is no longer safe for human use. One of the keys to ensuring we have sufficient water for the future is our ability to use small amounts of clean water to bring large productivity gains.

Since this book is about "sustainable" solutions to water resources, I would be remiss if I did not talk about the amount of energy it takes to meet water demands and the environmental impact of our actions. According to the National Resources Defense Council (2009), the collection, distribution, and treatment of drinking water and wastewater nationwide produce as much carbon dioxide each year as would 10 million cars on the road (www.nrdc.org/water/energywater.asp). We need to develop sustainable water resource policies that allow us to meet all of our needs.

The 1987 Bruntland report from the World Commission on Environment and Development defined sustainable development as development that "meets the needs of the present generation without compromising the ability of future generations to meet their needs." One objective of the Commission is to find the right balance between society's needs for economic growth, protection from floods, and affordable power, with environmental concerns such as water quality, the preservation of wetlands, and the protection of threatened or endangered species. (See Figure 1.3.)

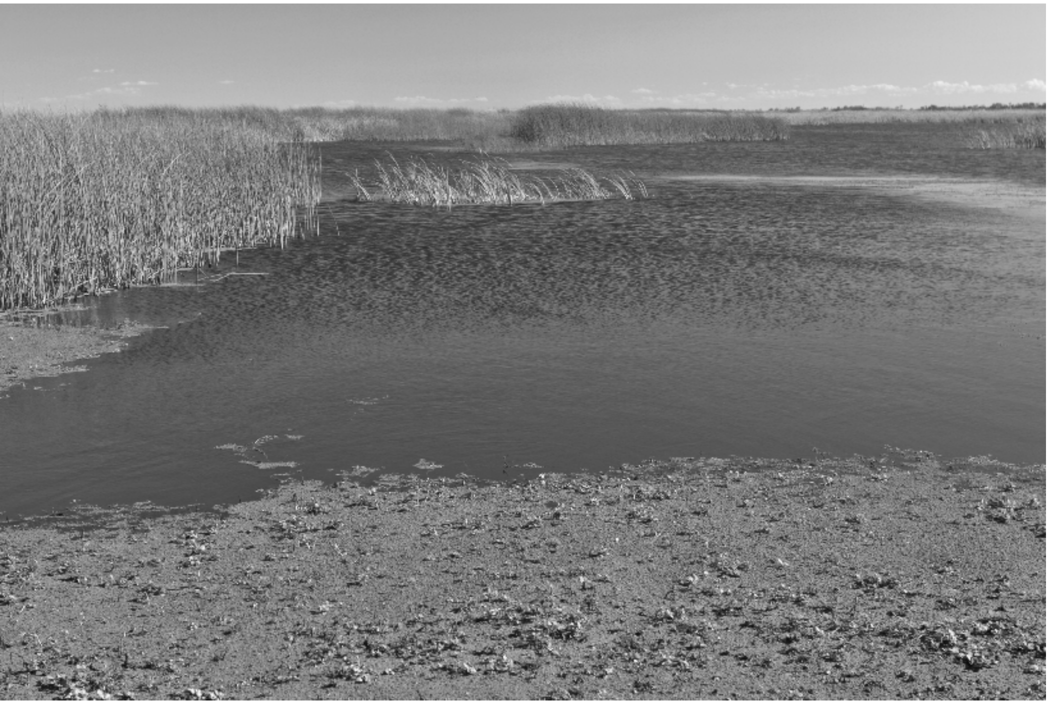

**Figure 1.3** *The Yolo Bypass Wildlife Area is a 3,700-acre restoration project that opened in 1997 near Sacramento and Davis, California. It is part of the 59,000-acre Yolo Bypass, which provides flood control for the cities in the area. Image courtesy NRCS.*

## 1.2 OVERVIEW OF WATER RESOURCES

Water resources involve surface water, water below ground, and water that falls from the sky. Most cities meet their needs for water by withdrawing it from the nearest river, lakes, reservoir, or aquifer. In some parts of the United States, precipitation is considered to be public domain because it is such a valuable resource.

One thing discovered over the years is that groundwater and surface water are fundamentally interconnected and are integral components of the hydrologic cycle. They have to be thought of as one cohesive system.

The United States Geological Survey (USGS) compiled estimates of surface-water and groundwater withdrawals for the nation at five-year intervals since 1950. The data are compiled at the county, state, and national levels for eight categories of water use. These include:

1. Public supply
2. Domestic
3. Irrigation
4. Livestock
5. Aquaculture
6. Self-supplied industrial
7. Mining
8. Thermoelectric power

### 1.2.1 Rivers and Streams

When we talk about water resources, most people probably think of rivers and streams. The United States has more than 250,000 rivers that collectively make up 3.7 million river miles in length. The longest river in the United States is the Missouri, which is approximately 2,500 miles in length, and the largest is the Mississippi, which has a flow volume of 593,000 cubic feet per second at its mouth (www.americanrivers.org/library/river-facts/river-facts.html). (See Figure 1.4.)

Figure 1.4 *The NRCS in Idaho has developed the Conservation Stewardship Program, which encourages producers to adopt new conservation practices and improve or maintain existing conservation practices that address resource concerns. The program has had a significant impact on water quality in the state. Image courtesy NRCS.*

Of the country's rivers and streams, 45% were reported as impaired according to the 2002 National Assessment Database. Sediment, pathogens, and habitat alterations are the biggest problems associated with the nation's rivers and streams. This fact obviously raises some big concerns.

The 2002 National Assessment Database includes water quality information for all states as well as the District of Columbia and the U.S. Virgin Islands. Alabama, North Carolina, Washington, Puerto Rico, the tribal nations, and the island territories of the Pacific did not provide data electronically in 2002.

A *watershed* is defined by the U.S. Environmental Protection Agency (EPA) as "the geographic region within which water drains into a particular river, stream, or body of water" (www.epa.gov/adopt/defn.html). Watershed drainage areas are large, ranging from 20 to 100 square miles or more. Each watershed is composed of a number of smaller "subwatersheds," which typically range from 5 to 10 square miles in size.

Rivers have had a major impact on settlement patterns in the United States. Most of the nation's major cities in the eastern part of the country were built along rivers. Rivers provide water needed for drinking, sanitation, growing crops, and even navigation.

