Water

and the Environment

AGI Environmental Awareness Series

"All things are water"

[Aristotle attributed this teaching to Thales of Miletus, the first known Greek philosopher, scientist, and mathematician. Thales lived from approximately 624-546 B.C.]

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AGI Environmental Awareness Series, 5

Water
and the Environment

Stephen J. Vandas
Thomas C. Winter
William A. Battaglin

With a Foreword by Philip E. LaMoreaux

American Geological Institute

in cooperation with

Bureau of Reclamation, National Park Service, U.S. Army Corps of Engineers,
USDA Forest Service, U.S. Geological Survey

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AGI Environmental Awareness Series

Groundwater Primer

Sustaining Our Soils and Society

Metal Mining and the Environment

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Water and the Environment

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Contents

Foreword

Within our Solar System, Earth is known as the water planet,

and water is an absolute requirement of life. On our planet, the most controlling resource is water — not oil or minerals — but water. Its distribution, quantity, availability, and quality are the controls for the development of agriculture, industry, rural, urban, and municipal use. The water-rich areas of the world are truly the richest places on Earth.

In the United States, approximately one third of the water diverted from streams or pumped from groundwater is used annually for the irrigation of crops. Almost as much water is diverted from streams for thermoelectric power generation. (However, approximately 61 percent of the water diverted for irrigation is used by crops, while only 2.5 percent of the water diverted for thermoelectric power is consumed at power plants.) It takes 15,000 gallons to build the average automobile and that does not include the water used in making the steel that goes into them. It takes about another 20 gallons of water to produce each gallon of gasoline. Flushing toilets and running water for appliances, such as air conditioners, dishwashers, and washing machines, usse billions of gallons more annually.

There would be little objection to many wasteful uses of water if fresh water of good quality were unlimited, however, the sad fact is that it is not. Only about 3 percent of the total water in the world is fresh water, and most of that is locked in ice caps and glaciers. Just a fraction of Earth's water — about 0.3 percent — is accessible fresh water, and approximately 98 percent of this amount is stored as groundwater. The rest is water in streams and lakes, stored in the soil, and in the atmosphere. All of the water on Earth, salty and fresh, is part of the hydrologic cycle that must be studied in great detail locally and worldwide to provide the data needed to properly develop and manage this most valuable resource.

Basic information is needed so that our water resources can be used wisely. We have learned that mismanagement of our water resources will bring on one water crisis after another. This Environmental Awareness Series publication is intended to give the general public, educators, and policy makers information related to water resources and supplies. The American Geological Institute produces this Series in cooperation with its 40 Member Societies and others to provide a non-technical geoscience framework considering environmental questions. *Water and the Environment* was prepared under the sponsorship of the AGI Environmental Geoscience Advisory Committee with the support of the AGI Foundation and the publishing partners listed on the inside front cover.

Philip E. LaMoreaux

Chair, AGI Environmental Geoscience Advisory Committee, 1993 – present

Preface

When we turn the faucet on we expect clean water to come out,

24 hours a day, seven days a week. Our expectations are so high that we have built large dams and associated reservoirs, pumped large quantities of groundwater from aquifers, and constructed intricate water distribution systems to transport water from areas where it is located to where we prefer to live. We monitor the quality of our water and spend billion of dollars to treat it.

In the United States, we have come to rely on good quality water and plenty of it; after all, water is essential to life. As a society, we depend upon water for many uses including irrigation, power generation, recreation, and transportation. But what happens when there is a drought, or even times when the supply of water is less than what we have become accustomed to? Or maybe there is too much water and it floods our home, farm, or city. What if the quality of our water is degraded and we can no longer use it for a desired purpose, or what if a dam is built across our favorite river or stream, changing its characteristics? How do natural or human-induced changes to water affect our lives as well as the plants and animals that also depend upon it for existence?

This publication provides information about water, its importance, where it comes from, water-related environmental concerns, water protection, polices and regulations, and our future needs for water. We greatly appreciate the contributions of many individuals; without their assistance this publication would not have been possible. Special thanks to Liz Ciganovich, John Evans, Robert Olstead, Edward Swibas, Elaine Simonson, and Margo VanAlstine for providing figures and photos and to John Flager, Lee Gerhard, Jack Hess, Phil LaMoreaux, Travis Hudson, Marcus Milling, Dennis Block, James Gauthier-Warinner, Steve Glasser, James Comiskey, Shannon Cunniff, Joseph Keely, John Keith, John Moore, Mark McCaffrey, Jim Washburne, M. Gordon (Reds) Wolman, Thomas La Point, and James McGonigle for reviewing the manuscript. Also, we gratefully acknowledge the editorial assistance of Julie Jackson, and the superb graphic design by Julie De Atley. Finally, we would like to acknowledge the American Geological Institute for the opportunity to produce this publication, and the U.S. Geological Survey, U.S. Forest Service, U.S. Bureau of Reclamation, U.S. Army Corp of Engineers, and National Park Service for their support of Water and the Environment. So pour a glass of water and read on.

Stephen J. Vandas
Thomas C. Winter
William A. Battaglin

November, 2002

Greer Spring, Mark Twain National Forest, Missouri

It helps to know... 1

Earth, the water planet,

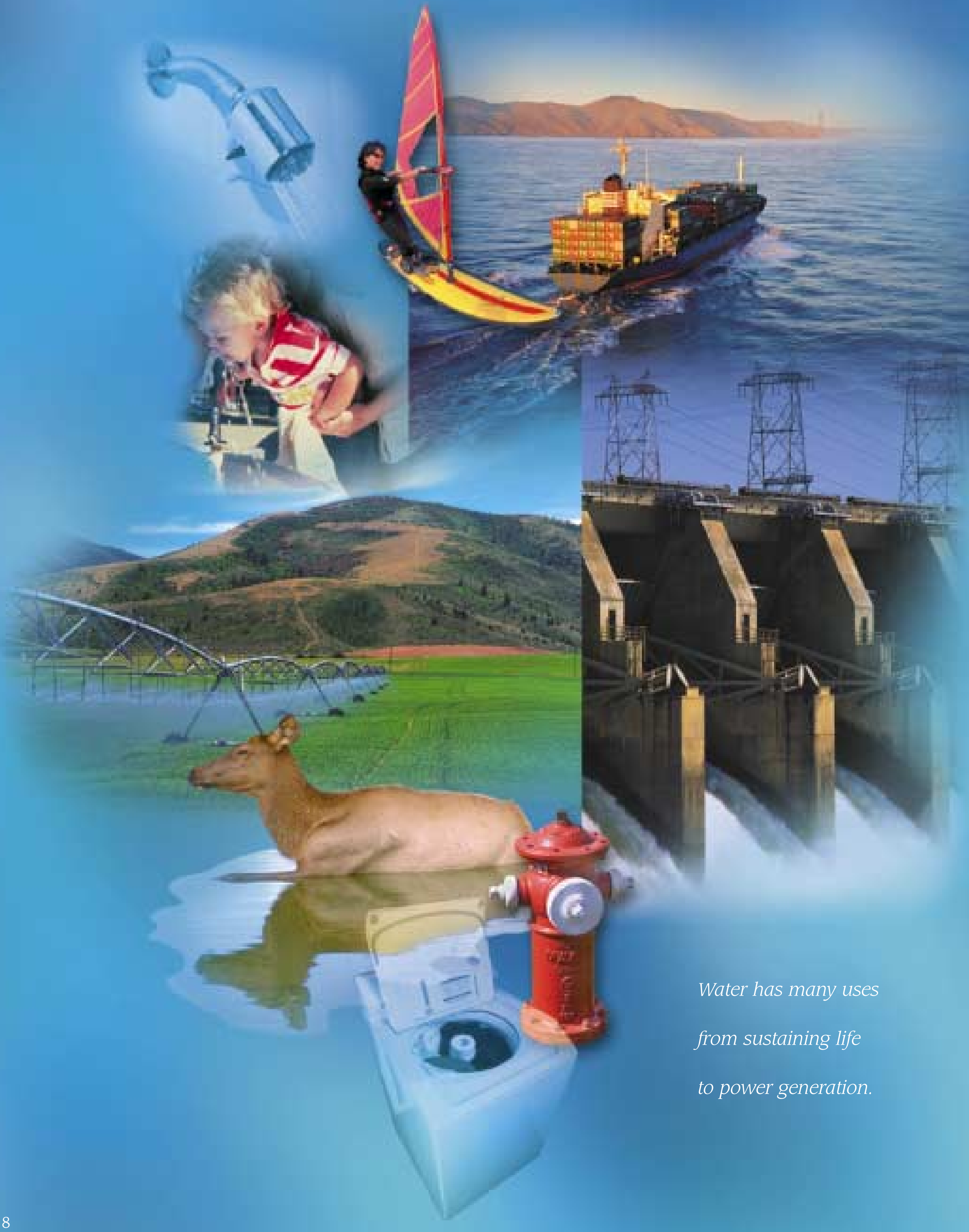
is the only one in our solar system presently characterized and shaped by abundant liquid water — a necessity for life. This vital resource makes up 60 percent of the human body. A person can live no more than 4 to 5 days without water, and we rely on it for drinking, cooking, bathing, washing clothes, growing food, recreation, industry, and mining, as well as generation of electric power. Like the air we breathe, water is essential to our daily life.

Water is a major factor in shaping our landscape. Through the processes of erosion and sediment transport, water forms many surface features such as valleys, flood plains, deltas, and beaches. Water also forms subsurface features such as caves. Natural wonders such as the Grand Canyon were, and are being, carved by water. Streams from upland areas carried much of the sand that is located on ocean beaches.

Water is a renewable resource. However, it is not always available when or where it is needed, and it may not be of suitable quality for intended uses. Although we commonly take for granted that clean and abundant water is as close as the nearest faucet, water resources

Fig. 1

E V E R Y D A Y   W A T E R   U S E



Water has many uses from sustaining life to power generation.

can be depleted or contaminated with pollutants. Having too much water (floods) or not having enough (droughts) may have serious consequences for people, wildlife, and their habitats. Providing sufficient quantities of good quality water is a major factor in creating the life style we enjoy in the United States (Fig. 1).

The objective of this book is to provide readers with information about water in the environment and the associated environmental concerns. Knowledge can help us — as individuals and as a society — protect and manage our precious water resources wisely.

Environmental Concerns

Environmental concerns associated with water result from natural events and human activities. Our towns and cities were developed near sources of drinking water and along rivers for transportation. Past policies favored "reclaiming" lands for agriculture and the consumption of water without much concern for the environment. These past decisions are reflected in the existing conditions of our water resources. Natural events, such as floods, droughts (Fig. 2), and changes to water quality, may cause problems for humans. Many human water uses require changes to the natural flow of water through the construction of dams, canals, and by the pumping of groundwater. These changes bring benefits to people, but they also affect natural environments. Municipal, industrial, or agricultural uses of water may degrade water quality and cause environmental problems.

If anything happens to disrupt our water supply or degrade the quality of our water, we become concerned. Changes to the water regime can impact human habitation, agriculture, sensitive ecosystems, economic development, and land-use decisions. Can we balance environmental

Fig. 2. Having too much water (floods) or not having enough water (droughts) may have serious consequences. Droughts impact vegetation, increasing the possiblity of fire and erosion.

concerns and societal needs? These are some of the questions to be answered:

- Are we running out of good quality fresh water and is this water available when and where it is needed?
- Are critical habitats and other natural ecosystems protected from a change in the presence, abundance, or quality of water?
- Can water users withstand a drought?
- What are the environmental benefits and potential risks associated with floods?
- Who can use water? Is water physically and legally available for a particular use?

Why Water Is Important

Water is essential to life. It is part of the physiological process of nutrition and waste removal from cells of all living things. It is one of the controlling factors for biodiversity and the distribution of Earth's varied ecosystems, communities of animals, plants, and bacteria and their interrelated physical and chemical environments. In terrestrial ecosystems, organisms have adapted to large variations in water availability. Water use by organisms in desert ecosystems is vastly different from those in forest ecosystems. For example, some seeds lie dormant for years in arid climates waiting to be awakened by a rare precipitation event. In contrast, a large oak tree in a temperate climate returns about 4,000 gallons of water a year to the atmosphere. Through the process of

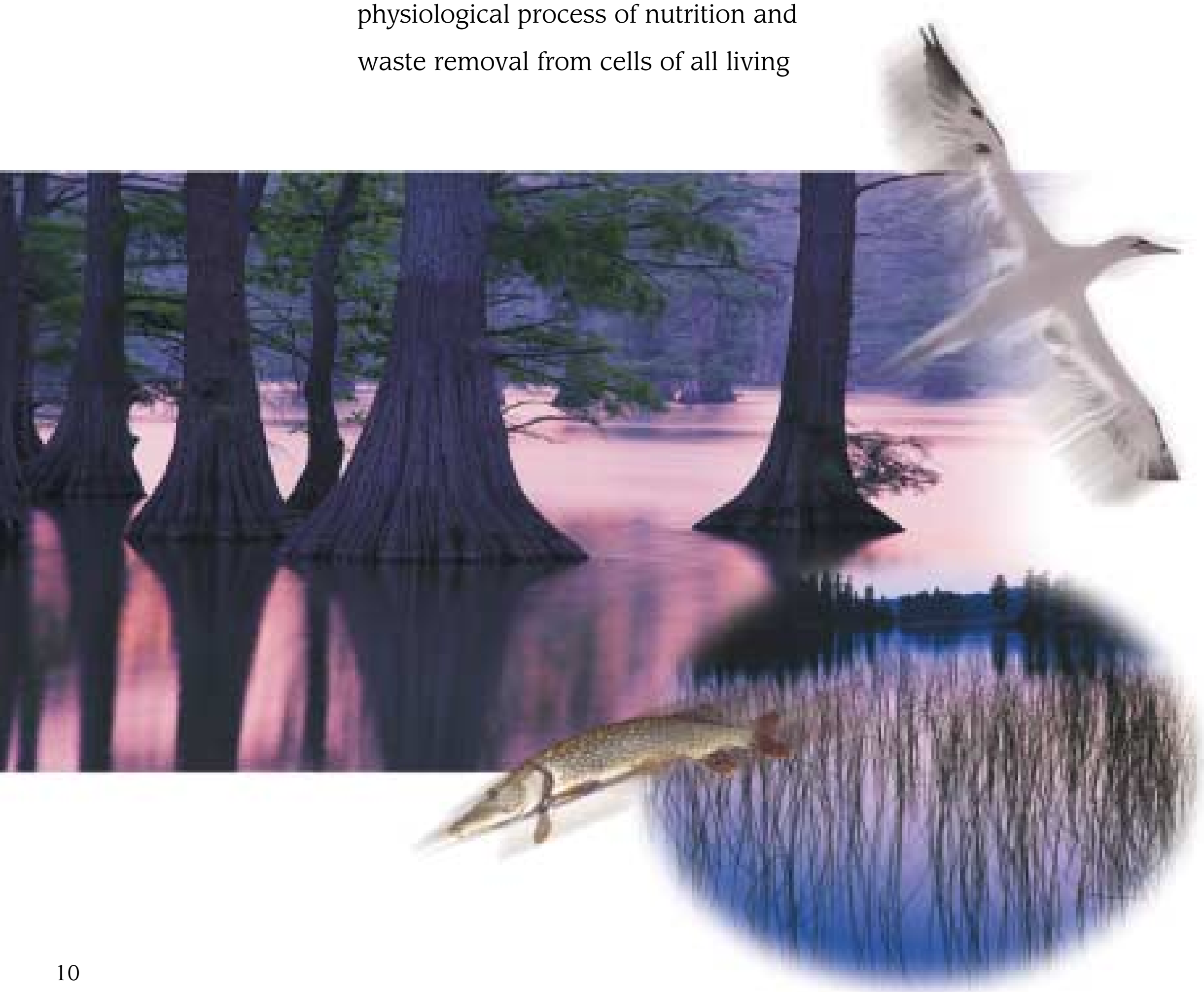


Fig. 3. Wetlands provide habitats to a great and varied array of life.

Fig. 4. Water plays a major role in shaping the land surface of the Earth.

transpiration, plants give off moisture largely through their leaves.

Aquatic ecosystems, such as wetlands, streams, and lakes, are especially sensitive to changes in water quality and quantity. These ecosystems receive sediment, nutrients, and toxic substances that are produced or used within their watershed — the land area that drains water to a stream, river, lake or ocean. As a result, an aquatic ecosystem is indicative of the conditions of the terrestrial habitat in its watershed.

Wetland ecosystems provide habitat to a great variety of birds, plants and animals. These transitional areas between dry and wet habitats help reduce floods and abate water pollution. They also support many recreational activities and commercial fisheries and provide a number of other important functions (Fig. 3). Nearly every activity that occurs on land ultimately affects groundwaters or surface waters.

Water plays a major role in shaping the land surface of the Earth. Canyons, flood plains, terraces, and watersheds are formed by the action of water flowing across the land surface (Fig. 4). As a result, watersheds have many different shapes and sizes (Fig. 5). Some contain parts of mountains and hills, and others are nearly flat.

Where Water Is Located

Every landmass on the planet contains water. It covers three-fourths of the surface of the Earth in oceans, rivers, streams, lakes, ponds, estuaries, wetlands, springs, ice caps and glaciers. It also occurs

Fig. 5. The line of topographic high points separating two drainage basins marks the watershed divide.