Unfortunately, many rivers and streams have been seriously impacted by human activities. The EPA considers urban runoff and pollution from other diffuse sources the greatest contaminant threat to the nation's waters. More than 235,000 river miles in the United States have been channelized, 25,000 river miles have been dredged, and another 600,000 river miles are impounded behind dams. Nearly 40% of the rivers and streams in the United States are too polluted for fishing and swimming. Thirty percent of the native freshwater fish species in North America are threatened, endangered, or of special concern (www.americanrivers.org/library/river-facts/river-facts.html).

## Floodplains

Floodplains are areas along rivers, streams, or creeks that may be inundated with water following storms. Floodplains help reduce the number and severity of floods, filter stormwater, and minimize nonpoint source pollution. Water expands into the floodplain areas and infiltrates into the ground, slowing water flow and allowing groundwater recharge. Floodplains also provide habitat for both flora and fauna. One significant problem, though, is that human activities have had significant adverse impacts on the effectiveness of a stream's floodplain to convey and store floodwater.

## Riparian Corridors

Riparian corridors include grass, trees, shrubs, and a combination of natural features along the banks of rivers and streams. Protecting these corridors is critical for preserving water quality. Riparian zones also harbor a disproportionately high number of wildlife species and perform a disparate number of ecological functions compared to most plant habitats (Fischer and Fischenich, April 2000). Riparian corridors often are considered to coincide with the 100-year floodplain.

### *Impaired Rivers and Streams Database*

Information on state-reported causes and sources of impairment is available from the National Assessment Database at www.epa.gov/waters/305b.

Environmental Protection Agency, *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*.

# 1.2.2 Groundwater and Aquifers

Groundwater is one of the world's most critical natural resources. It is vital to most nations, and worldwide more than 2 billion people depend on groundwater for their water needs. It provides half the drinking water in the United States and is essential for maintaining the hydrologic balance of surface streams, springs, lakes, wetlands, and marshes around the world.

Groundwater is the largest source of usable water storage in the United States, containing more water than all of the reservoirs and lakes combined, excluding the Great Lakes. According to scientists, an estimated 1 million cubic miles of groundwater is located within one-half mile of the land surface. Only a very small percentage of groundwater is accessible and can be used for human activities (http://pubs.usgs.gov/gip/gw/gw_a.html).

Groundwater is stored in an underground aquifer as a geologic formation, group of formations, or part of a formation that contains sufficient saturated, permeable material to yield significant quantities of water to wells and springs (www.nationalatlas.gov/mld/aquifrp.html). The top of the zone of saturation is known as the *water table*, and it varies significantly in depth from one region to the next. The water table can rise in wet years and fall in dry years. All aquifers have an impermeable layer beneath that stops groundwater from penetrating farther.

The area over which water infiltrates into an aquifer is known as the *recharge zone*. Rainwater that falls in the recharge zone typically makes its way into the aquifer below. Rates of recharge for many aquifers can be very slow because water has to infiltrate through layers of soil and rocks. Preservation of the water resources requires protection of groundwater quality and recharge capacity. Recharge to shallow, unconfined aquifers can be preserved by restricting the amount of impervious areas. Some aquifers were formed a long time ago and are no longer actively recharged. If water is pulled from these aquifers, eventually they will become empty.

Most cities meet their water needs by withdrawing it from the nearest river, lake, or reservoir, but many depend on groundwater as well. Water is already in short supply in many parts of the world, and the situation is only going to get worse. According to USGS, groundwater is the source of about 40% of the water used for public supply and provides drinking water for more than 97% of the rural population in the United States. Between 30% and 40% of the water used for the agricultural industry comes from groundwater. An understanding of groundwater is important if we are going to continue to make good decisions about sustainable resources.

In recent years we have learned that groundwater and surface water are fundamentally interconnected and are integral components of the hydrologic cycle. Interestingly enough, most laws governing groundwater issues are based on the notion that groundwater and surface water have nothing to do with each other. In most parts of the United States, surface water is governed by doctrines of riparian law or prior appropriation. Groundwater traditionally has been treated as a common resource, with virtually no restrictions on accessing it. If you can afford to pay someone to drill a well and you happen to hit water, you can do whatever you want with it.

Today, the unregulated pumping of groundwater is no longer a viable option. In many parts of the United States, groundwater is being withdrawn at rates that are not sustainable, and the result is a degradation of water quality and quantity. The water level in aquifers is being lowered, and because people keep digging deeper and deeper wells in order to access the water, the water quantity is depleted even more. In coastal areas, intensive pumping of fresh groundwater has caused salt water to seep into fresh-water aquifers. Groundwater is also critical for the environmental health of rivers, wetlands, and estuaries. Groundwater withdrawals can result in reduced flows to streams and alter wetland hydrology. Changes in stream flow have important implications for water and flood management, irrigation, and planning.

Data about groundwater has been collected worldwide for decades. The Worldwide Groundwater Organization was formed in 1956, and it is just one organization involved in collecting such data. Worldwide maps of groundwater resources are available, and most countries produce their own maps. In the United States, one responsibility of the U.S. Geological Survey is to assess the quantity and quality of the nation's water supplies. On a national scale, quite a bit is known about groundwater resources, but most of that information is very general in nature. The USGS National Water Information System (NWIS) contains water data for the nation. USGS has offices around the country that collect local data and conduct studies as part of NWIS. The groundwater database contains records from about 850,000 wells, and data have been collected for more than 100 years. Measurements are commonly recorded at 5- to 60-minute intervals and transmitted to the NWIS database every 1 to 4 hours. The Ground-Water Database includes more than 850,000 records of wells, springs, test holes, tunnels, drains, and excavations. Each well location includes information such as latitude and longitude, well depth, and aquifer. This information is available online through USGS's NWISWeb, the National Water Information System Web Interface (http://waterdata.usgs.gov/nwis). (See Figure 1.5.)

The Regional Aquifer-System Analysis Program was initiated in 1977 as a response to droughts during that year. Computer models were used to develop estimates of current and future water availability for aquifers and to provide a baseline for future studies. The National Water-Quality Assessment Program was developed by the USGS in 1991 to determine the condition of the nation's streams, rivers, and groundwater.

The location, hydrologic characteristics, and geologic characteristics of the principal aquifers throughout the 50 states, Puerto Rico, and the U.S. Virgin Islands are described in the Ground Water Atlas of the United States (Miller, 2000; http://capp.water.usgs.gov/gwa/). The atlas consists of an introductory chapter and 13 descriptive chapters, each covering a multistate region of the country. The atlas provides useful information in a regional and national context, but it is not useful for design or planning projects. The information summarized in the atlas has been collected over many years by the USGS with state and local agencies as well as other partner agencies (USGS; Reilly, Dennehy, Alley, and Cunningham, 2008).

In the United States, groundwater management decisions are made at a local level, not at the federal level. State and local agencies manage water resources and collect and analyze local data. Each state produces a report about groundwater within its borders. For landscape architects,

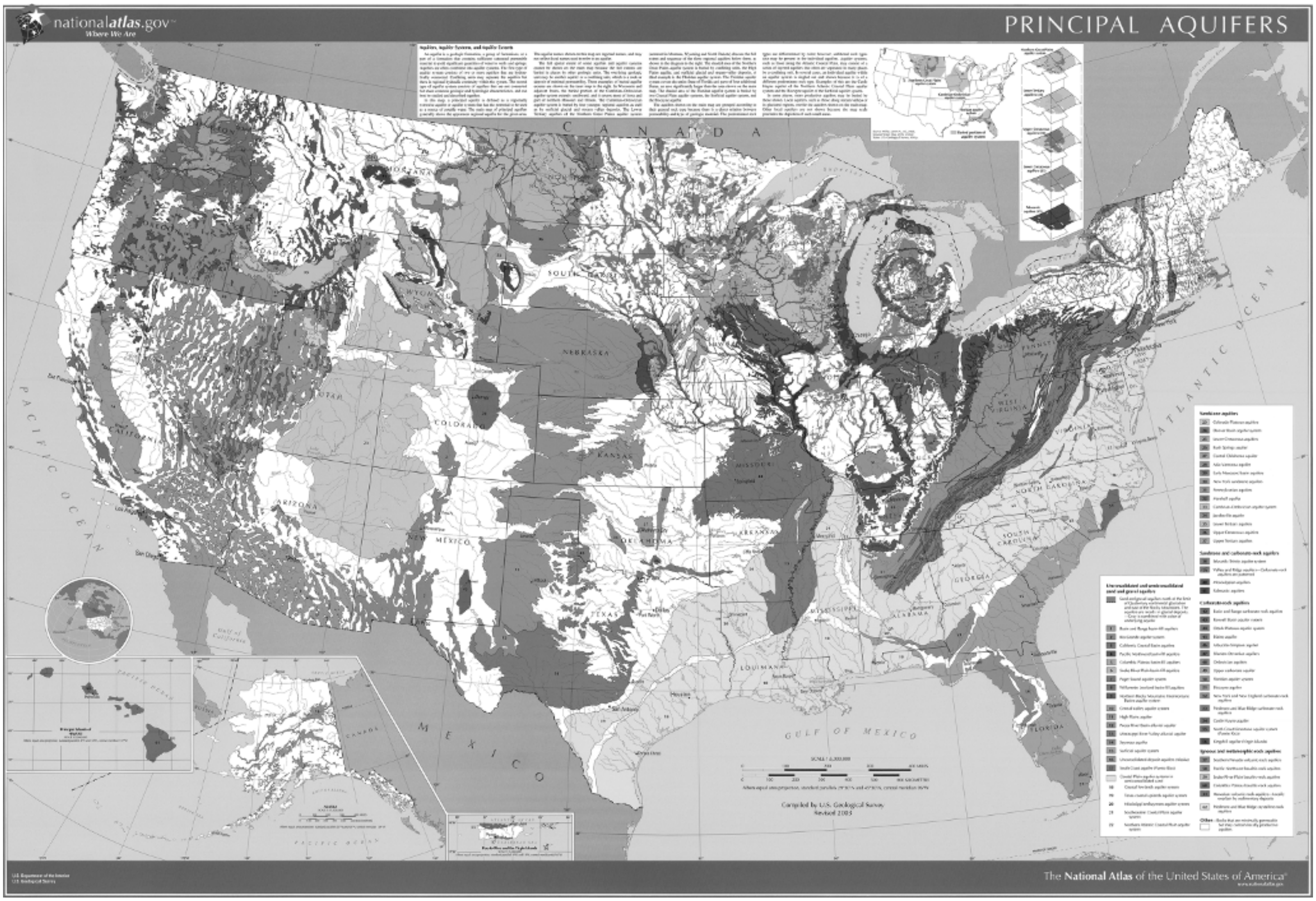


Figure 1.5 *The U.S. Geological Survey produces geospatial data for water resources. This map shows the major aquifers in the United States. Image courtesy USGS.*

the best source of groundwater information is from state, counties, or regional water districts.

Many states are using interactive maps for sharing groundwater information (see Figure 1.6). For example, the Kentucky Geological Survey (KGS) Interactive Groundwater-Quality Data Map displays groundwater-quality data for Kentucky. Users can choose from a list of 32 layers to display including geology, watershed boundaries, roads, orthophotography, and sinkholes. There are seven types of information about groundwater, including:

1. Water well and spring record search
2. Water well and spring location map service
3. Groundwater-quality data search
4. Graphical groundwater-quality comparison service
5. Groundwater-quality data map service
6. Karst potential index map service
7. KGS water research home page (www.uky.edu/KGS/water/research)

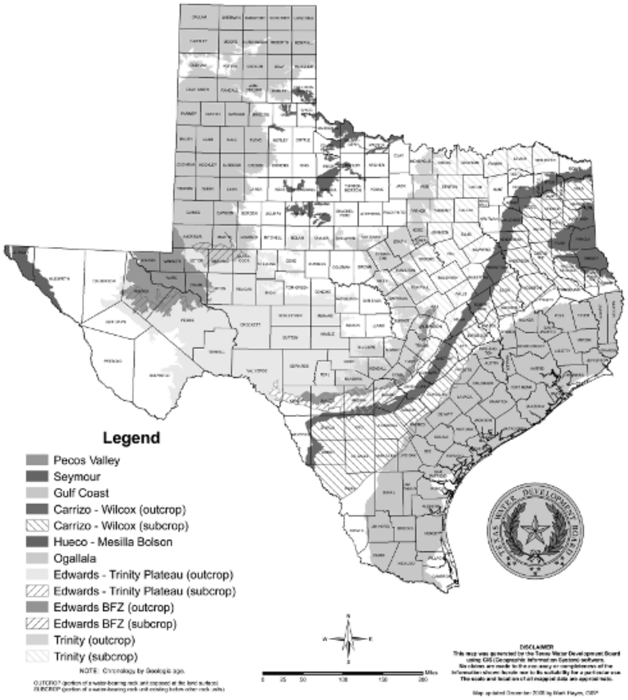


Figure 1.6 *This map shows the major aquifers in the State of Texas. Most states collect data on groundwater and utilize this information to augment national water resource data. Image courtesy USGS.*

Counties across the United States are also implementing their own groundwater policies. For example, in 2001, the King County (WA) Council created the Groundwater Protection Program to provide management, policy, and technical expertise to help protect the quality and quantity of the groundwater resources in the county. One objective of the program is to help local communities identify groundwater protection needs and to integrate groundwater issues with other local planning efforts, such as growth management plans. King County uses an interactive map that enables visitors to select and query groundwater information through Web-based maps and geographically based software.