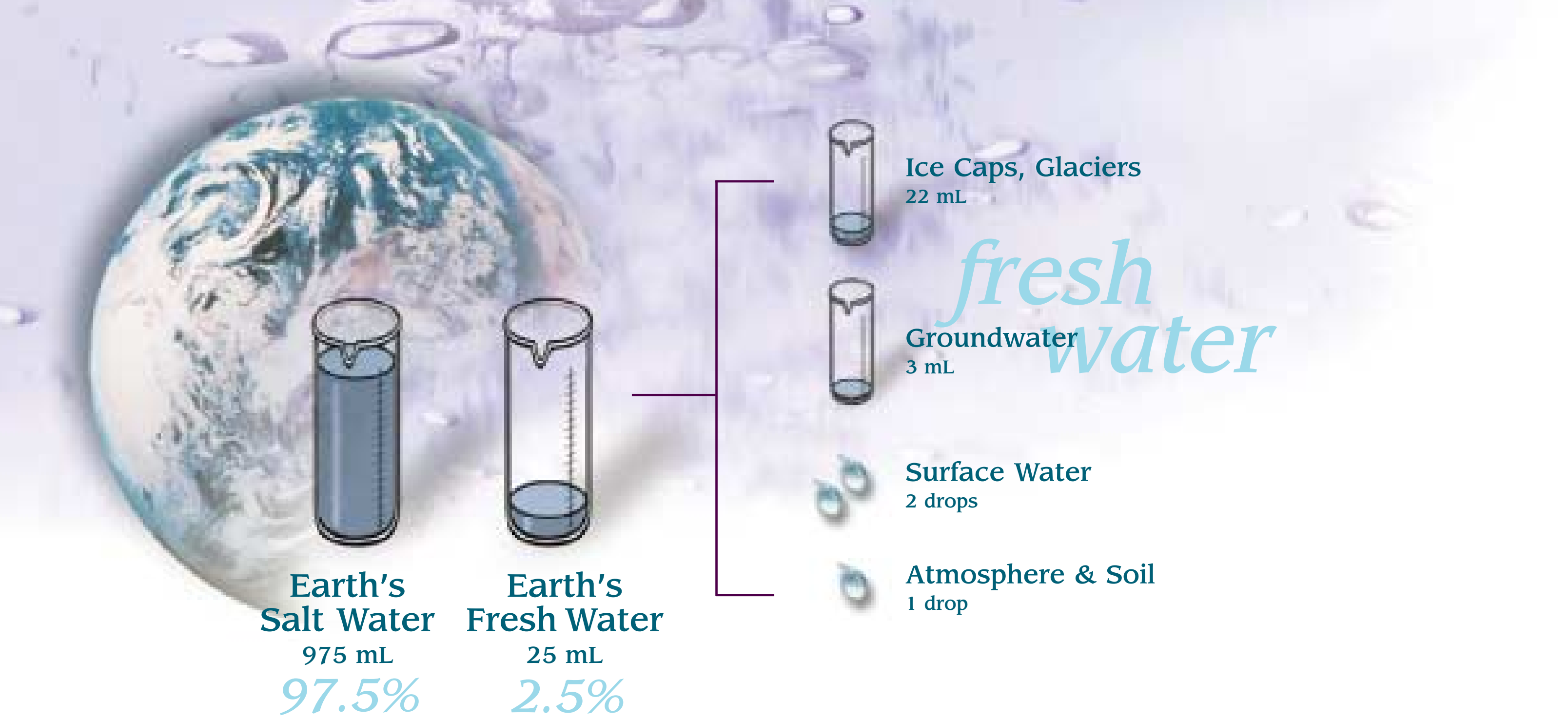


Fig. 6. Approximately 88 percent of the Earth's fresh water is frozen in polar ice caps and glaciers, making it unavailable for use. Of the remaining fresh water supply, most is groundwater.

underground and in the atmosphere. Most of the water on Earth, (approximately 97.5 percent) is salt water located mostly in the oceans, and only 2.5 percent is fresh water (Fig. 6). The fresh water available for our water needs is less than 1 percent of Earth's supply. The problem is that fresh water is not evenly distributed on Earth.

Some desert areas, like Kuwait, have very limited fresh water resources, whereas rain forest areas, such as in Papua New Guinea, can have as much as 30 feet of rainfall in a year! Approximately 88 percent of the Earth's fresh water is frozen in polar ice caps and glaciers, making it unavailable for use. Of the remaining fresh water supply, most is groundwater.

The uneven distribution of water resources has been an important control on human habitation and development throughout history. Societies have struggled to control water resources, human migrations have been made to obtain water resources, and litigation is commonly used to resolve conflicting water needs.

About Water Use

Water either is used in the stream (instream use) or it may be diverted from a stream or reservoir or taken from a well, then transferred to a place of use (offstream use).

Examples of instream water use include recreation, hydroelectric power generation, fisheries, ecosystem and channel maintenance, and transportation. Water-use estimates for these categories are difficult to obtain because water is used numerous times as it flows down a river. For example, in 1995, (the most recent year water-use statistics were calculated) water use for hydroelectric power generation in the United States was approximately 3 times the total accumulated flow to the oceans from all streams in the conterminous United States. Reuse of the water accounts for this large total. Water flowing from an upstream hydroelectric power plant is used by the power plants downstream, and because very little water is consumed by instream uses, near-continual water reuse is possible.

Domestic, commercial, agricultural, industrial, mining, and thermoelectric power generation are examples of offstream uses. Only a portion of the water removed for an offstream use is actually consumed. The remaining water returns to the stream or the aquifer and can be used again. For example, approximately 39 percent of the water withdrawn for agricultural use and 85-90 percent for industrial and municipal use is returned to surface water or groundwater.

In 1995, approximately 78 percent of water used in the United States was supplied by surface water from streams and lakes, and 22 percent was supplied by wells from groundwater sources. The quantity of water diverted from streams and pumped from wells in the United States was estimated to be 402 billion gallons per day in 1995. This amount is more than 1,400 gallons per person per day or almost 6,000 gallons per day for a family of four. More than you thought? It is the many industrial and agricultural water uses that our society and economy depends on that makes this per capita amount so high.

How Water Resources are Managed

The need for water resources, combined with their environmental importance and variable availability, necessitates that we manage them wisely. Historically, management focused only on supplying water to areas of need. In the United States, fresh water supplies were developed by diverting streams, building water supply reservoirs, and drilling wells into aquifers. For example, the populous Los Angeles area supplies its water needs with a complex system of reservoirs, aqueducts, and pipelines that transfer water from locations hundreds of miles away. Diversion is a common practice but it has proven to be only part of what is needed for sound water management.

Water transfers can affect ecosystems and decrease the amount (and in some cases the quality) of water available to downstream users. Such transfers must be accomplished according to legal rights to these resources. In most cases, state law governs water rights within individual states, but there are large variations in water laws between states. Agreements can be made between states allocating stream flow between them but constant changes in precipitation, and historic land and water use patterns, continue to test these agreements. Few states have agreements on groundwater usage. Situations that evolve into litigation are a clear sign that better water management is needed.

Effective management of water resources is a complex task that requires knowing where water is located, where it is needed, its physical and legal availability, its quality, the effects of its use on ecosystems, the risk of contamination, and the cost of meeting the demand. Modern management of surface water resources addresses concerns throughout the watershed (Fig. 7). By assessing land and water-use practices within a watershed, water managers are able to determine the human activities and natural processes that affect both the quantity and quality of water within it. Activities in one part of a watershed can influence the water resources in other parts of the watershed.

Groundwater resources do not necessarily correspond to surface watershed boundaries. However, surface waters and groundwater generally are connected. Besides recently fallen precipitation, most of the water we see flowing in streams day to day is water that is returning to the surface from groundwater and not just runoff from the land surface. Thus, land and water-use activities, such as withdrawing or contaminating groundwater, can affect either resource in more than one watershed. In some areas, aquifers are being managed as water-resource units, much like watersheds are for surface waters.

All sound water management programs strive to find a balance between human water needs and the desire to maintain healthy environments and ecosystems. As population grows, demands increase for water resources. In some areas water demand exceeds water supply. This situation is a growing concern in the western United States where important water sources such as the High Plains Aquifer have been depleted over large areas by irrigation. Because of over use, conservation of our water resources is becoming an increasing part of sound water management and not just a temporary response in times of drought and low supply.

Fig. 7

National Watershed Characterization Map

The Index of Watershed Indicators characterizes the condition and vulnerability of aquatic systems in each of the watersheds in the United States.

Water quality	Vulnerability	
Better	Low	(310) watersheds
Better	High	(29)
Less serious problems	Low	(736)
Less serious problems	High	(58)
More serious problems	Low	(496)
More serious problems	High	(38)
Data sufficiency threshold not met		(595)

U.S. Environmental Protection Agency watershed information network

www.epa.gov/iwi/1999sept/catalog.html

Source: Natural Resources Conservation Service

W A T E R S H E D S

To find your watershed and what's happening in it visit

www.epa.gov/surf

We each live in a watershed — the land area that drains water to a stream, river, lake, or ocean. A watershed is a land surface feature that can be identified by tracing a line on a map along the highest elevations between two areas. These high points form a watershed boundary, similar to the edge of a bowl. Large watersheds, such as that of the Mississippi River, contain thousands of smaller ones.

Many different activities and events can affect a watershed. Human activities such as construction, farming, logging, and the application and disposal of many garden and household chemicals can affect the quantity and quality of water flowing from a watershed. The natural characteristics of a watershed (soil type, geology, vegetation, slope, and aspect) also control the quantity and quality of water that flows from them. Activities in one part of the watershed can influence the water resources in other parts of the watershed. By assessing land and water-use practices within a watershed, water managers are able to determine the human activities and the natural processes that affect both the quantity and quality of water within it.

"When the well's dry,
we know the worth of water"

Benjamin Franklin, 1706-1790
Poor Richard's Almanac
January, 1746

Water Basics 2

Natural events and the environment

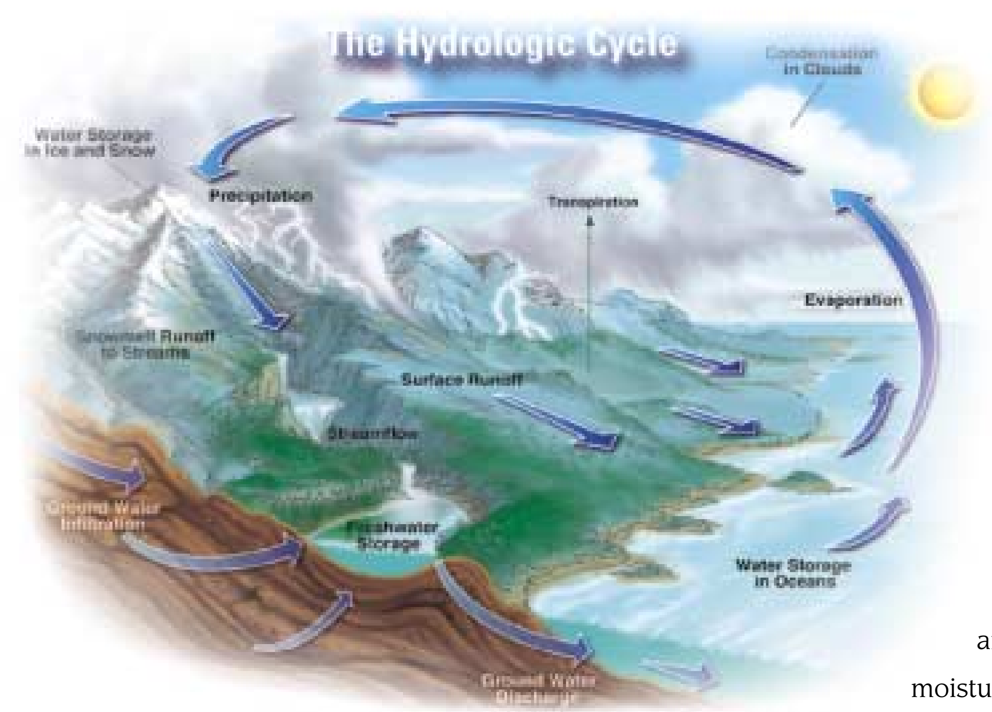
affect the quantity and quality of water, which is in constant motion above, on, and below the Earth's surface. This chapter provides information on the fundamentals of the water cycle (Fig. 8) and the impacts natural processes have on water quality and quantity.

The Water Cycle

The constant movement of water from oceans, to atmosphere, to land surface, and back to the oceans again is known as the water — or hydrologic — cycle. To understand water availability and quality, this cycle must be viewed at several spatial and temporal scales. Precipitation events that occur over a small area can cause local flooding, but have minimal affect on the larger watershed. Water can infiltrate rapidly into sandy soils, or run off rapidly from bare rock.

Precipitation is the source of fresh water virtually everywhere on Earth, but the location, timing, and amount of precipitation are highly variable. Evaporation and transpiration return water to the atmosphere and also are highly variable in space and time. Water that falls to the Earth's surface follows one of several paths, it evaporates, infiltrates into the soil, flows along the soil surface into streams or other water bodies, or recharges groundwater. Precipitation in the form of snow eventually (after melting) evaporates, infiltrates into the soil, flows into water bodies, or recharges groundwater. While in its solid state, snow can lose water vapor to the atmosphere through sublimation. The portion of the precipitation that infiltrates into soils and is not captured by plant roots percolates into (recharges) the groundwater system. Because of large variations in the distribution of precipitation, evaporation, and transpiration, much of the water that falls on the Earth's surface never reaches the ocean as stream or groundwater flow. As water moves through the hydrologic cycle, it comes in contact with natural and human-made materials that change its quality.

Fig. 8. The constant movement of water from oceans, to atmosphere, to land surface, and back to the oceans again is known as the water (or hydrologic) cycle.



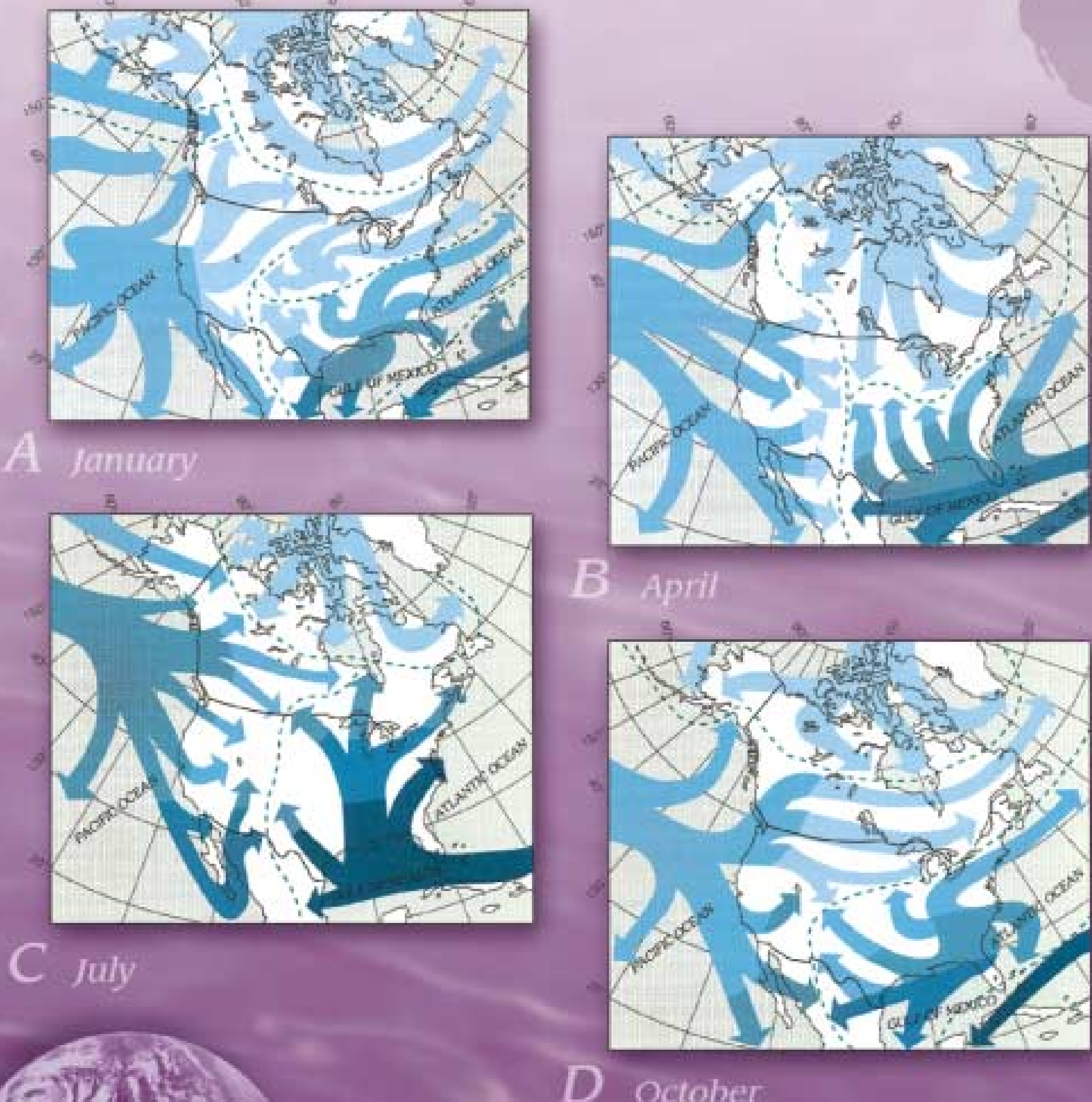
Water in the Atmosphere

There is a constant exchange of water between the Earth and the atmosphere. This exchange occurs largely because of water evaporation from the Earth's surface caused by the Sun's heat and the pull of gravity that makes precipitation fall from the atmosphere. Most of the water in the atmosphere is derived from evaporation of ocean water. However, sublimation from polar ice caps and glaciers; evaporation from land surfaces, lakes, and streams; and transpiration by plants are also sources of water to the atmosphere.

The atmosphere is a temporary reservoir and delivery system for water. Evaporation from the oceans is transported to the continents in the form of water vapor in large air masses controlled by the general circulation patterns of the atmosphere. This water vapor is then returned to the Earth as precipitation (i.e. rain, fog, snow, sleet, or hail). Warm air has a greater capacity for retaining water vapor than does cold air; thus, air masses that flow over warm tropical parts of the oceans evaporate and transport greater amounts of moisture than air masses that flow over cold parts of the oceans (Fig. 9).

Fig. 9

MOISTURE-DELIVERY PATHWAYS



Greatest Average Yearly Precipitation

460 inches during a 32-year period
Mt. Waialeale, Kauai, Hawaii

Lowest Average Yearly Precipitation

.03 inches during a 59-year period
Arica, Chile

Average lower atmosphere (from land surface to 6 miles above sea level) precipitable water vapor; in inches

- 0 to 0.4
- 0.4 to 0.8
- 0.8 to 1.2
- 1.2 to 1.6
- 1.6 to 2.0
- Large-scale, moisture-delivery pathway
- Average boundary of moisture-source influence

Large-scale pathways for moisture delivery change with the season, represented by midseason months.

Fig. 10. Stream gages are used to provide a continuous record of discharge. The stage of a stream is measured continuously and discharge is determined from a stage-discharge relationship at a location of known cross-sectional area.

The primary pathway for these moist large air masses over the United States are determined by the direction of winds at different times of the year. At any given time, the primary pathways over the conterminous United States originate from four different regions, the Pacific Ocean, the Atlantic Ocean, Gulf of Mexico, and the Arctic Ocean. Regionally, the dominant air masses and moisture delivery pathways shift as the season's progress. July is the month with the greatest average precipitation in the United States.

Surface Water

Surface waters include streams, rivers, lakes, reservoirs, and wetlands. The term stream is used here to represent all flowing surface water, from brooks to large rivers. Surface waters and their associated ecosystems provide habitat to many plant and animal species. Because surface waters are on the land surface, they are easily developed for use and provide about 78 percent of the United State's total offstream water use.

Stream flow varies in response to climatic factors and human activities. Some streams have a small annual discharge for the large size of their drainage area, such as the Colorado River, and some have a greater demand for their water than they can supply without reservoir storage. Because of their importance as a water source, flow rates for selected streams are continuously monitored by stream gages (Fig. 10). Discharge is the amount of water moving down a stream per unit of time. Discharge is the product of the average velocity of flowing water and the cross-sectional area at a selected site on a stream. Average velocity is determined by measuring flowing water at many locations and depths across the selected measurement site. The cross-sectional area and the average velocity at each of these measured locations are multiplied to calculate discharge at that point. The discharges for all locations are added to obtain the total discharge of the stream.

Streams are a dynamic part of the environment and are good indicators of what is happening in a watershed. Stream flow in a watershed includes all water contributed from headwater areas, stream banks, channels, flood plains, terraces, connected lakes, ponds, wetlands, and groundwater (Fig. 11). Because watersheds are complex systems, each tends to respond differently to natural or human activities.

The physical characteristics of a watershed (land use, soil type, geology, vegetation, slope, and aspect) and climate control the quantity and quality of water that flows from them. Changes to any of these characteristics can affect water quantity and quality. For example, the removal of vegetation by natural causes such as fire can change the water storage and infiltration characteristics of a watershed. Because burned areas contain

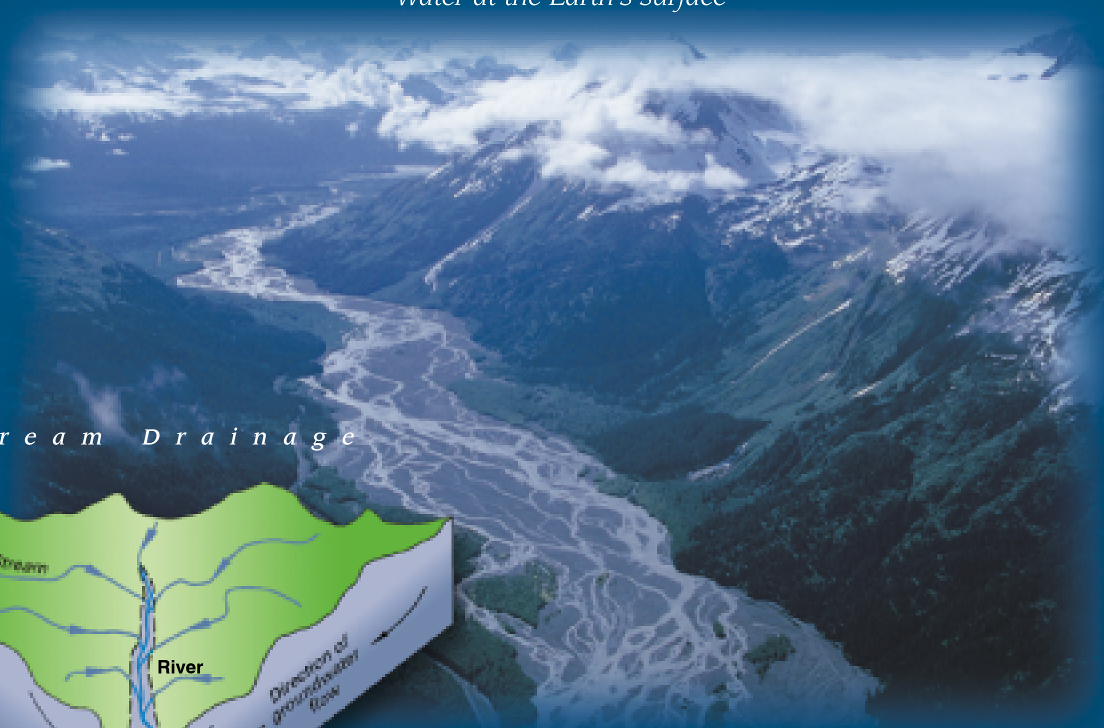
To monitor stream flow, go to

http://water.usgs.gov/realtime.html

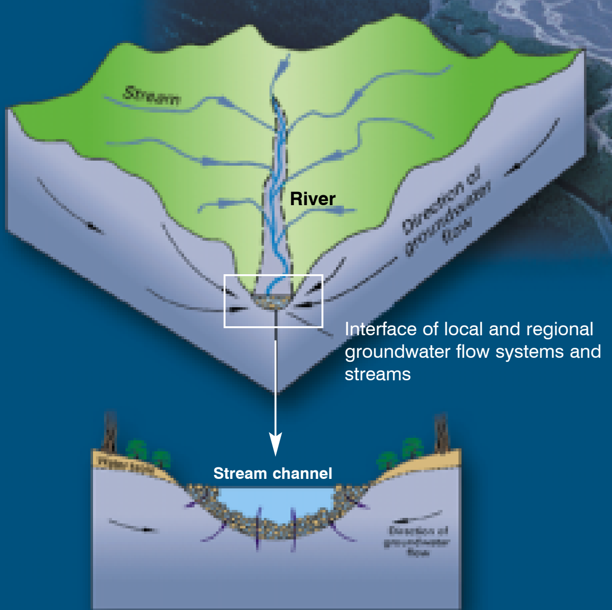
Fig. 11

S U R F A C E W A T E R

Water at the Earth's surface

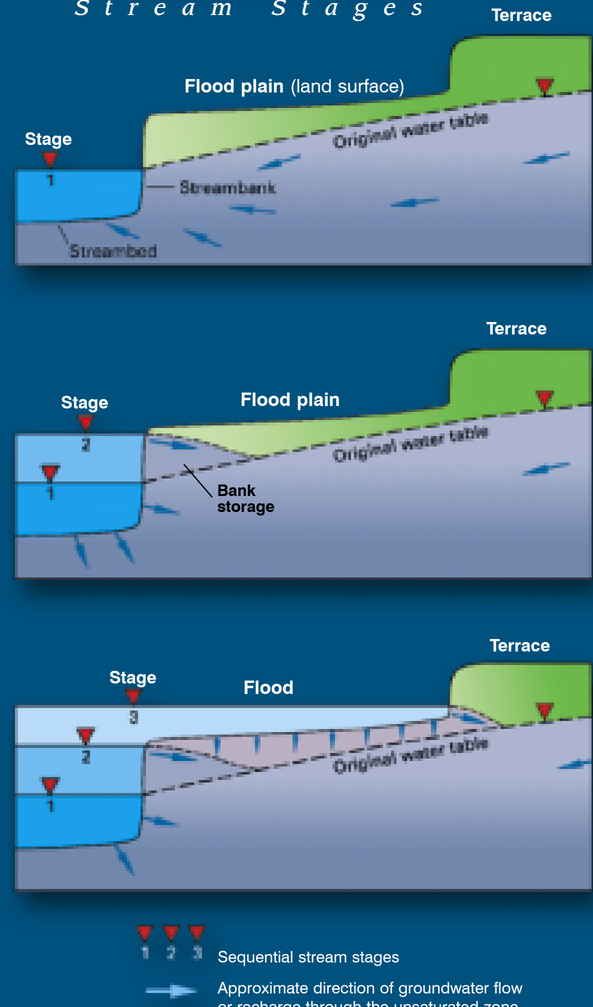


Stream Drainage



A **drainage basin** is the land area drained by a stream. The term **watershed** commonly refers to the whole drainage basin. As streams flow, the water near the **stream bed** commonly moves into the bed for short distances and then returns to the stream a short time later. When a stream rises, some of the surface water may move into the **stream bank**. This water, which is temporarily stored in the groundwater system, is referred to as **bank storage**. Eventually, most of this water returns to the stream. **Stage** is the elevation of the water surface of a stream.

Stream Stages



less vegetation to slow runoff and hold soil in place, the rate and quantity of water that runs off the surface to streams increases, and so does erosion. During heavy rains, the increased runoff and erosion can result in increased chance of flooding, mudslides, and impaired water quality.

Water seeks the path of least resistance. As water flows through a watershed, it picks up and deposits sediments, soil and rock particles, creating stream corridors. These corridors, which consist of stream channels, banks, and flood plains, are affected by natural and human activities that occur within watersheds. The physical processes of sediment transport and deposition are critical to the formation of the stream corridor.

The transport of sediment within and from a watershed is one of the major processes that help shape the surface of the Earth. Sediment particles are classified by size, with smallest being clay and the largest being boulders. Smaller particles are usually carried in suspension while the

Fig. 12. Lack of flow in the Rio Grande River below Elephant Butte Dam has resulted in sediment accumulation on the stream bed, and vegetation has encroached onto the channel.

Estimated use of

GROUNDWATER as DRINKING WATER

Fig. 13. Groundwater is an important source of drinking water for every state. The numbers are the estimated percentage of the population using groundwater as drinking water in each state in 1995. States with more than 50% are highlighted.

larger materials are moved along the channel bottom by rolling, sliding, or bouncing.

One of the major activities of a stream is to transport materials within and out of a watershed. Sediment transport rates of a stream are a function of stream power, which is a measure of the combined effect of the slope at the streambed (higher slopes generate higher stream velocities) and discharge (volume of water). Where stream power is reduced, a stream's sediment carrying power is also reduced, and a portion of the sediment is deposited. For example, sediment is deposited following the peak, or highest, discharge of a flood. Sediments can be deposited in channels for short periods of time and moved again or remain stationary as in alluvial fans or in large reservoirs. Stream channels and their flood plains are constantly adjusting to changing water quantities and sediment supplied by their watersheds. Long-term changes in runoff and sediment load may lead to long-term changes in channel characteristics (Fig.12).

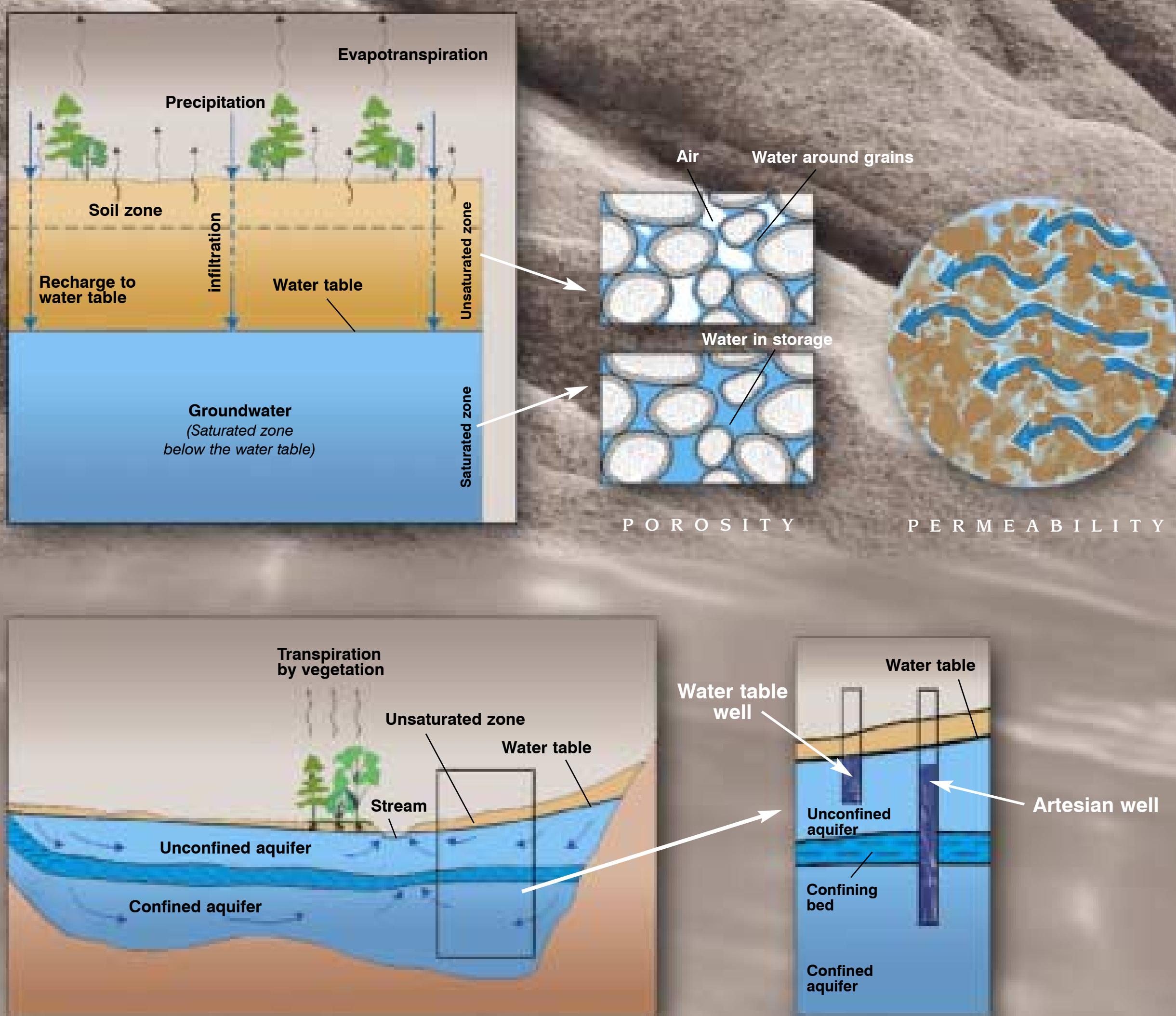
Groundwater

Groundwater occurs almost everywhere beneath the land surface. Although surface water is currently the most commonly used water source, groundwater provides about 50 percent of the drinking water in the United States (Fig. 13). Because groundwater is our principal reserve of fresh water, it represents much of the Nation's potential future water supply. Much groundwater is used for irrigation. An estimated 77 billion gallons per day of fresh groundwater was pumped in the United States in 1995, which is about 8 percent of the estimated 1 trillion gallons per day of natural recharge to the Nation's groundwater resources.

Shallow domestic wells provide much of the rural population with their drinking

Fig. 14

GROUNDWATER



Groundwater moves from areas of recharge to areas of discharge in groundwater flow systems. Water that infiltrates the land surface first enters the **soil zone**, the upper part of the **unsaturated zone**. Most of this water is transpired by plants and moves back into the atmosphere, but some continues to move downward to recharge groundwater.

The upper surface of the **saturated zone** is the **water table**. Water moving through the unsaturated zone that reaches the water table is called **groundwater recharge**. **Groundwater discharges** to streams, lakes, wetlands, coastal areas, or when groundwater is pumped from wells.

Porosity is a measure of pore spaces between the grains of a rock or of cracks in it that can fill with fluid. The quantity of water a given type of rock will hold depends on its porosity. In the unsaturated zone, the pores are filled with water and air. In the saturated zone, the pores are filled only with water.

Permeability is a measure of how easily water moves through pore spaces. If water can move through the pore spaces relatively easily, the aquifer is said to be **permeable**. If not, the aquifer is said to be poorly permeable. A confining bed is poorly permeable.

An aquifer is a geologic formation that is permeable enough to allow groundwater to be withdrawn by pumping wells or flow to a spring. An **unconfined aquifer** does not have a poorly permeable rock unit above it. A **confined aquifer** is one that is overlain by a poorly permeable geologic formation.

The water level in shallow wells completed in an unconfined aquifer will rise to the level of the water table. Hence, such wells are called **water-table wells**. If the water level in wells completed in a confined aquifer rises to a level above the top of the confined aquifer, such wells are called **artesian wells**.

water. In certain urban areas, deeper municipal wells supply water to many customers from a central location. Locally, the availability of groundwater varies greatly, and only a part of the groundwater in storage underground is recoverable by pumping wells. The location and movement of the Nation's fresh groundwater resources are still being evaluated.