USGS also has geospatial information on aquifers and other water resources for use with Geographic Information Systems (GIS) programs. GIS are used to capture, store, retrieve, analyze, and display geospatial data. GIS and data management technologies allow users to manage the complexity of information needed on many design and planning projects. The power of today's GIS programs and the use of open GIS standards, combined with the vast array of digital data available via the Web, makes it easier than ever before to ask "what if" questions about a site, regardless of how large or small it is. The GIS data include information on:

- Aquifers
- Dams
- Groundwater climate response network
- Hydrologic units
- Surface-water sampling sites
- Stream-flow stations
- Water use
- General hydrography data

Groundwater maps show several types of data, including:

- Expected yield of a particular drilled well
- Well depth
- Aquifer type
- Depth to bedrock
- Naturally occurring, inorganic chemicals
- Groundwater geology

Groundwater maps are defined primarily using geologic contacts and hydrogeologic divides. These maps typically use USGS topographic maps as a base and include significant natural and man-made features, such as roads, streams and rivers, lakes, and buildings. The maps are generated from well log and drilling reports, bedrock information, and geologic and hydrogeologic data.

The volume of groundwater is decreasing in many areas of the world because of large-scale development of groundwater resources and a significant increase in withdrawals. Many people are concerned that if this trend continues, nations will not be able to meet domestic, agricultural, industrial, and environmental needs (USGS; Reilly, Dennehy, Alley, and Cunningham, 2008).

One positive sign is that groundwater withdrawals for irrigation decreased in the western United States in recent decades as a result of expanding urban areas, an increase in dry-land farming, and increased efficiencies of application. In contrast, groundwater withdrawals for irrigation in the eastern half of the country increased steadily over the same period, in part as a supplemental source of water to protect

### *Aquifers*

The Ogallala Aquifer is one of the largest underground sources of water in the world. It covers around 174,000 square miles of the Great Plains and includes parts of eight U.S. states. The amount of water in the aquifer varies from region to region but is typically between 100 to 300 feet below ground. Most of the water in the aquifer comes from the last Ice Age. If irrigation demands continue at their current rate, there is a real chance that the Ogallala Aquifer will eventually run dry.

Despite its size, the Ogallala does not compare in size to the Guaraní Aquifer, which lies under Argentina, Brazil, Paraguay, and Uruguay, and covers 1,200,000 square kilometers. In places this aquifer is more than 1,800 meters in depth. Like the Ogallala, there are concerns that increased demand on the waters of the Guarani will have a negative impact on water quality and availability.

against dry periods (USGS, 1960–2000; Hutson, Barber, Kenny, Linsey, Lumia, and Maupin, 2005).

## 1.2.3 Lakes and Reservoirs

Did you know that other than Earth, the only planetary body that we know that has lakes is Titan, Saturn's largest moon? On our planet, most of the lakes are freshwater and most are in the northern hemisphere. Canada has 60% of the world's lakes. Worldwide, estimates are that there are more than 304 million standing water bodies, but the vast majority are small ponds, not lakes.

There are more than 39.9 million acres of lakes and reservoirs in the United States. Freshwater inland lakes and reservoirs provide 70% of the nation's drinking water (www.epa.gov/owow/lakes/lakessurvey). (See Figures 1.7 and 1.8.)

Freshwater lakes and rivers contain less than 0.01% of all water on Earth (USGS. The Water Cycle: Freshwater Storage. http://ga.water.usgs.gov/edu/watercyclefreshstorage.html), but they are an important water resource in many parts of the country. They are a major source of recreation, provide drinking water to many cities and rural developments, and are a major attraction for people seeking to build vacation homes. Most man-made lakes are created by constructing dams in river or stream valleys. These lakes and reservoirs typically are constructed for purposes of power generation, flood control, navigation, water supply, and recreation.

There are some major fundamental differences between natural lakes and man-made lakes, or reservoirs. The drainage basins of natural lakes typically are much smaller than are the basins of man-made lakes. In contrast, reservoir basins tend to be narrow and elongated, with dendritic branching, because they are most commonly formed in river valleys. Reservoirs receive runoff from large streams and rivers, and are not typically intercepted by wetlands or shallow interface regions.

Natural lakes tend to be located at the headwaters of rivers or streams, and the water levels are fairly consistent. Man-made lakes tend to be closer to the mouth of a river or stream.

Natural lakes tend to have lower nutrient and sediment concentrations than those in man-made systems. Small man-made lakes frequently have no outflow point, so they accumulate sediments and nutrients much faster than do natural lakes.

The water levels in natural lakes are fairly constant, while those in reservoirs fluctuate because typically they are managed for flood control, hydropower production, and/or navigation. Water released from reservoirs frequently comes from the bottom of the dam pool; as a result, it contains little dissolved oxygen. This may impact water quality downstream. Natural lakes, in contrast, typically release water from the surface of the lake, and it is well aerated.

One of the biggest benefits of reservoirs is that they provide a reliable source of water for human use. Water released downstream from reservoirs is regulated according to water use. Smaller man-made lakes may be constructed for agricultural irrigation, recreation, or aesthetic purposes. Deciding how much water to release and how much to store depends on the time of year, flow predictions for the next several months, and the needs for residential and commercial uses.

Figure 1.7 *Lake Tahoe is a large freshwater lake in the Sierra Nevada mountains on the California/Nevada border. The lake is a major tourism destination in all seasons. Image courtesy J. Sipes.*

## 1.2.4 Wetlands

In the United States, *wetlands* are defined in federal regulations as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas" (EPA, Manual Constructed Wetlands Treatment of Municipal Wastewaters, September 1999). (See Figure 1.9.)

The U.S. Army Corps of Engineers uses three characteristics when making wetland determinations: vegetation, soil, and hydrology. Unless an area has been altered or is a rare natural situation, indicators of all three characteristics must be present during some portion of the growing season for an area to be a wetland.