The availability of groundwater as a water source depends largely upon surface and subsurface geology as well as climate. The porosity and permeability of a geologic formation control its ability to hold and transmit water (Fig. 14). Porosity is measured as a ratio of voids to the total volume of rock material and is usually described as a percentage. Unconsolidated sands and gravels make some of the most productive aquifers because they have many internal voids (porosity) that are well-connected. If the grains of sand or gravel that make up an aquifer are all about the same size, the water-filled voids between the rock grains account for a larger portion of the volume of the aquifer than if the grains are of varied size. Therefore, an aquifer with uniform grain size usually has a higher porosity, than one with grains of varied size.

Permeability is a measure of the ability of fluids to move through geologic formations. Geologic formations with a high permeability can be the best aquifers. For water to move through an aquifer, the internal voids and fractures must be connected. Geologic formations can have significant porosity and not be good aquifers if the voids are not connected, or if they are very small.

Some sedimentary rocks, such as sandstone and limestone, can also be good aquifers. Permeability in limestone is commonly provided by fractures and by openings caused by water dissolving the rock (Fig. 15). In "karst" areas, landscapes are characterized by sinkholes, caves, and underground drainage. Karst aquifers, such as the Edwards Aquifer in Texas, are discussed in book 4 in this Series, *Living with Karst — A Fragile Foundation* (See Veni, G., p. 60). Most igneous rocks, such as granite, and metamorphic rocks, such as quartzite, have very low porosity and make poor aquifers unless they have interconnected fractures.

Water moves through an aquifer from areas of recharge to areas of discharge. Recharge of groundwater occurs from precipitation that infiltrates soils or that seeps from the bottom of surface-water bodies such as lakes and streams. Discharge areas include streams, lakes, wetlands, coastal areas, springs, or where the

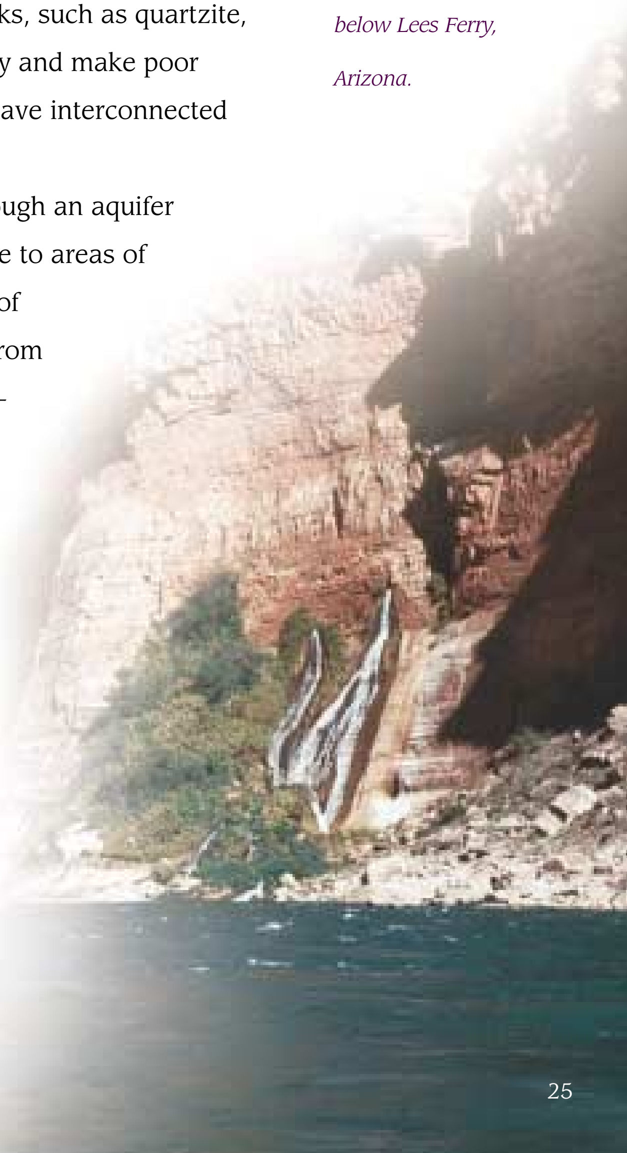


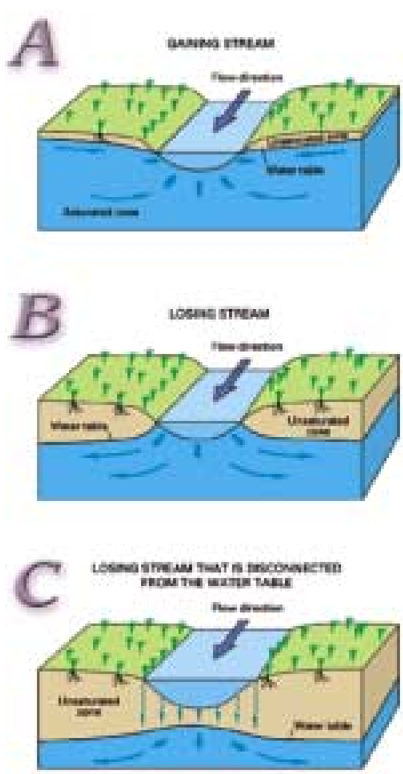
Fig. 15. Groundwater discharges from the Redwall Limestone into the Colorado River, at Vasey's Paradise, 31.7 miles below Lees Ferry, Arizona.

groundwater flow is intercepted by wells. Water between the recharge and discharge areas is said to be in storage. Before wells are developed in an aquifer, the groundwater system is in long-term equilibrium, with recharge equal to discharge. Because the undeveloped system is in equilibrium, the quantity of water in storage is fairly constant, changing in response to annual or long-term climatic variations.

Surface Water and Groundwater Relations

Surface water and groundwater systems are connected in most landscapes. Streams interact with groundwater in three basic ways: streams gain water from inflow of groundwater through the streambed, streams lose water by outflow through the streambed, or they do both depending upon the location along the stream. It is the groundwater contribution that keeps streams flowing between precipitation events or after snowmelt. For a stream to gain water, the elevation of the water table in the vicinity of the stream must be higher than the stream-water surface. For a stream to lose water to groundwater, the water table must be below the elevation of the stream-water surface in the vicinity of the stream (Fig. 16). If the water table has large variations during the year, a stream segment could receive water from groundwater for a portion of the year and lose water to groundwater at other times. Surface-water bodies such as lakes and wetlands can receive groundwater inflow, recharge groundwater, or do both.

The movement of water between groundwater and surface-water systems leads to the mixing of their water qualities. High quantities of nutrients or other dissolved chemicals in surface water can be transferred to the connected groundwater system.



streams

Fig. 16. Streams and groundwater interact. Gaining streams (A) receive water from the groundwater system, whereas losing streams (B) lose water to the groundwater system. Some losing streams (C) are separated from the saturated groundwater system by an unsaturated zone.

Floods

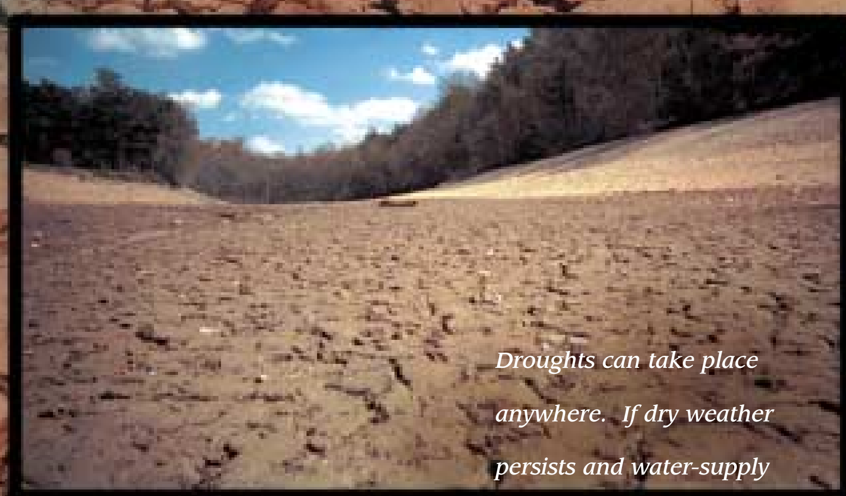
Floods occur when the volume of water in a stream or lake exceeds the amount that can be contained within its normal banks (Fig. 17). The size or magnitude of a flood is described in terms of its recurrence interval, which is based on probability. By studying the discharge records of a stream over a long period of time, it is possible to estimate how often a flood of a certain magnitude might occur. For example, a 100-year flood has

Fig. 17

F L O O D S & D R O U G H T S

Typical seasons during which the largest floods of the year occur in different parts of the United States.

By studying the discharge records of a stream over a long period of time, it is possible to estimate how often a flood of a certain magnitude might occur.



Droughts can take place anywhere. If dry weather persists and water-supply problems develop, the dry period can become a drought.

a one percent chance of occurring during any given year. As more information becomes available concerning the flow regime of a stream, and changes occur in the contributing watershed, the calculated recurrence interval of a given flood magnitude can change.

The primary physical feature used by a stream to dissipate floods is its flood plain (Fig. 11). When water rises above the banks of a stream, it flows onto its flood plain, spreads out, and reduces the force of the flood. Flood plains may not have water on them every year, and parts of some flood plains may not have water on them for hundreds of years. Because many flood plains are infrequently flooded, relatively flat, and close to surface water bodies, they are prime locations for agricultural, commercial, industrial, and residential development. Human developments on flood plains are a major cause of loss of life and property damage from floods. Flood plains may be classified according to frequency of flooding, such as 10, 50, 100, and 500-year recurrence intervals.

Floods are natural events that can occur in any watershed. Floods can occur at anytime, but they are most likely to occur when soil moisture is at a maximum, snowmelt in the watershed is rapid, and/or substantial precipitation results from storms (Fig. 17).

Droughts

Droughts are also naturally recurring events that are caused by periods of little or no precipitation (Fig. 17). The amount of precipitation at a particular place or at a particular time varies from year to year. When precipitation is less than normal for several weeks, months, or years, water levels decline in lakes, reservoirs, and wells, and stream flow decreases. If dry weather persists and water-supply problems develop, the dry period can become a drought. A drought ends when the water deficit ends, usually after significant precipitation.

Droughts can occur anywhere; however, some areas are more likely to have droughts than others. In humid or wet regions of the United States, a reduction in precipitation for only a few weeks can be reflected in a decrease in soil moisture and declining stream flow. Water users who rely upon streams in such areas have shortages as soon as the stream flow declines. In arid areas, water users rely more on water stored in reservoirs and in aquifers. While these users do have some protection against the impacts of a short-term drought, they can still be severely affected by long-term droughts.

Natural Water Quality

The fundamental controls on natural water quality, water not impacted by the activities of humans, are the types of organic and geologic materials it contacts and the duration of this contact. As water moves

PPM

Parts per million (PPM) is the number of "parts" by weight of a substance per million parts of water. This unit is commonly used to represent pollutant concentrations.

through organic materials like leaves and roots, it reacts with them and with the living things associated with them, such as soil bacteria and algae. As water moves through geologic materials, it dissolves them.

The processes of rock weathering on the Earth's surface are strongly influenced by climatic factors such as temperature and the quantity and distribution of precipitation. Climatic patterns and environmental conditions affect plant communities and soil types, causing the waters that flow from these areas to have a certain chemical signature. The influence of climate and geology on water quality is indicated by the quantity and kinds of dissolved materials contributed from an area and the amount of sediment carried by streams.

Natural water can vary greatly in the dissolved materials that it carries. Natural springs that flow through salt-bearing geologic formations can have as much as 200,000 parts per million (PPM) of dissolved materials (Fig. 18). Some streams that flow over rocks with low solubility can have as little as 50 parts per million (PPM) of dissolved materials. For drinking water purposes it is recommended that waters contain less than 500 parts per million of dissolved materials.

Natural events such as droughts and floods may cause substantial changes in stream water quality. Reduced flow resulting from droughts can cause an increase in the concentrations of dissolved materials and a decrease in the load or amount of solid material carried by a stream. The reverse is true of floods; high flows generally dilute the concentrations of dissolved materials, and flush new sediments from flood plains, increasing the sediment load.

Biological factors can have a major effect on the quality of natural waters. Changes to any of the environmental factors that make up ecosystems can result in changes to the ecosystem as a whole. Through the process of photosynthesis, aquatic plants produce oxygen and consume carbon dioxide, nitrogen, and phosphorous in the water. The decay of plant materials consumes oxygen and produces carbon dioxide. Change in the balance between growth and decay can result in a change in the ecosystem and its water quality.

Fig. 18. Natural water can vary greatly in the dissolved materials that it carries. Natural springs that flow through salt-bearing geologic formations can have as much as 200,000 parts per million of dissolved materials.

Environmental Concerns 3

Some environmental concerns related to water, such as droughts and most floods, are naturally occurring. Others are caused by human activities. Humans can affect water resources by changing the use, distribution, quantity, or quality of water. Human activities have caused degradation of stream habitat, groundwater depletion, changes in land use, and contamination of water supplies. Many of the changes humans impose on water systems can cause undesirable impacts on watersheds and their ecosystems. Increased awareness of these concerns is the first step towards balancing the needs of humans and nature and becoming sound stewards of essential and valuable water resources.

Surface-Water Management

Water is not always available when and where it is needed; thus, storage and/or diversion systems have been developed to help meet this need. The most common surface-water structure for storage and transfer of water is a reservoir and canal system (Fig. 19). Dams and their associated reservoirs provide water supplies, help minimize downstream flooding, generate electricity and provide recreation. Dams and reservoirs change the historic flow patterns of the stream, which can affect the environment above and below the dam. Canals are one method of transporting water from a stream to its place of use. Through this transfer, water can be lost to the surrounding environment. Loss of water from canals by evaporation or seepage reduces the quantity of water available for use at the destination point, requiring a larger quantity of water to be diverted to meet demands. However, the water lost from unlined canals can recharge local groundwater and create new areas of wildlife habitat.

Fig. 19. Diversion dam on the Colorado River near Blythe, California.

Storage in Reservoirs

Dams reduce peak discharge and sediment supply to downstream stream reaches. The stream that flows from a dam is not the same as the stream that enters the reservoir behind the dam. Water in the stream below the dam commonly is different in quantity, quality and temperature. The hourly, daily, seasonal, and annual flow patterns of a stream below a dam also tend to differ from that of the stream that entered the reservoir. Variations in quantity, quality, temperature, and flow patterns can impact biota dependent upon the flow and water characteristics of the stream prior to the changes. Examples include the Colorado River pike minnow, the snail darter, razorback sucker, and humpback chub. These fish are now so scarce and

Fig 20. The humpback chub, a Colorado River endangered fish, can grow to nearly 20 inches and live more than 30 years.

localized in their distribution that they have been federally declared as endangered (Fig. 20). In the Columbia and Snake Rivers, dams have greatly impacted the migration of salmon.

Streams that flow into reservoirs deposit some of the sediment they are carrying, reducing reservoir storage. The stream that emerges from the reservoir contains little sediment, and immediately begins to pick up sediment from the channel banks, bed, and sand bars directly below the reservoir. Thus, there is scouring of the stream banks, stream bed, and sand bars immediately below the reservoir. Meanwhile, sediment continues to be deposited at the mouths of tributaries downstream from the reservoir (Fig. 21). The flow from the reservoir is insufficient to remove sediment deposited by downstream tributaries. The resulting modified stream channel can change the habitat for the native plants and animals that live there. The following example describes environmental consequences associated with the alteration of stream flow, and an experiment, using a controlled release of water, to assess potential mitigation measures.

Fig. 21. Sediment deposited from a tributary, Long Gulch, to the Gunnison River downstream from Crystal Reservoir near Montrose, Colorado.

Controlled Release

The Colorado River has been called the lifeblood of the southwestern part of the United States and it is the heart of the Grand Canyon. Glen Canyon Dam and its reservoir, Lake Powell, form the largest of the reservoirs on the Colorado River that comprise the Colorado River Storage Project. Without the Colorado River Storage Project, much of the development in the arid southwest of the United States would not have been possible. Glen Canyon Dam began storing water in March of 1963 to fill the 26.7 million acre-feet (Fig. 22) of Lake Powell. One of the impacts to the stream system below the dam was the loss of sand bars that were formed by high flows of the

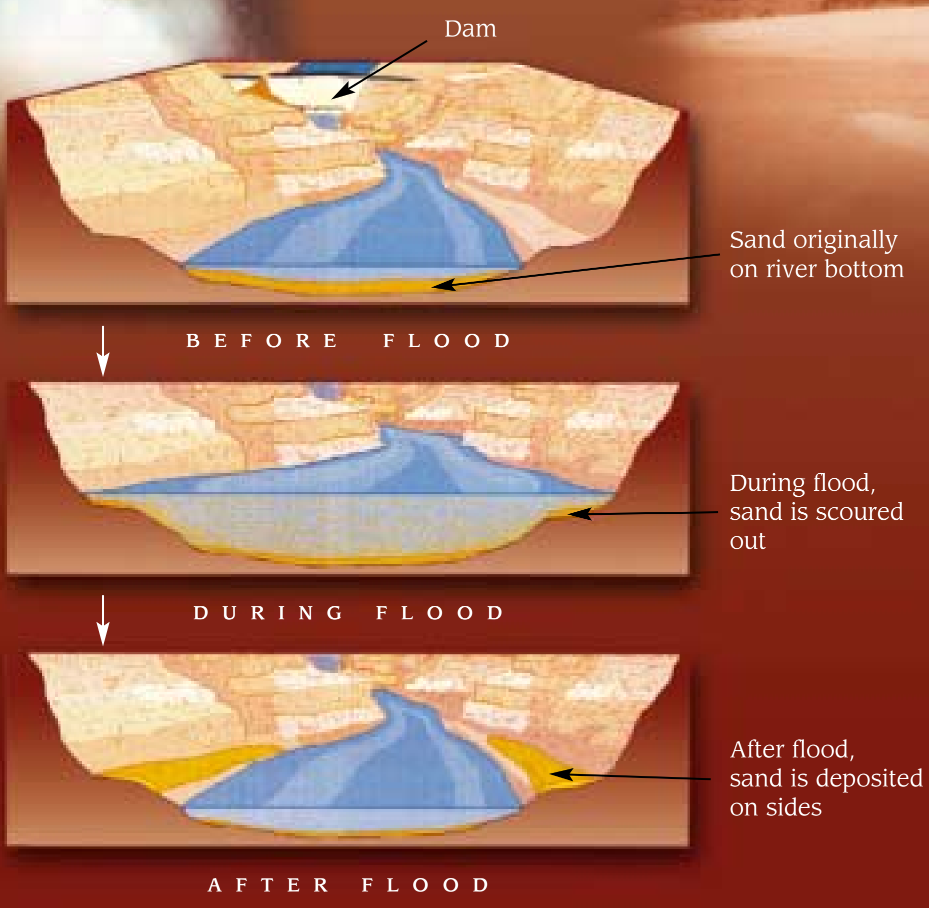
Fig. 22
An acre foot of water, 325,900 gallons, is enough water to cover a football field approximately one foot deep.