**Figure 1.8** *Lake Tahoe is the second deepest lake in the United States. The depth of the water helps create the deep, rich blue that is visually so attractive. Image courtesy J. Sipes.*

*Wetland hydrology* refers to the presence of water at or above the soil surface for a sufficient period of the year. It is not always possible to identify a wetland during a field review because water is not always present. A more reliable approach is to measure the amount of water with a gauging station, but that is not always a viable option.

Wetlands serve as filters that minimize the amount of nutrients and sediments that drain into a lake. Bogs, marshes, ponds, estuaries and wet meadows, bottomland forests, mudflats, and wooded swamps are all different types of wetlands. Wetlands can range from small marshes to massive ecosystems such as the Everglades, which cover thousands of square miles. The Everglades National Park is 2,357 square miles in size, making it by far the largest national park east of the Mississippi River.

Wetlands are among the most productive ecosystems in the world; most environmental experts consider wetlands to be second only to rain forests in terms of environmental importance. But only in recent years have we begun to recognize the value of these resources. Historically, wetlands

Figure 1.9 *This open-water wetland is located in Newago County, Michigan. This type of wetland typically is located in shallow basins and includes shallow ponds and reservoirs. Image courtesy NRCS.*

were considered wastelands with little if any economic value. "Progress" was when we filled wetlands to create developable land. As a result, more than half of the wetlands in the United States have been destroyed by filling and draining. (See Figure 1.10.)

Wetlands provide a number of benefits, including improving water quality, reducing pollution, providing sediment filtration, reducing potential flood damage, producing oxygen, providing temporary water storage, and impacting nutrient recycling.

Worldwide, we have lost over half of our wetlands in the last 100 years. In New Zealand, for example, only 8% of the original wetlands remain. In Alberta, Canada, more than 60% of the wetlands have been lost. Since the 1600s, the United States has lost more than half of its native wetlands. Today, the United States has adopted a national policy of "no net loss" of wetlands and a goal of a net gain.

## 1.2.5 Coastal Zones

Population growth along the world's shorelines continues at a rapid pace, threatening coastal resources, global fisheries, and biodiversity. Two categories of coastal resources are identified in the U.S. National Assessment Database:

1. Coastal shorelines—the water immediately off shore, reported in miles
2. Ocean/near-coastal waters—the area of water extending into the ocean or gulf, range not specified, in square miles

A total of 27 states in the United States have coastal shorelines. Collectively there are a total of 58,618 miles of shoreline. The National Assessment Database assessed 2,571 miles of coastal shorelines, or about 4% of the nation's total. More than 83% of these shorelines were considered to be supportive of their anticipated use. The other 17%

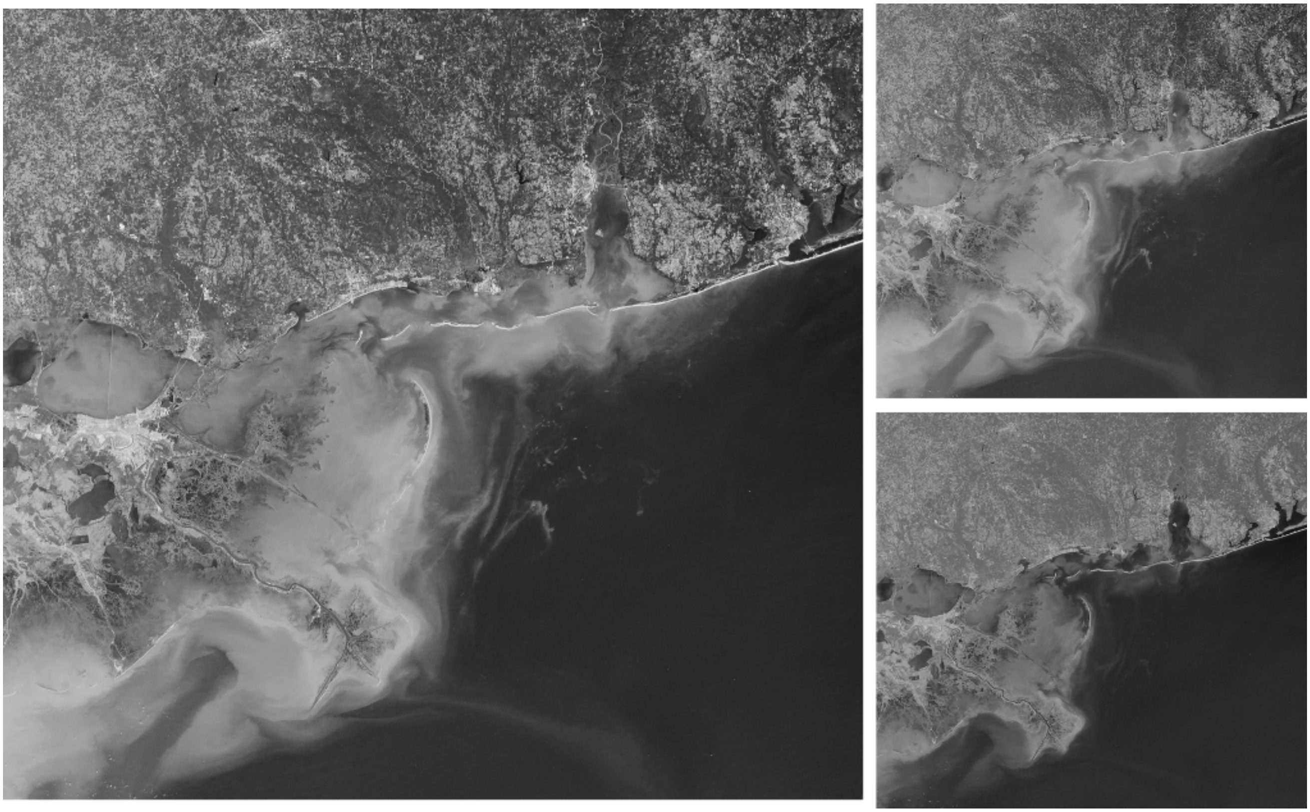

Figure 1.10 *The state of Louisiana has lost up to 40 square miles of marshes and wetlands a year for the last several decades. Extensive renovation efforts are being undertaken to restore many of its wetlands and barrier islands. Image courtesy USGS.*

of shoreline miles were negatively impacted by pollutants, stormwater runoff, and industrial discharge.