Fig. 23

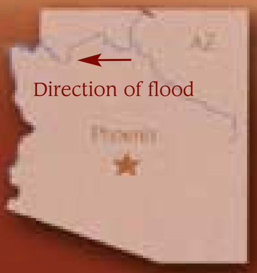
CONTROLLED RELEASE OF WATER ON THE COLORADO RIVER

1996

Glen Canyon Dam



Glen Canyon Dam



Prior to completion of Glen Canyon Dam in 1963, the flows of May and June typically peaked at about 86,000 cubic feet per second (cfs). Once the reservoir was filled with water, releases from Lake Powell were used for power generation. A maximum of 33,200 cfs was initially allowed for power generation; however, this amount was subsequently reduced by law to 25,000 cfs. Between 1965 and 1983, an estimated 25 million tons of sand were deposited on the riverbed in the first 90 miles below the dam. The source of this sand was sediment contributed by tributaries and from beaches slumping into the river. The sand was deposited due to a lack of high flow of sufficient volume and duration to remove it from the riverbed and redeposit it on the beaches.

After years of study, it was determined that a controlled release or habitat-maintance flow from Lake Powell was necessary to reestablish the beaches and associated ecosystems in the Grand Canyon. On March 26, 1996, a controlled flow of 45,000 cfs of water was released from Glen Canyon Dam. This flow lasted for eight days and was the first intentional flood ever released for environmental study purposes. When the flood receded, a great deal of new sand had been removed from the streambed and deposited on the beaches above the normal high water line. This experiment showed that there is enough sand from tributaries downstream of the dam to rebuild the sand bars, and that controlled floods can redeposit the sand from the riverbed. Changes to habitat associated with the controlled flood release are still being studied.

river and their associated ecosystems. The sand bars were popular camping sites for rafters. They also provided key habitat for plants and animals that rely on sand bars as an important part of this ecosystem. Without the high flows, the sand bars gradually eroded and disappeared (Fig. 23).

Diversions

Water diverted directly from streams reduces its flow and ability to transport sediment. Depending upon the time of year that diversions occur and the quantity of water diverted, diversions can affect the stream corridor and the ecosystems that have developed there. The stream channel and flood plain can become overgrown with vegetation (Fig. 24) reducing the ability of the stream to transport water during a flood. Where a large amount of a stream's normal high flow is diverted, the stream corridor can be affected much as if a dam controlled the flow. The reduced flow can also affect the water quality and temperature of the stream, leading to changes to the ecosystem below the diversion.

Fig. 24. In the Platte River, greatly reduced water flow has resulted in the channel narrowing to as little as 15% of its former width in some places.

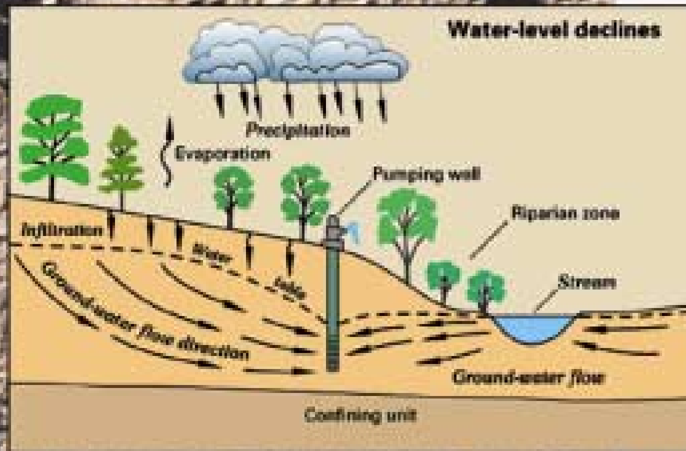
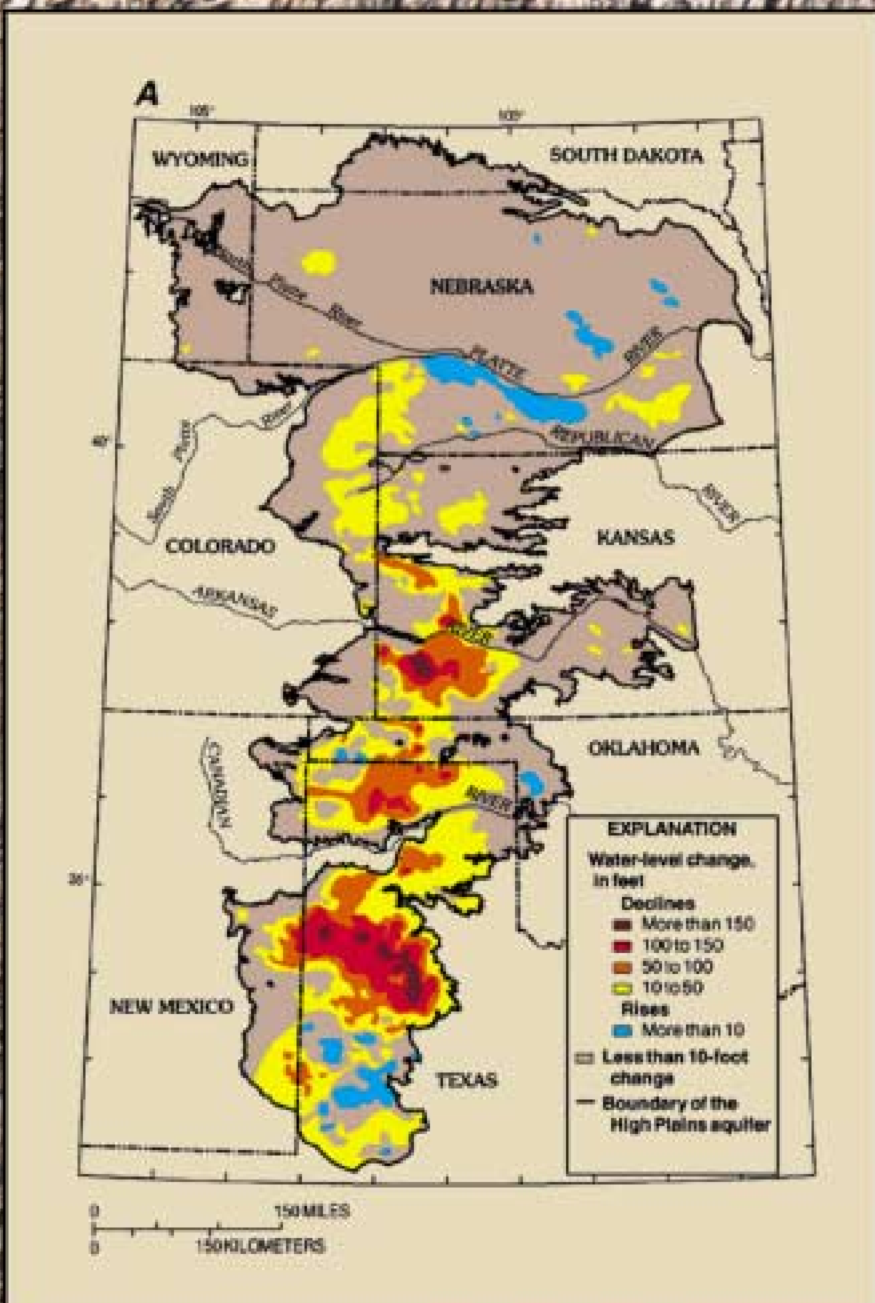


Fig. 25. Pumping removes groundwater from storage. This can intercept groundwater that would normally discharge to the stream and divert stream water to the well.



HIGH PLAINS AQUIFER

Fig. 26. Irrigation has made the High Plains Aquifer, a 174,000 square mile area underlyiing parts of 8 states from South Dakota to Texas, one of the nation's most important agricultural areas. Extensive groundwater withdrawals exceed recharge, resulting in the lowering of groundwater levels. Conversely, diversion of surface waters for irrigation can raise groundwater levels. On the map, areas where recharge exceeds withdrawal are shown in blue. The map shows changes in groundwater levels from before groundwater development to 1997.

Groundwater Withdrawals

Pumping removes groundwater from storage. This water can be replaced by recharge, either by infiltration of rainfall through the unsaturated zone or by infiltration of surface water. As pumping increases, water levels decline, causing surface-water sources to either contribute more water to the connected groundwater system, or receive less water from the groundwater system (Fig. 25). Declining water levels increase pumping costs and if the levels are lowered too much, wells can go dry. Surface-water sources that are affected by groundwater withdrawal can have environmental or economic impacts on the users of a stream. To reduce impacts of groundwater withdrawal, groundwater needs to be managed properly. The following are examples of environmental problems caused by mismanagement of groundwater.

Depletion

The Edwards Aquifer in Texas and the High Plains Aquifer are examples of principal aquifers that are currently impacted by groundwater depletions. The High Plains Aquifer (consisting largely of the Ogallala Formation) is an unconfined aquifer that underlies parts of South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, and Texas (Fig. 26). Annual precipitation in the area is 15 to 20 inches per year, but only a fraction of an inch recharges the aquifer because of high amounts of evaporation and transpiration in the area. Between 1949 and 1980, groundwater removed from this aquifer by wells, mostly for irrigation, increased from about 480 million cubic feet per day to about 2,150 million cubic feet per day. Pumping groundwater resulted in the largest decrease in storage of any major aquifer in the United States. In parts of the central and southern High Plains, more than 50 percent of the aquifer's predevelopment saturated zone has been dewatered. This removal of groundwater has resulted in impacts to surface waters and the ecosystems that depend upon them, and to human uses such as agriculture.

Land Subsidence

The subsurface rock matrix and the fluid pressure in rocks support the land surface. If substantial clay and silt formations are present, the surface may sink when the underground fluids, such as water or oil, are removed. Land subsidence results in a permanent reduction in the storage capacity of a confined aquifer. The first area in the United States where subsidence resulting from groundwater withdrawal was recognized is an area now known as "Silicon Valley" in California. Other areas having substantial land subsidence from groundwater withdrawal include the San Joaquin Valley in California (Fig. 27), south-central Arizona, the Las Vegas Valley in Nevada, and the Houston-Galveston area of Texas.

Fig. 27. Land subsidence in the San Joaquin valley, California. The year designations on the pole indicate the level of the land surface at those times.

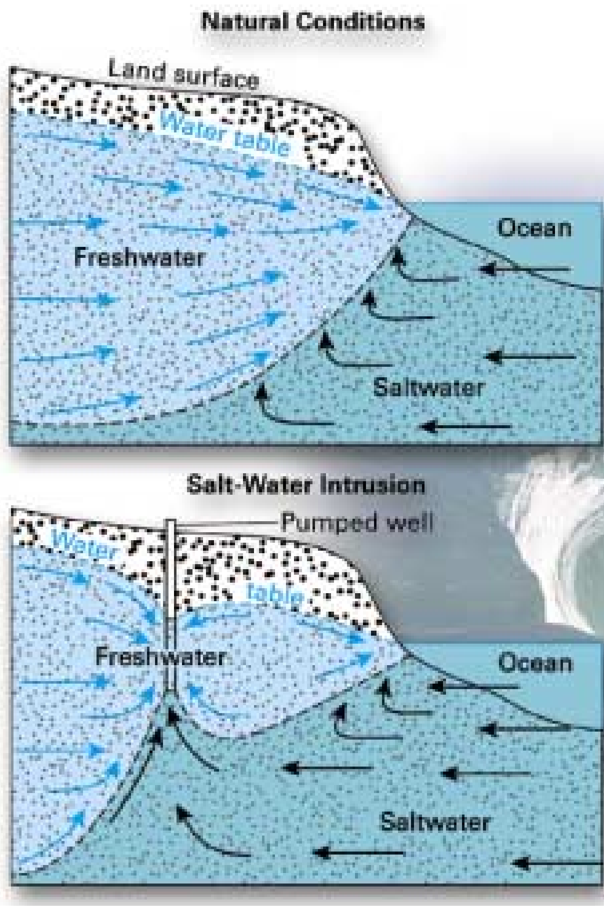


Fig. 28. Intensive groundwater pumping can cause salt-water intrusion in coastal aquifers.

Salt-water Intrusion

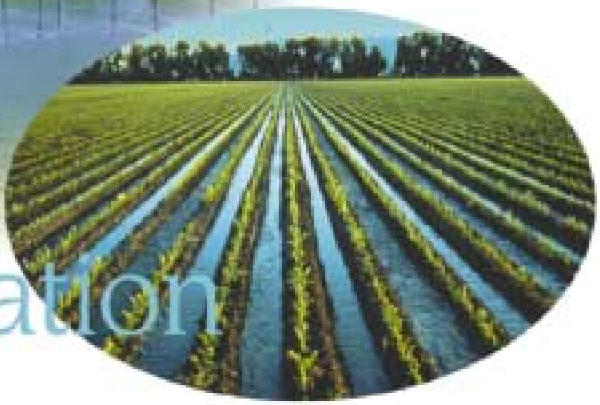
Saline water surrounds much of the fresh groundwater of the United States, either laterally along the seacoasts or deep beneath aquifers in deeper parts of the Earth's crust. Fresh water is less dense than saline water and tends to naturally separate by floating on top of the saline water. However, when fresh groundwater is withdrawn, the boundary between fresh and saline groundwater moves (intrudes) into the space formally occupied by the fresh groundwater (Fig. 28). Salt-water intrusion is a problem in nearly every state because deep-saline water usually underlies the freshwater. Examples of salt-water intrusion are especially numerous along the sea coasts. To create a hydraulic barrier to prevent further salt-water intrusion, Los Angles and Orange Counties in California pump fresh water into the aquifer near the coast. In Florida, salt-water intrusion occurs in the Tampa, Jacksonville, and Miami areas. Saltwater intrusion also is occurring in Savannah, Georgia, Hilton Head Island, South Carolina, and in several counties in New Jersey.

Changes in Land and Water Use

Land uses that impact water resources include agriculture, forestry, urbanization, recreation, and industrialization. Agriculture, the clearing of forests, and the draining of wetlands have caused significant modifications to the surface of the Earth. Tillage of the land and clear cutting of forests change infiltration and runoff characteristics, which affect groundwater recharge, sediment and water yield, and evapotranspiration.

Irrigation of lands changes the use and distribution of water (Fig. 29). The removal of surface water and groundwater for irrigation changes the water's natural distribution and impacts the ecosystems that depend upon it. Demand for water to irrigate crops usually occurs when there is insufficient precipitation during the growing season, potentially causing stream and groundwater levels to be reduced. In addition, irrigation waters that return to either groundwater or surface waters can contain salts, pesticides, or have elevated levels of nutrients such as nitrate and phosphorous.

Fig. 29. Irrigation changes the natural distribution of water, the infiltration and runoff characteristics of the land surface, and the type of vegetation.



irrigation

These contaminants in turn can cause harm to plant and animal life that depend on the returned water.

Drainage of shallow subsurface water is common in areas with high water tables and extensive wetlands. Drainage of such areas is necessary to convert land to agriculture or urban development, but it can result in decreased recharge to groundwater and increased flooding in the developed area. If wetlands are drained, biological impacts may be substantial because wetlands are some of the most biologically productive ecosystems on Earth. Between 1780 and 1980, an estimated 60 million acres of wetlands in the Mississippi River Basin were drained.

The Everglades in south Florida are an excellent example of how land use changes, specifically changes in water flow, can impact wetlands (Fig. 30). In 1948, Congress authorized the Central and Southern Florida Project for Flood Control and Other Purposes (C&SF Project). Through this act, levees were constructed to divert surface water to control flooding,

Fig. 30. Wetland development in Dade County, Florida.

Fig. 31. Tampa, Florida. Urbanization requires large quantities of water, while changing the infiltration and runoff characteristics of the land surface.

and drainage ditches were dug to lower groundwater levels so agriculture and residential areas could be developed in marsh and swamp lands. Flood control efforts focused on directing interior waters through canals to coastal areas. The drainage ditches quickly lowered groundwater levels. Within a few decades these flood and drainage systems changes caused:

- Elimination of approximately 1,500,000 million acres of wetlands,
- Reduction in the number of species located in the Everglades; such as the Florida panther, snail kite, and the American crocodile,
- Depletion of the water supply needed by the human population, and the
- Increased likelihood of wildfires.

The growth of cities and their associated infrastructure have greatly changed the historic uses of water. The removal of water from streams and groundwater systems to supply cities, and the land use

Fig. 32.   Economic impact of flooding in the United States.

changes associated with the development of the city, have consequences on the natural environment. For example, infiltration of water is reduced as the result of construction of highways, streets, parking lots and buildings (Fig. 31). A reduction of infiltration can also increase runoff and the likelihood of flooding.

Effects of Floods

Floods are natural events that help shape the land surface. About 7 percent of the land area in the United States is subject to flooding, and many natural ecosystems in these areas depend upon floods for their existence. For example, some plants bordering water bodies depend upon flooding for regeneration, and flooding resupplies flood plains with sediments and nutrients that support the diverse ecosystems that develop on them.

Flooding is the most destructive and costly type of natural disaster encountered by people in the United States (Fig. 32). Flooding accounts for a majority of all Presidential disaster declarations and about 90 percent of all damage resulting from natural disasters in the United States. While most floods are naturally occurring events, many of the impacts from floods are made worse by human activities. The construction of housing and businesses on a flood plain greatly increase the chances of loss of life and property from a flood. The construction of levees along a stream prevents the spread of water across flood plains during a flood resulting in higher water stages for a given discharge. This situation increases the potential damage for areas and communities downstream should a levee fail.

Effects of Droughts

Droughts also are naturally recurring events. Many native plants and animals have adapted to variations in precipitation and can survive short-term droughts. However, extended droughts can damage wildlife habitat and increase mortality rates. Droughts can cause increased insect infestations, plant disease, and wind erosion. The incidence of forest and range fires increases substantially during extended droughts, which in turn place both wildlife and human populations at higher levels of risk (Fig. 33).

Direct impacts of droughts include a reduction of crops, rangeland, and forest productivity; increased fire hazard; lowered water levels; and increased livestock mortality rates. Decreased crop yields have negative economic impacts for agricultural and related sectors within the drought area. If these yield reductions are large enough,

Fig. 33. These web sites provide up to date information and current drought conditions in the United States.

drought.unl.edu

www.drought.noaa.gov/

water.usgs.gov/waterwatch/

drought conditions

WWW

they can result in increased prices for consumers.

Water users that rely on precipitation, unregulated streamflow, or shallow groundwater as their primary sources of water are more susceptible to short-term droughts than users that have water storage in both groundwater and surface-water reservoirs. The 1999 drought in the northeastern United States and Ohio Valley is an example. Beginning in the spring and into the summer, this region had record and near-record deficits in short-term precipitation. This water deficit caused record low streamflow and groundwater levels at some locations, and drought emergencies were declared in several states. Agricultural losses approached 1.1 billion dollars.

Fig. 34. Point sources contribute contaminants from discrete sources, such as from a drain.

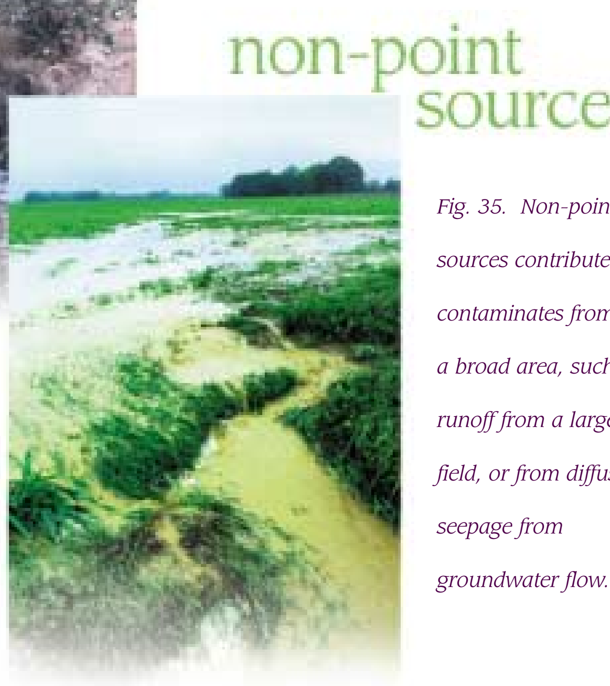


Fig. 35. Non-point sources contribute contaminates from a broad area, such as runoff from a large field, or from diffuse seepage from groundwater flow.

Water Quality

Many factors affect the quality of surface and groundwater. Water moving over or under the land surface can undergo physical and chemical changes. These changes may be caused by either natural factors or human activities.

Contaminants can impair water quality and affect water use. A contaminant is an undesirable substance in water that either is not normally present or is a naturally occurring substance at an unusually high concentration. Contaminants can be divided into four general classes: sediment and natural organic materials, nutrients, bacteria, and toxic substances. These can contribute to water by either point or non-point sources.

Point sources contribute contaminants at a discrete site, such as the outflow from a pipe, ditch, tunnel, well, concentrated animal-feeding operation, or floating craft (Fig. 34). These sources can be controlled to some degree by treatment at or before the point of discharge.

Non-point sources contribute contaminants from a broad area; as a result, such sources are not as easily identified or controlled as point sources. Non-point sources include the atmosphere, agricultural areas, golf courses, residential developments, roads, parking lots, and contributions from groundwater along lengthy reaches of streams (Fig. 35).

Sediment and Natural Organic Materials

Sediment is defined as particles derived from soil, rock, or organic matter that have been, or are being, transported by water or wind. Natural organic materials include plant debris, and human and animal wastes. The erosion of land surfaces and stream banks produces sediment. Erosion occurs naturally, but human activities, like farming, logging, or road construction can increase sediment transport to and within streams. Sediment deposited in streams can restrict navigation. Sediment can also increase the potential for floods by decreasing reservoir storage and stream-channel capacity. Suspended sediments contribute to the reduction of water clarity and quality. Fine sediments can severely alter aquatic communities by clogging fish gills and suffocating fish eggs and aquatic insect larvae. Harmful materials such as heavy metals and toxic chemicals can attach to sediments and move with them down the stream system. Sediment is a major water quality issue in most places (Fig. 36).

Nutrients

Nutrients are any organic or inorganic compound needed to sustain life. Examples include carbon, nitrogen, phosphorus, and potassium. Nutrients are contributed to waters from the atmosphere, agricultural lands, golf courses, lawns, septic systems, wastewater treatment plants, and factories. An excess amount of nutrients in water can result in a disproportionate amount of aquatic vegetation (Fig. 37). The decomposition of this excess vegetation can remove oxygen from water and cause fish and other aquatic life to die. An overabundance of aquatic vegetation can also interfere with recreation. High nitrate or ammonia concentrations can impact drinking water or kill fish. Nitrate and ammonia are forms of nitrogen.

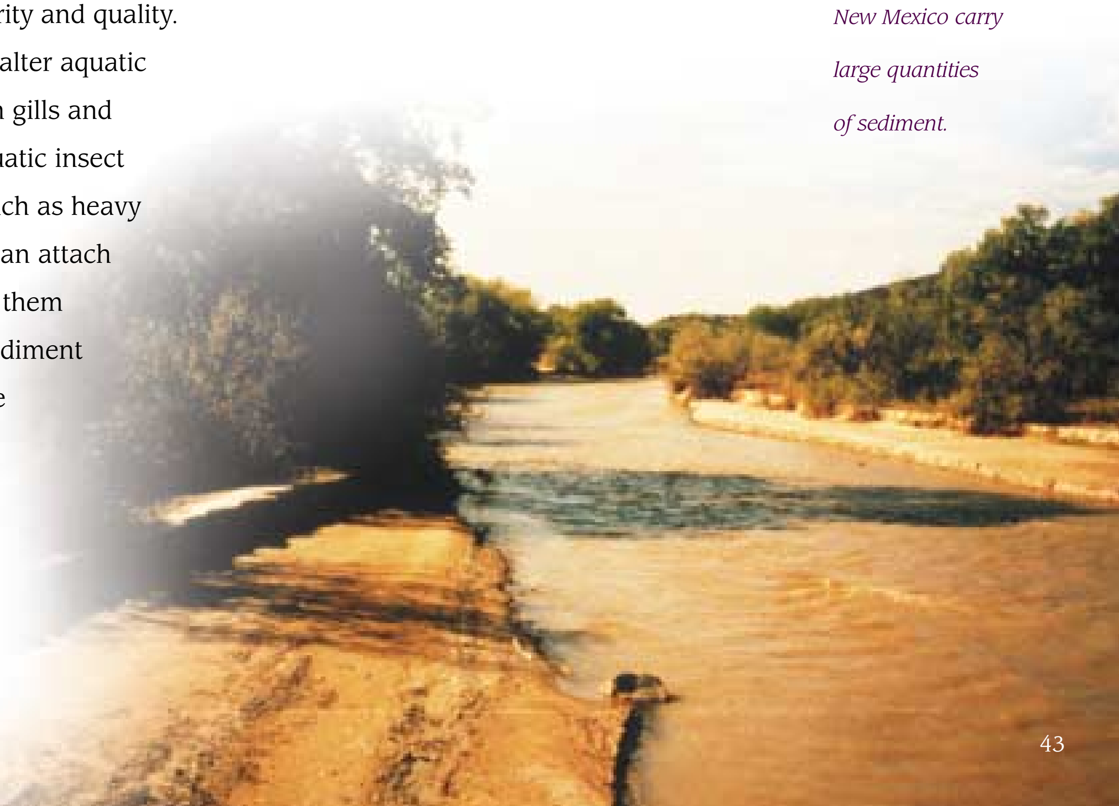


Fig. 36. Streams such as the Rio Chama in New Mexico carry large quantities of sediment.

Fig. 37. A bloom of aquatic plants can result from elevated levels of nutrients, such as nitrogen and phosphorus, associated with human activities.

intestines of humans and other warm-blooded animals. When water tests confirm the presence of the indicator bacteria, the water body may be contaminated by untreated sewage and other more dangerous organisms may be present.

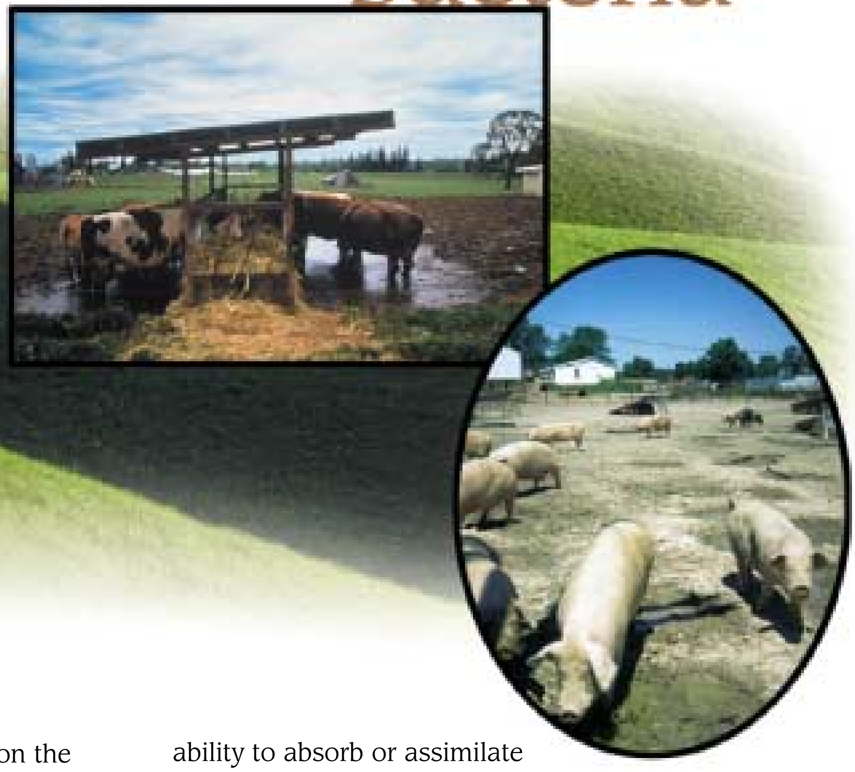
Toxic Substances

In sufficient quantities, toxic substances, such as cleaning solvents, pesticides, and certain metals, can cause sickness, genetic disorders, and even kill organisms. Toxic chemicals can enter waters through direct discharge from industry or by improper disposal of industrial, mining, farm, and household wastes. Contaminants contributed from industrial uses of water include toxic substances produced from cleaning solvents, acids, and alkalis. The over application of pesticides can result in the excess entering waters through runoff to surface water and infiltration into groundwaters (Fig. 39).

Even extremely low concentrations of some chemicals are hazardous to humans and aquatic life. Toxic substances also can affect an organism's growth, metabolism, reproduction, or behavior. The potential dangers of many toxic substances are only now being recognized. Assessing the environmental dangers of these substances has been enhanced as our ability to detect smaller concentrations has improved and

Bacteria

Some bacteria are disease-causing organisms that may be delivered to surface water and groundwater by sewer overflows, leaking septic tanks, and runoff from animal feedlots or pastures (Fig. 38). Some bacteria are a threat to humans, and indicator organisms such as fecal coliform are used to determine their presence. Indicator bacteria are found in great numbers in the



our understanding of their effects on the environment has increased.

Effect of Contaminants on Water Quality

The effect that a contaminant has on water depends upon the characteristics of the water itself and the quantity and characteristics of the contaminant. Each body of water can be described according to its physical, chemical, and biological characteristics. Collectively, these characteristics give each water body an ability to absorb or assimilate some contaminants without becoming degraded. For example, large streams can absorb a larger quantity of a contaminant than a small stream.

Many human activities can alter or impair the quality of the water. Commonly, these activities increase the concentrations of dissolved or suspended contaminants, change the acidity of receiving waters, and/or increase the water temperature. The United States has made progress over the last 30 years in reducing the human

Fig. 38. Animal feedlots can contribute disease-causing organism to the surface and groundwaters.

Fig. 39. Agricultural application of chemicals.

sampling

Fig. 40. Hydrologists sampling water for determination of its chemical quality.

impacts to our water resources, yet a widespread and serious problem still exists from non-point sources.

The degree to which human activities have altered the water quality of a particular stream or aquifer can commonly be determined by sampling and comparing the water chemistry and biota of the impacted system with the chemistry and biota from a nearby area that is not impacted by humans (Fig. 40). The chemistry of the non-impacted water is called the background chemistry. While this approach is simple in concept, it is challenging to accomplish.

The quantity of contaminants reaching water sources is dependent upon many factors including land management practices, watershed characteristics, chemical properties of the contaminant, and the amount of the contaminant that is released to the environment. Sediment concentrations tend to be the highest in the western part of the Nation in areas where watersheds are largely range and agricultural lands, which have less groundcover to hold soils in place compared to humid regions. Concentrations of fecal-coliform bacteria are highest in the agricultural areas of the Midwest and south-central portions of the country. More than half of the streams sampled by the U.S. Geological Survey's National Water Quality Assessment Program(NAWQA) contained nitrogen and phosphorus concentrations above background levels. Most of the streams with high concentrations of nutrients drain areas of agricultural or urban land.

Streams and shallow unconfined aquifers are more vulnerable to contamination than water in deep aquifers. Confined aquifers generally are buried deeper beneath the land surface and are protected by layers of relatively impermeable materials that impede the movement of

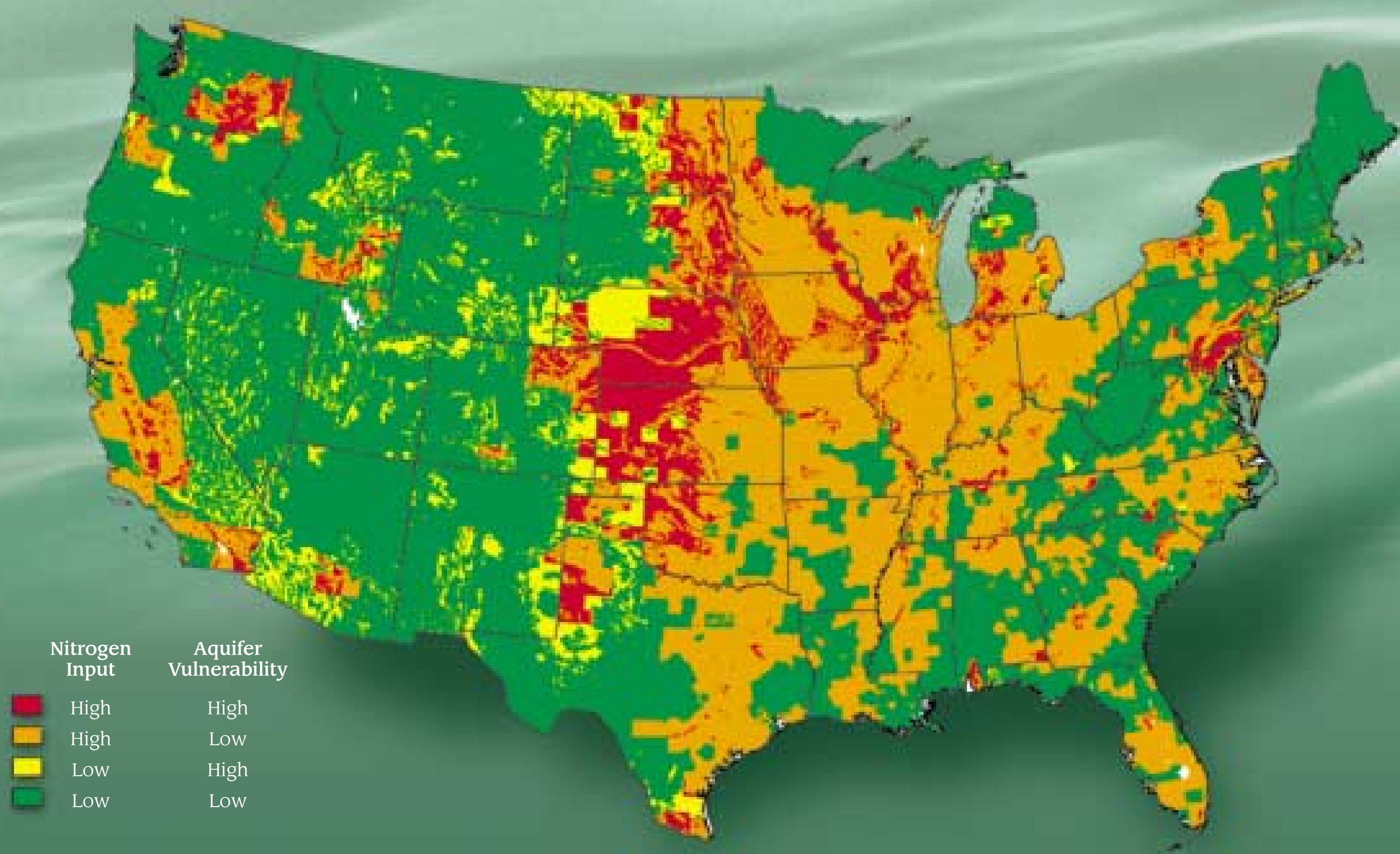
Fig. 41

NITRATE CONTAMINATION RISK MAP

Areas with the highest risk for contamination of shallow groundwater by nitrate.

contaminated water from the land surface. Of the aquifers sampled by the NAWQA program, increased levels of nutrients were found in 53 per cent of the shallow aquifers and only 9 percent of the major deeper aquifers. Groundwater contamination is extremely difficult to reverse in part due to the slow rate at which water moves through aquifers (Fig. 41).