There are also more than 54,120 square miles of oceans and near-coastal waters in the United States, but of the 5,000 square miles that have been assessed, 87% were identified as impaired. For example, it has been estimated that virtually all of Texas's coastal waters are impaired due to mercury contamination.

## Data on Coastal Areas

In the last couple of decades, we have come to realize how little we actually know about coastal areas, so there has been a concentrated effort to collect more information and expand our knowledge base. In the United States, the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) mandated that the EPA develop the Coastal Management Measures Guidance, which functions as a blueprint for coastal states and territories in putting together Nonpoint Source Pollution control programs. Under CZARA, states are required to develop management measures to address nonpoint source pollution, land use conflicts, and other issues that may have an adverse impact on coastal areas. The Coastal Management Measures Guidance includes management measures for urban areas, agriculture, silviculture, marinas, hydromodification, wetlands and riparian areas protection, and constructed wetlands. State Coastal Zone Management Programs address nonpoint source pollution under Section 6217 CZARA. These programs can provide the basis for developing or consolidating watershed plans in coastal areas. Coastal zone management measures guidance documents are available at www.epa.gov/owow/nps/pubs.html.

In the United States, the National Coastal Assessment addresses the condition of the nation's coastal resources. The results of these surveys are compiled periodically into a *National Coastal Condition Report*. EPA, the National Oceanic and Atmospheric Administration (NOAA), USGS, the U.S. Fish and Wildlife Service, and the states with coastal areas are all involved with developing the report. The *National Coastal Condition Report II,* which was published by NOAA in 2005, found that 35% of U.S. coastal resources were in poor condition, 21% were in good condition, and 44% were threatened. (See Figure 1.11.)

Under the Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000, EPA is working on addressing contaminants and pollutants in recreational waters. Detailed information on U.S. coastal condition trends are also available in the series of *National Coastal Condition Reports*, which includes information collected by the states, EPA, and other federal agencies to characterize the condition of the nation's coastal resources.

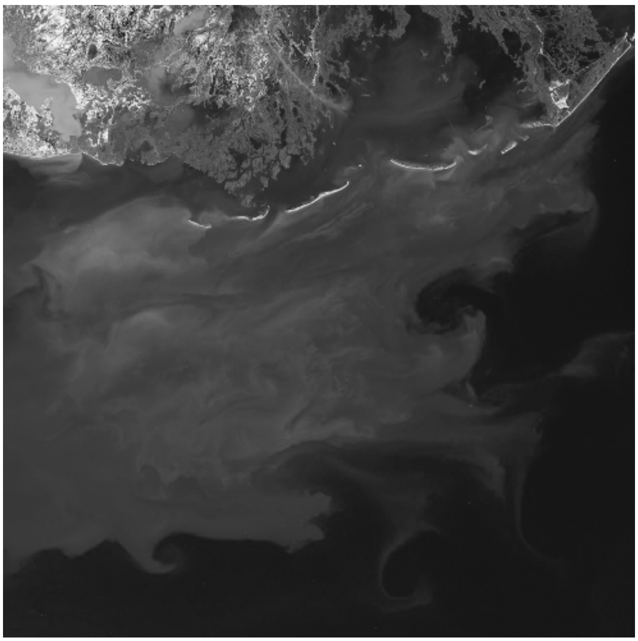

**Figure 1.11** *This satellite image shows the extent of siltation along the Louisiana coast. Image courtesy USGS.*

The National Estuary Program (NEP) was established in 1987 by amendments to the Clean Water Act. The intent of NEP is to identify, restore, and protect nationally significant estuaries in the United States. Under NEP, states work together to evaluate water quality problems and their sources, collect and compile water quality data, and integrate management efforts to improve conditions in estuaries. There are currently 28 active NEPs along the nation's coasts.

## Coastal Issues

Coastal zones have their own unique issues. Alternative water supply projects, such as desalination, aquifer storage and recovery, and reclaimed water use, are all being explored in coastal areas. Desalination is a process that removes salt and other minerals from brackish water and seawater to produce high-quality drinking water. There are more than 12,500 desalination plants worldwide, and that number is growing. Currently, about 60% of these plants are located in the Middle East. Although there is some discussion in the southern United States about utilizing seawater treated through desalination, the process is very expensive and currently is not affordable. It is much less expensive to treat and transport river water or to build a new reservoir than to treat seawater.

One concern along the Atlantic and the Gulf coasts is that drawing too much water from freshwater aquifers will result in "saltwater intrusion." Saltwater intrusion is a natural process that occurs in virtually all coastal areas and involves the encroachment of saltwater from the sea flowing inland into freshwater aquifers. In particular, the Floridan aquifer, which lies beneath Florida, southern Georgia, and parts of South Carolina and Alabama, is being threatened by saltwater intrusion in places. Some public wells on the northern end of Hilton Head Island, South Carolina, were closed after saltwater started seeping into the source there about 20 years ago.

In many coastal areas, aquifers are critical for supplying a substantial portion of water. The easiest way to avoid saltwater intrusion is to maintain an adequate level of freshwater in the aquifers. That is easier said than done, though. For example, currently more than 7 million people live in South Florida, and the result is a huge demand on the region's water resources.

There is also concern about the vulnerability of coastal areas, especially after Hurricanes Rita, Katrina, and Ike. Along the East and Gulf coasts, more than $3 trillion in infrastructure adjacent to shorelines is susceptible to erosion from flooding and other natural hazards. In the next few decades, these issues will have to be addressed. (See Figure 1.12.)

## 1.2.6 Precipitation

The term *precipitation* includes rain and snow that falls to the ground. In most of the United States, there is sufficient rain to grow crops and maintain rivers and lakes. According to USGS, the continental United States receives enough precipitation in one year to cover the land to a depth of 30 inches (http://ga.water.usgs.gov/edu/earthrain.html). One inch of rain falling on 1 acre of land is equal to about 27,154 gallons of water, so that is a lot of water, isn't it?

The amount of precipitation that falls varies considerably worldwide. London, England, receives 29.6 inches of rain per year and Rome, Italy, receives 2 inches more. Sydney, Australia, receives 48.1 inches and Tokyo, Japan, receives 60 inches per year. In Egypt, Cairo receives just 1 inch per year.