Some pesticides have the potential to harm humans, wildlife, and native plants if they are exposed to high enough levels for a long enough period of time. Depending on the chemical and concentrations, possible health effects include cancer, reproductive or nervous-system disorders, and acute toxicity. Pesticides found in major rivers and aquifers reflect the pesticides applied on both urban and agricultural areas. At least one pesticide was found in almost every surface water and fish sample collected by the NAWQA program. Pesticides found in water were primarily those that are currently used, whereas those found in fish and stream sediments are frequently ones that were banned years ago but breakdown very slowly in the environment. About 50 percent of the wells sampled contained one or more pesticide, and more frequent detections were found in shallow aquifers below agricultural and urban areas.



"The greatest domestic
problem facing our country
is saving our soil and water."

Sam Rayburn, 1882-1961
(Congressman and longtime speaker of the United States House of Representatives) On Conversation. From Valton J. Young, The Speaker's Agent [1956]

Protecting our water resources 4

For the future

it is important to protect our water resources from depletion, waste, and contamination. Water managers require an increased understanding of water movement, quantity, and quality, and the environmental impacts associated with any water management decision they make. Conservation, establishing water quality standards, and preventing water from becoming contaminated all contribute to assuring that we will have sufficient quantities of clean water now and in the future.

Water Management

Water management is dictated by water use and controlled by water availability and water quality. Today, public policy makers must consider the entire hydrologic system, environmental concerns, and social needs when water management decisions are made. An increased demand for water requires water managers to assess the availability of water, its quality, and any environmental impacts associated with an increase in demand. Understanding the extreme events of stream discharge

xeriscape

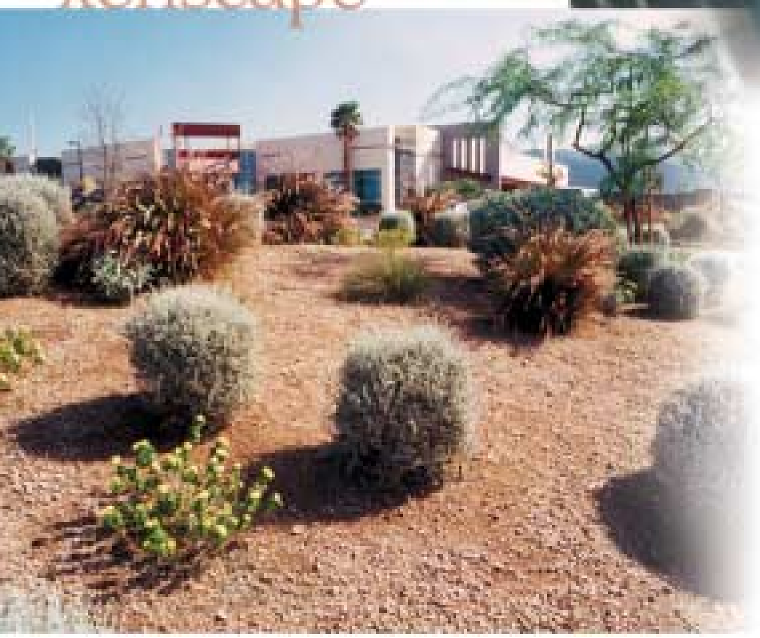


Fig. 42. Landscaping using natural vegetation- that relies only on precipitation for moisture can conserve water. This photo is of a post office in Henderson Nevada.

is necessary for the planning of bridges, highways, storm water management, flood plain management, and storage requirements for reservoirs. Knowledge of aquifer characteristics is required for the management of groundwater systems. In addition, the connection between surface water and groundwater resources is increasingly being recognized as a major management issue.

To ensure consideration of all uses and interested parties, the management of surface water is most effectively addressed through a watershed approach. Every watershed is unique, requiring a close working relationship between interested stakeholders to solve the complex physical, environmental, and social problems associated with balancing needs within the watershed. By taking a watershed approach, the variables associated with water management can be analyzed from headwater sources to the lower reaches of the watershed. One of the issues associated with a watershed approach is that watershed boundaries commonly do not correspond with political boundaries, nor do they correspond with boundaries of groundwater flow systems.

The sound management of groundwater resources ensures the sustainability of the quantity and quality of the water withdrawn from the system. Knowledge of the recharge to, flow through, and discharge from a groundwater system, including how it interacts with surface water, is needed to manage the system. This knowledge will assist in determining where to locate wells and the quantity of water that can be optimally withdrawn from the groundwater system. Maintaining good groundwater quality requires protecting the aquifer from sources of contamination.

Conservation

Water conservation is an efficient and effective means of solving many water supply problems (Fig. 42). Conservation can help reduce the effects of short-term drought and to some degree eliminate the need for development of new water sources. Water conservation is the responsibility of everyone. Individuals can conserve water by fixing leaking faucets and toilets, installing water-saving showerheads, taking shorter showers, watering lawns sensibly, and running full loads in washing machines and dishwashers. From the municipal and industrial standpoint, conservation can be achieved through supply management, such as metering and distribution system improvements, or by demand management, such as pricing, water use restrictions, and education. From the agricultural standpoint, water conservation can be achieved through decreasing distribution losses, changes in irrigation practices, and conversion to crops having lower water demands.

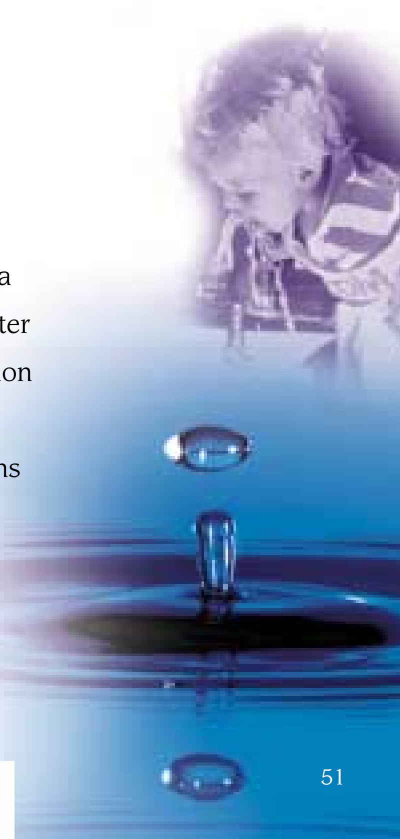
Water Quality Standards

Water quality standards are established to assure that the uses of water are protected. States, Indian Tribes, and other jurisdictions establish water quality standards for the waters within their jurisdiction and then survey those waters to see if they meet the designated standards. The U. S. Environmental Protection Agency (EPA) provides oversight and guidance in the development of water quality standards required under provisions of the Clean Water Act. Water quality standards are determined based on one or all of the following considerations: beneficial use for the waters, numeric and narrative criteria for supporting each use, and an antidegradation statement (Fig. 43). Designated beneficial uses are the desired uses the water quality should support. Numeric criteria establish the minimum physical, chemical, and biological parameters required to support a beneficial use. Narrative water-quality criteria define conditions and attainable goals that must be maintained to support a designated use. Antidegradation statements protect existing uses and prevent water bodies from deteriorating even if their water quality is better then necessary for an existing use.

In 2000, 19 percent of the streams in the United States were surveyed to determine the water quality conditions of those waters. Of the streams sampled, 53 percent met the designated water quality use criteria and 8 percent supported existing beneficial uses but may not in the future unless action is taken. Some form of pollution or habitat degradation impairs the remaning 39 percent of the assessed streams.

To improve the quality of our nation's waters, states, Indian tribes, and other jurisdictions are to identify waters that do not meet water quality standards and establish Total Maximum Daily Loads (TMDLs) for those water bodies. TMDLs specify the amount of any pollutant that a water body can absorb and still meet water quality standards. Based on the calculation of the total load for a specific pollutant, TMDLs recommend waste load allocations for individual point sources and load allocations for non-point sources. These calculations include a margin

Fig. 43. The U.S.Environmental Protection Agency provides oversight and guidance in the development of water quality standards for states, Indian tribes, and other jurisdictions.



To learn more about Water Quality Standards

www.epa.gov/seahome/wqs.html

of safety to account for uncertainty in contaminant measurement and environmental impact. TMDLs typically specify the amount that the pollution must be reduced to meet the water quality standards, provide a scientific and policy basis for taking actions needed to restore a water body, and are used to allocate pollution control actions among sources in a watershed.

Preventing Contamination

If water becomes contaminated, it may be unsuitable for some uses. The contaminant and the process by which the contaminant is generated and transported to the water body need to be identified. Once identified, an appropriate control method designed to interfere with the availability, detachment, or transport of the contaminant needs to be implemented. For example, many forms of phosphorus attach to soil particles rather than dissolve. A large portion of the phosphorus is transported to streams through sediment transport. Land use practices that reduce the exposure of soil to the erosive forces of water help keep the soil in place, thus reducing the transport of sediment and the attached phosphorus to streams.

Preventing contaminants from reaching streams or aquifers is the most effective way to reduce water contamination. Proper handling, storage, and disposal of toxic substances can prevent these substances from reaching waters. Where contaminant discharge exceeds allowable limits, point sources need to be identified, monitored, and treated. Reduction in non-point source contaminants such as nutrients and pesticides can commonly be accomplished through careful selection of methods, rates, and timing of application. Best management practices such as building sediment and runoff ponds, equipment wash-off areas, capture and treatment of urban runoff, and vegetated buffer strips next to stream channels and lakes are effective in reducing non-point source contamination (Fig. 44). In more urbanized areas, the capture and treatment of storm runoff from impervious areas, like roads and parking lots, can reduce contaminant input to streams. Preventing certain activities in aquifer recharge areas, lining impoundments and landfills, replacing leaking underground storage tanks, and plugging abandoned wells are all methods to prevent direct contamination of groundwater resources.

Water Treatment

Because water is used and reused, waste materials, nutrients, pesticides, pathogenic bacteria, and viruses may need to be removed. The use of the water dictates the treatment needed. Water may need to be treated both before and after use. Billions of dollars have been spent on treating water for domestic purposes. Water may be treated differently from different sources for different water supply systems, depending on the natural quality of the water. The basic water treatment process used for public water supply systems includes removal of suspended materials by settling and filtration and the addition of a small amount of chlorine or some other disinfectant to kill any bacteria or microorganisms that may be in the water.

The most common after-use treatment is provided by wastewater treatment facilities. Wastewater treatment facilities treat water discharged from municipal supply systems. Storm runoff, water that is collected in storm drains from streets and parking lots, is now also being diverted to some facilities for treatment. The function of wastewater treatment facilities is to speed up the natural processes by which water is purified. In the primary phase of treatment, the solids settle out and are physically removed from the wastewater. The secondary phase of treatment uses biological methods to remove biodegradable materials. Bacteria are intentionally added to consume as much of the organic matter as possible during the time available for secondary treatment. Aeration of water aids bacterial growth. Any remaining materials in the water can be removed through advanced treatment, such as further filtration or disinfection through the addition of chlorine or exposure to sunlight.

Water Rights

Water rights are the right to use water for a beneficial purpose in accordance with applicable state and federal law. The administration of these rights varies from state to state. These rights are especially important to environmental protection in the western United States where water commonly is removed and transferred to locations outside of the originating watershed. Keeping water in a stream for as long as possible before diverting it has become a major strategy for protecting the uses that depend upon adequate flows of the stream.

There are two major water allocation systems used in the United States: one in the eastern part of the country "riparian rights" and the other in the western part of the country "prior appropriation doctrine." Riparian rights have evolved over time from the traditional system that allowed only landowners bordering a water body to put the water to use, into a system that requires water users to obtain a permit from a state agency. Some states exempt prior users or certain categories of use from the permit requirement. These permits allow water to be transferred elsewhere in the watershed for use. Every mid-western and eastern state except South Carolina has changed their surface water laws to allow for water transfers. In most states, the permits are issued for a specified time period or may be terminated at the discretion of the state agency, and other conditions may be included to prevent

Fig. 44. Vegetation along waterways can help slow surface runoff and movement of nutrients, pesticides, and sediment from farm fields to surface water bodies.

P R O T E C T I V E

Laws & Regulations

Laws and regulations have been designed to protect our waters. Implementation of these laws and regulations is usually accomplished at the state level with oversight from the Federal government. Water rights are the exception to this; states have the primary role in their administration. Most of the federal legislation is concerned with water quality, whereas water rights primarily deal with water quantity.

Clean Water Act

The Clean Water Act (CWA) is a 1977 amendment to the Federal Water Pollution Control Act of 1972, which set the basic structure for regulating discharges of contaminants to waters of the United States. The law gave the U. S. Environmental Protection Agency (EPA) the authority to set effluent standards on an industry basis and to set water quality standards for all contaminants in surface waters. The CWA makes it unlawful for any person to discharge any contaminant from a point source into navigable waters unless a permit is obtained under provisions of the act.

Safe Drinking Water Act

The Safe Drinking Water Act of 1974 was established to protect the quality of drinking water in the United States. This law focuses on all waters actually or potentially designated for drinking, whether from surface or groundwater sources. The act authorized EPA to establish safe standards of purity and required all owners or operators of public water systems to comply with health-related standards.

Resource Conservation and Recovery Act (RCRA)

RCRA gave EPA the authority to control hazardous waste from the "cradle to grave", including the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also set forth a framework for the management of non-hazardous wastes. The 1986 amendments to RCRA enabled EPA to address environmental problems that could result from underground tanks storing petroleum and other hazardous substances. RCRA focuses only on active and future facilities and does not address abandoned or historical sites.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

CERCLA, commonly referred to as "Superfund", provides Federal funding to help clean up uncontrolled or abandoned hazardous-waste sites as well as accidents, spills, and other emergency releases of contaminants into the environment. Through the act, EPA was given power to seek out those parties it considers responsible for any release of contaminants and obtain their cooperation and monetary contributions in the cleanup.

www.epa.gov/teachers/environmental_laws.htm over-use. Priority dates are not considered when issuing a water use permit. While few of these new permit systems have been tested in state courts, the trend toward permit systems is very clear.

Under the prior appropriation doctrine, water is treated like a property right. To obtain water, a physical diversion needs to be made and a beneficial use identified, at which time a priority date is established for the right. The priority date is very important, as the earlier the date the more "senior" the right. Thus, if the senior right is located at the lower end of a stream the holder of this right obtains water before anyone else on the stream. The farther downstream the senior right holders are, the longer water stays in the stream, which benefits aquatic plants and animals. Under the prior appropriation doctrine, the water does not have to be used in the watershed; it can be transferred to other watersheds. A water right can be lost if it is not put to use. Water rights are administered by the states, and the purchase and transfer of water rights are critical to all water uses in the West.