Across the United States, Savannah (GA) receives 129 inches of rain per year, while Los Angeles (CA) gets 12

Figure 1.12 *When Hurricane Katrina hit the Gulf Coast in 2005, it devastated much of New Orleans. Stormwaters that breached a levee flooded most of the Ninth Ward. Image courtesy FEMA.*

inches a year, and Las Vegas receives 4 inches of rain per year. Houston (TX) receives 46 inches; Knoxville (TN), 47 inches; Philadelphia (PA) 41 inches. It may surprise many who believe that it always rains in Seattle (WA), but the city only receives an average of 38 inches of rain per year, and Portland (OR) receives 36 inches. (See Figure 1.13.)

According to the National Weather Service, more than 50 trillion gallons of water fall over Georgia each year. If the State of Georgia was able to manage a major portion of this rainfall, it would have sufficient water to accommodate any future needs (Bazemore, 2007). Unfortunately, approximately 70% of Georgia precipitation is lost as evapotranspiration, while the other 30% runs into rivers, streams, and lakes. The state experiences little monthly or seasonal variations in rainfall, so there is a relatively uniform distribution of precipitation throughout the year.

In many southern states of the United States, tropical depressions, tropical storms, and hurricanes can result in long-duration rainfall of moderate to high intensity over large areas, and this can restore lake levels very quickly. Most of these types of events occur between June and November.

Much of the precipitation from rainstorms is absorbed back into the ground close to where it falls as long as there is sufficient pervious surface to allow this to happen. In urban areas, though, where the percentage of paved, impervious surfaces is much greater, much of the precipitation that falls runs off.

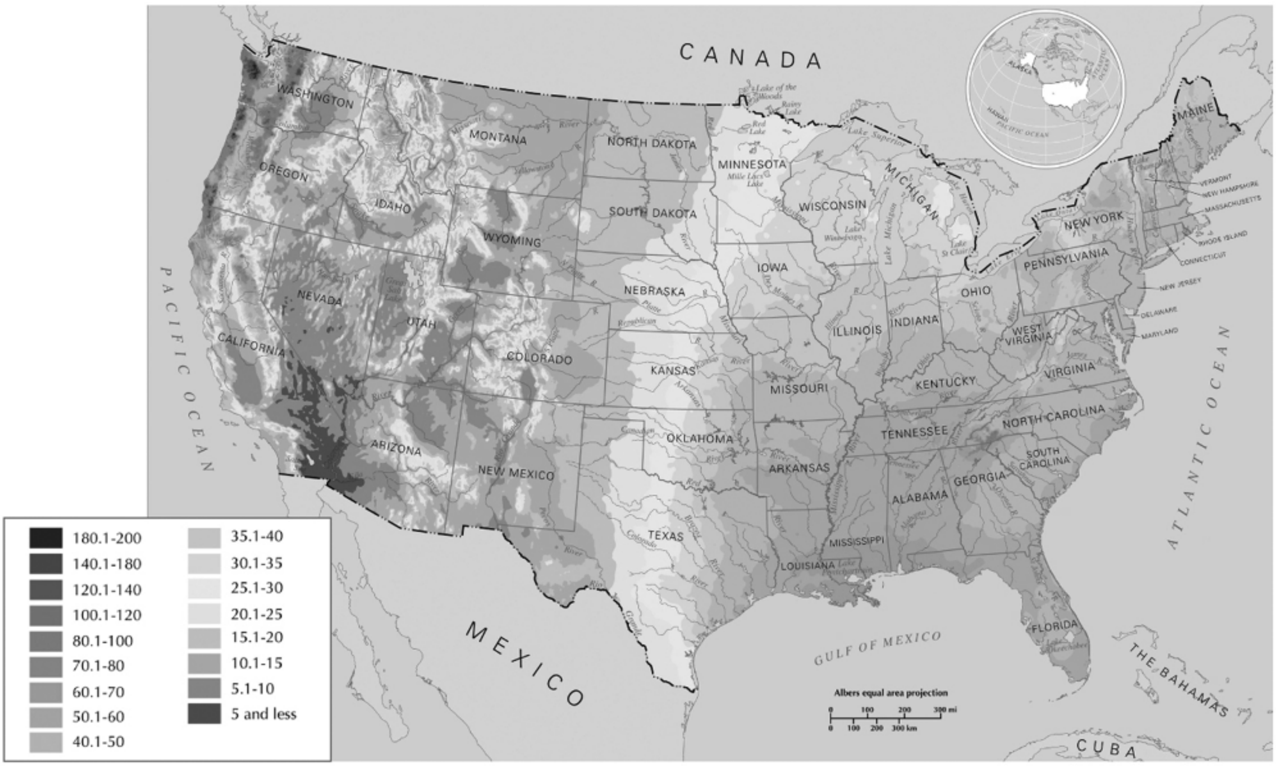


**Figure 1.13** *The National Weather Service produces precipitation maps at both the national and local level. Image courtesy National Weather Service.*

*Rainfall per City*

| Amount of water received when an inch of rain occurs | | |
|---|---|---|
| City | Area (square miles) | Amount of water (million gallons) |
| Atlanta, GA | 131.7 | 2,289 |
| Baltimore, MD | 80.8 | 1,404 |
| Chicago, IL | 227.1 | 3,947 |
| Cincinnati, OH | 78.0 | 1,356 |
| Denver, CO | 153.4 | 2,666 |
| Detroit, MI | 138.8 | 2,412 |
| Honolulu, HI | 85.7 | 1,489 |
| Houston, TX | 579.4 | 10,069 |
| Jacksonville, FL | 757.7 | 13,168 |
| Louisville, KY | 62.1 | 1,079 |
| Milwaukee, WI | 96.1 | 1,670 |
| New Orleans, LA | 180.6 | 3,139 |
| New York, NY | 303.3 | 5,271 |
| Philadelphia, PA | 135.1 | 2,348 |
| Salt Lake City, UT | 109.1 | 1,906 |
| Seattle, WA | 83.9 | 1,458 |
| Washington, DC | 61.4 | 1,067 |

Note: 1 inch of rain falling on 1 acre is equal to about 27,154 gallons of water, and there are 640 acres in a square mile.
Source: http://ga.water.usgs.gov/edu/earthrain.html.

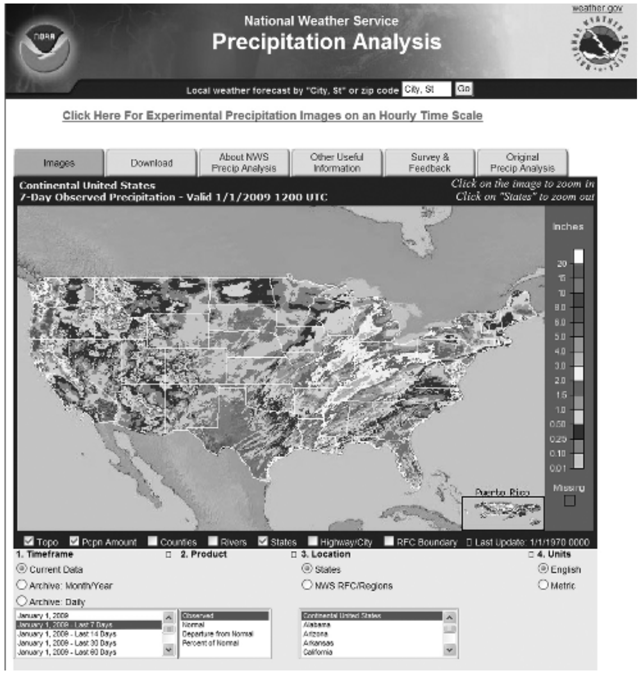


Figure 1.14 *The National Weather Service produces maps that show precipitation patterns for a specific period of time. This map shows the amount of precipitation in the United States for a 7-day period. Image courtesy National Weather Service.*

## 1.2.7 Sources of Information

Changes in precipitation patterns have significant impacts on our water resources. Developing a better understanding of precipitation and drought—regardless of whether it is for a national, state, or local level—will enable us to make better decisions about how to protect water resources. This knowledge will also help government agencies, private institutions, and stakeholders make more informed decisions about risk-based policies and actions to mitigate the dangers posed by floods and droughts. We may not be able to prevent droughts, but we can certainly help develop alternative water sources, introduce water-efficient planning approaches, and help establish effective and affordable redundancy in water systems.

It is difficult to predict future changes in regional precipitation patterns and to identify areas where drought is a priority, but there are digital tools that realistically generate forecasts across the United States with seasons and geographic area. For example, continuous, national-scale precipitation estimates are available through the Advanced Hydrologic Prediction Service (AHPS), a Web-based suite of forecast tools that are part of the National Weather Service's Climate, Water, and Weather Services. AHPS products are developed using sophisticated computer models and large amounts of data from multiple sources, including automated gauges, geostationary satellites, Doppler radars, weather observation stations, and the Advanced Weather Interactive Processing System. (See Figures 1.14, 1.15, and 1.16.)

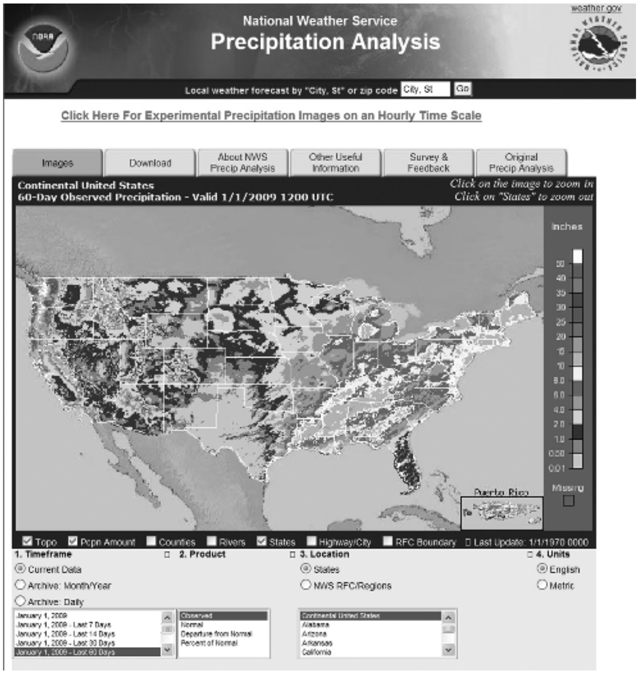


Figure 1.15 *This map shows the amount of precipitation in the United States for a 60-day period. Image courtesy National Weather Service.*

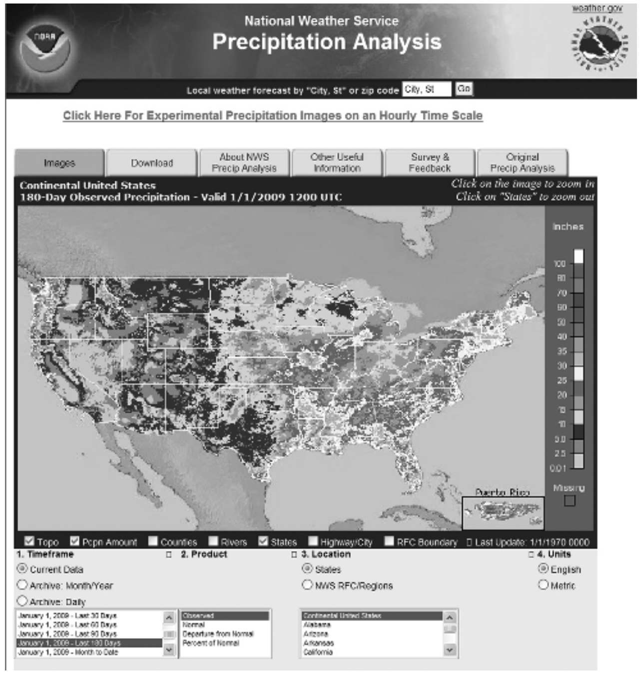


Figure 1.16 *This map shows the amount of precipitation in the United States for a 180-day period. Image courtesy National Weather Service.*

AHPS allows users to view a national composite map or to zoom into regions, states, and county-level areas over multiple time periods, including for the previous day and precipitation totals over the past 7, 14, 30, or 60 days. Archived data are available back to 2005 with monthly estimates of departure from normal and percent of normal precipitation. There are also links to historic data going back decades.

U.S. Snowfall Maps are Web-based products available from the National Climatic Data Center (NCDC). The data are extracted from a meteorological database from the U.S. Cooperative Observer Network (COOP). COOP consists of about 8,000 stations operated by state universities, state or federal agencies, and private organizations. The earliest data are from 1886, and they are organized by month. Data on snow are available from the National Operational Hydrologic Remote Sensing Center, which provides information on snow cover, snow depth, average snowfall, snowfall total the past 24 hours, and more. Information from radars, gauges, and satellites is combined to provide fairly accurate estimates of precipitation. According to the National Weather Service, the data set is one of the best sources of timely, high-resolution precipitation information available.