Providing for the Future

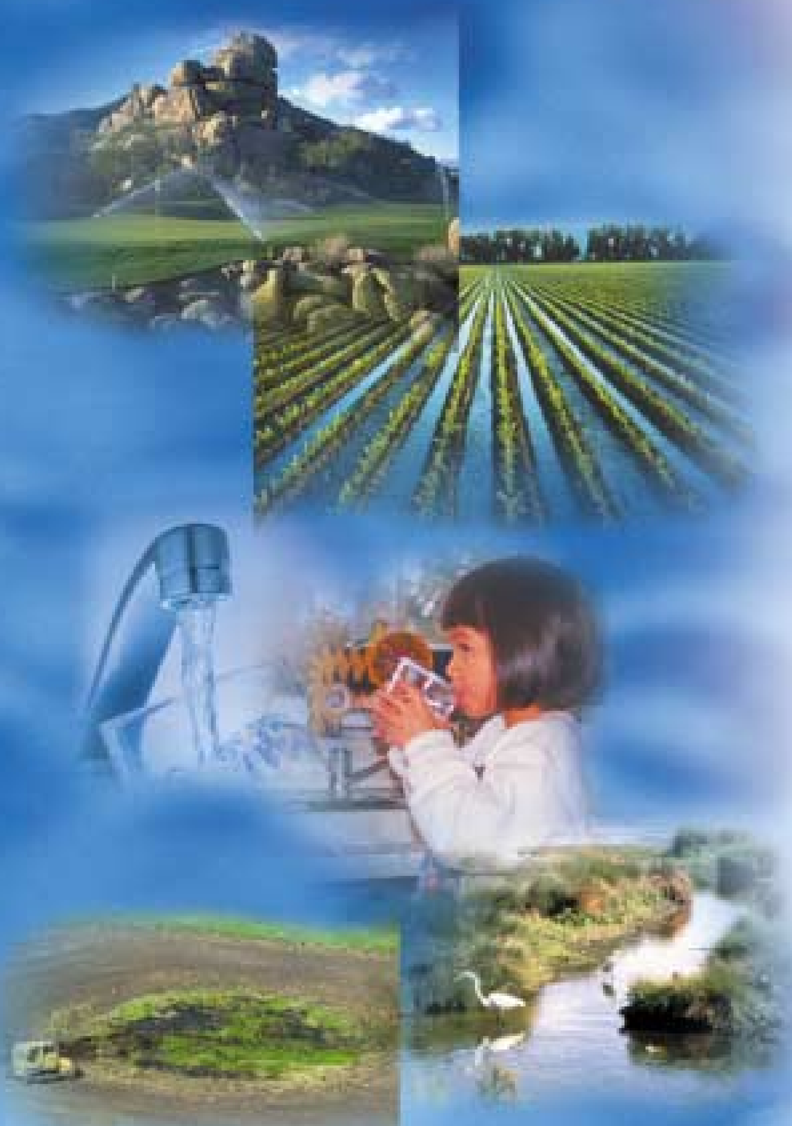
Sustainable development is based upon meeting the needs of present generations without compromising the ability of future generations to meet their needs. The sustainablility of water resources is affected by many factors, including reductions in streamflow, potential loss of wetlands, riparian ecosystems, and free flowing rivers, depletions of groundwater storage, land subsidence, salt-water intrusion, and changes in water quality. Each water system and development situation is unique and requires an analysis based on the nature of the existing water issues. Critical to this issue is the framing of hydrologic implications of various management alternatives in a way that they can be properly evaluated.

As the Nation's population continues to grow, increased demands will be placed on the Nation's water resources. Growth in human population will result in competing demands for water between urban development, agricultural, recreational, and environmental uses (Fig. 45). Increased needs for water for economic development must be balanced with recreational and environmental needs. Studies need to be conducted to determine the effects of dams and diversions on stream systems, and the impacts associated with groundwater development. The quantity and quality of water needed to maintain existing habitats needs to be determined. Finding the balance between development and other uses of water requires site-specific information about the environmental impacts and mitigation measures associated with individual projects.

Water management in the 21st Century will require an understanding of the connection between surface water and groundwater because they are continually interacting with each other. Future water supply can make use of aquifers for storage, greatly reducing the environmental

Fig. 45

TRADE-OFFS



Growing demands for water resources will necessitate trade-offs between water uses.

concerns associated with development of new dams and associated reservoirs. Artificial recharge is one method of using aquifers for storage. Artificial recharge is accomplished by pumping water directly into the aquifer by wells, or by the surface spreading of water over the aquifer allowing water to infiltrate to recharge the system.

Interaction between groundwater and surface water creates habitat for aquatic species. Determining the contributions of groundwater in these settings is also critical to water-quality management. Much of the groundwater contamination is in shallow aquifers that are directly connected to surface water, or in karst areas.

Natural disasters such as floods and droughts take lives, disrupt communities, destroy property, and affect the economy. The cost of natural disasters, both in human and financial terms, has greatly increased over the past century and could continue on the same course over the next century. Continued studies of these natural disasters are necessary so that people can plan and build accordingly and thus live safely under these conditions.

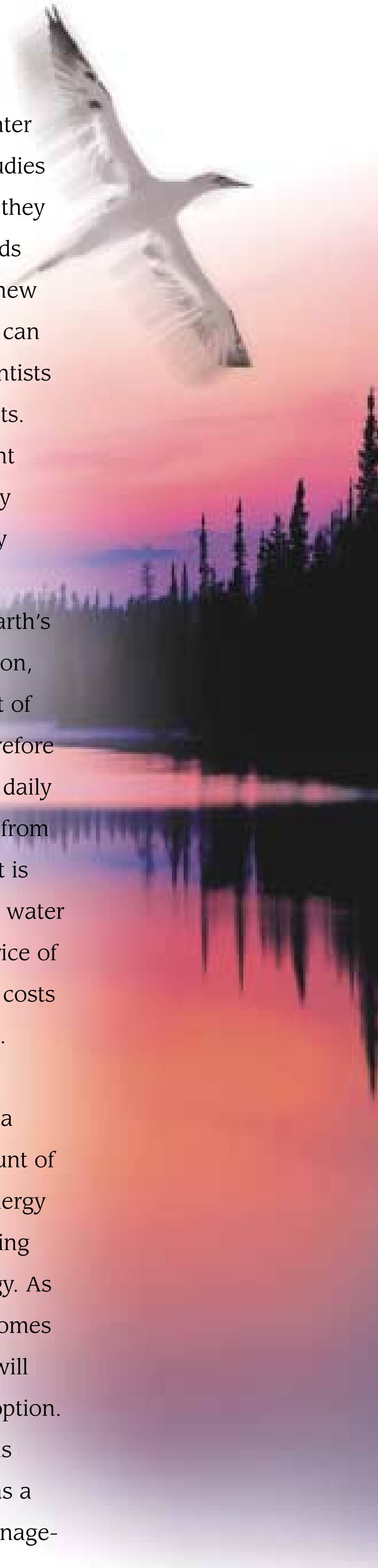
Sufficient quantities of clean water are needed for drinking, economic development, and recreation. Current environmental problems need to be resolved, and future problems prevented. An increased knowledge of how ecosystems function and the effects of human activities on them is required to provide for the future. Individuals need to be conscious of their impacts on both the quantity and quality of water, and they need to act to prevent waste or degradation whenever possible. Decision makers need good, sound, scientific data, and predictive analyses based on the data to make the appropriate water resource decisions for the 21st century.

Strategies to provide and protect drinking water must go beyond reliance on water treatment plants and disinfection to assure safe water supplies. Microbial pathogens that are resistant to chlorination, and the ever-increasing use of synthetic compounds that may have adverse health effects are challenging treatment technology. Future protection requires an increased awareness that drinking water supplies are dependent upon whole systems that include source areas, groundwater wells, surface-water intakes, treatment plants and distribution systems. Understanding and protecting the sources of drinking water is the most desirable strategy for the future.

The continual development and production of new chemical compounds has greatly improved human health, food production, and our daily lives. However, these chemical compounds are beginning to appear in low concentrations in water resources. Examples of some compounds found to date include caffeine, codeine, over-the-counter pain relievers, hormones, and antibiotics. The impacts of these chemical compounds on human or aquatic life in the low concentrations currently found in the environment are presently unknown. Analytical methods are needed to identify new compounds as they enter our water resources, and scientific studies are needed to determine any impacts they may have. Because there are thousands of chemicals already being used and new ones being developed every day, they can accumulate in waters faster than scientists can assess their environmental impacts. People can help prevent the movement of chemical compounds into waters by using proper disposal methods for any unused medicines or other chemicals.

Today, less than one percent of Earth's water is available for drinking, irrigation, and industrial use. About 97.5 percent of the Earth's waters are saline, and therefore not of suitable quality for most of our daily needs. Although salt can be removed from water, desalination is very costly. Cost is the major drawback to using desalted water to meet our fresh water needs. The price of desalination of water includes capital costs and operating and maintenance costs. Costs can vary considerably from one desalination site to another based on a number of factors, including the amount of salt to be removed, and the cost of energy required to operate the plant. Removing salt from water requires a lot of energy. As the supply of existing fresh water becomes scarcer, desalination of ocean water will become a more economically viable option.

Because water is a resource that is used and reused for so many needs, as a society we must make wise water management decisions that consider all of the demands made on our water resources.



Glossary

aquifer A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield useful quantities of water to a well or spring.

alluvial fan A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream.

artesian well A well tapping a confined aquifer. Water in the well rises above the top of the aquifer under artesian pressure, but does not necessarily reach the land surface; a flowing artesian well is a well in which the water level is above the land surface.

beneficial use A use of water resulting in appreciable gains or benefit to the user, consistent with state law, which varies from one state to another.

consumptive use The removal of water from the water environment by evaporation, transpiration, incorporation into products or crops, or consumption by people or livestock.

ecosystem A unit consisting of the environment with its living elements, plus nonliving factors that exist in and affect it.

effluent Wastewater, treated or untreated, that discharges from a factory, sewer works, or treatment plant; water discharged from a storm sewer or from land after irrigation.

erosion The general process or group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another by natural agents, which include weathering, solution, corrosion, and transportation, but usually exclude mass wasting.

evapotranspiration Loss of water from a land area through transpiration of plants and evaporation from the soil and surface-water bodies.

flood plain The surface or strip of relatively smooth land adjacent to a river channel constructed by the present river in its existing regimen and covered with water when the river overflows its banks.

fresh water Water that contains less than 1,000 parts per million (ppm) of dissolved solids; generally, water with more than 500 ppm of dissolved solids is undesirable for drinking and many industrial uses.

groundwater That part of the subsurface water that is in the saturated zone.

instream Water that is used, but not withdrawn, from a groundwater or surface-water source for uses such as hydroelectric power generation, navigation, water-quality improvements, fish propagation, and recreation. Sometimes called in-channel use.

karst A type of topography that is formed on limestone, gypsum, and other rocks, primarily by dissolution, and that is characterized by sinkholes, caves, and underground drainages.

load The material that is moved or carried by a natural transporting agent, such as a stream.

nonpoint source A diffuse source of contaminants, i.e., without a single point of origin or not introduced into a receiving streams from a specific outlet.

offstream Water withdrawn from surface or groundwater sources for use at another place.

point source A stationary location or fixed facility from which contaminants are discharged.

riparian Pertaining to or located on the bank of a body of water.

salt water Water that contains significant amounts of dissolved salts and solids. A synonym of seawater; the antonym of fresh water in general.

saturated zone A subsurface zone in which all the interstices or voids are filled with water under pressure greater than that of the atmosphere.

sediment Solid fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice, or that accumulates by other natural agents, and that forms in layers on the Earth's surface at ordinary temperatures in a loose, unconsolidated form.

sediment transport The movement and carrying-away of sediment by a natural agent such as a stream.

stream power Stream power is measured in foot-lbs/second foot and is equal to the specific weight of water (lbs/ft3) times discharge (ft3/second) times slope (feet/feet).

sublimation The process by which a solid substance, such as ice and snow, vaporizes without passing through a liquid stage.

surface water All waters on the surface of the Earth, including fresh and salt water, ice, and snow. Surface water includes water in ponds, lakes, inland seas, and streams.

transpiration The quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time.

unsaturated zone A subsurface zone immediately below the land surface where the pores or fractures contain both water and air.

watershed The land area that drains water to a stream, river, lake, or ocean.

wetland A group of wet habitats, that includes areas that are permanently wet and/or intermittently water-covered.

withdrawal The act of removing water from a source for use; also, the amount removed.

Credits

Front Cover — (Counter-clockwise from top) Thunderstorm (Digital Vision); Mountain lake (Corbis); Ruth glacier, Alaska (Digital Vision); Frost crystal, Rock Bridge State Park, Missouri (Digital Vision); Grand Canyon (Corbis); Aerial view of rivers (unknown); Pumping groundwater (USGS); Irrigation field, Idaho (M. Milling, AGI); Dallas skyline (Corbis); Cypress trees in wetland (Digital Vision); Greer Spring, Mark Twain National Forest, Missouri (Digital Vision); Ocean (Corbis).

Inside Front Cover — Ocean (Digital Vision).

Contents — Landscape (Corbis).

Foreword/Preface — Lily pads and Foggy woods (Digital Vision).

Chapter 1 — Opening — Greer Spring, Mark Twain National Forest, Missouri (Digital Vision).
- Page 8 — Fig. 1, (Counter-clockwise from top) Transport ship (Corbis); Water sports (Hemera); Shower head (USGS); Drinking fountain (Lee Trotta); Irrigation field, Idaho (M. Milling); Elk, Washing machine and Fire hydrant (Hemera); Dalles Dam, OR (Corbis).
- Page 9 — Fig. 2, Flood and Drought (USGS).
- Page 10 — Fig. 3, Cypress trees in wetland (Digital Vision); Wildlife (Hemera); Reeds in wetland (Corbis).
- Page 11 — Fig. 4, Colorado River, AZ (Collier, M., 1996); Fig. 5, Watershed Divide illustration (Nelson, M. 1990).
- Page 12 — Fig. 6, Earth's fresh water (DeAtley Design).
- Page 14-15 — Fig. 7, National Watershed Characterization Map (EPA/National Resources Conservation Service).

Chapter 2 — Opening — Thunderstorm (Digital Vision).
- Page 18 — Fig. 8, The Hydrologic Cycle (J. Evans, USGS).
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Sources of Additional Information

The organizations listed here are only a fraction of the additional sources of water resource information. For example, within each state government an agency is responsible for water resources within that state. Check the blue pages (government section) of the telephone directory for contact information for the agency in your state.

American Ground Water Trust
www.agwt.org/

AGWT, a not-for-profit education organization, is an independent authority on the hydrologic, economic and environmental significance of groundwater.

American Water Resources Association
www.awra.org

AWRA works for the advancement of water resources research, planning, development, management and education.

American Water Works Association
www.awwa.org

AWWA is an international nonprofit scientific and educational society dedicated to the improvement of drinking water quality and supply.

Bureau of Reclamation
www.usbr.gov/

The Bureau of Reclamation manages, develops, and protects water and related resources in an environmentally and economically sound manner in the interest of the American public.

CUAHSI
www.cuahsi.org

The Consortium Universities for the Advancement of Hydrologic Science was established in 2001 to foster advancements in hydrologic science in the broadest sense.

Groundwater Foundation
www.groundwater.org/

The Groundwater Foundation is a nonprofit organization that is dedicated to informing the public about one of our greatest hidden resources, groundwater.

National Park Service
www.nps.gov

The National Park Service Water Resources Division, in partnership with parks and others, works to preserve, restore, and manage water and aquatic resources of units of the National Park System. The Division oversees programs that integrate the disciplines of hydrology, water quality, wetland and riparian ecology, aquatic/fisheries biology, and planning.

USDA Forest Service
www.fs.fed.us/geology

The Forest Service Minerals and Geology Management staff manages the mineral resources, geologic resources, paleontologic resources, and the mined land reclamation program on National Forest System lands. Emphasis is on the role of these disciplines in overall ecosystem conservation and sustainability.

U.S. Army Corps of Engineers
www.usace.army.mil

The U.S. Army Corps of Engineers provides quality, responsive engineering and environmental services to the Army and Nation in peace and war, at home and abroad. The Corps takes seriously its role as public steward of much of the Nation's infrastructure. More information about the Corps and its water resources programs can be found at the web site.

U.S. Geological Survey
www.usgs.gov

The USGS, a bureau within the Department of the Interior, serves the nation by providing relevant, impartial scientific information to describe and understand the Earth; to minimize the loss of life and property from natural disasters; to manage water, biological, energy, and mineral resources; and to enhance and protect our quality of life.

Water Environment Federation
www.wef.org/

The Water Environment Federation, a not-for-profit technical and educational organization was created in 1928 to continually assess and study the quality of our global water environment.

STATE GEOLOGICAL SURVEYS

Geological Survey of Alabama
www.gsa.state.al.us

Alaska Division of Geological and Geophysical Surveys
wwwdggs.dnr.state.ak.us/

Arizona Geological Survey
www.azgs.state.az.us

Arkansas Geological Commission
www.state.ar.us/agc/agc.htm

California Geological Survey
www.consrv.ca.gov/cgs/

Colorado Geological Survey
http://geosurvey.state.co.us/

Connecticut Geological and Natural History Survey
http://dep.state.ct.us/cgnhs/

Delaware Geological Survey
www.udel.edu/dgs/index.html

Florida Geological Survey
www.dep.state.fl.us/geology/

Georgia Geologic Survey Branch
www.dnr.state.ga.us/dnr/environ/aboutepd_files/branches_files/gsb.htm

Hawaii Geological Survey
www.state.hi.us/dlnr/cwrm

Idaho Geological Survey
www.idahogeology.org/

Illinois State Geological Survey
www.isgs.uiuc.edu/

Indiana Geological Survey
http://igs.indiana.edu/

Iowa Geological Survey Bureau/IDNR
www.igsb.uiowa.edu/

Kansas Geological Survey
www.kgs.ku.edu/

Kentucky Geological Survey
www.uky.edu/KGS/home.htm

Louisiana Geological Survey
www.lgs.lsu.edu/

Maine Geological Survey
www.state.me.us/doc/nrimc/mgs/mgs.htm

Maryland Geological Survey
www.mgs.md.gov/

Massachusetts Geological Survey
www.state.ma.us/envir/eoea

Michigan Geological Survey Division
www.michigan.gov/deq/1,1607,7-135-3306_3334_3568—,00.html

Minnesota Geological Survey
www.geo.umn.edu/mgs/

Mississippi Office of Geology
www.deq.state.ms.us/

Missouri Geological Survey and Resource Assessment Division
www.dnr.state.mo.us/dgls/homedgls.htm

Montana Bureau of Mines and Geology
http://mbmgsun.mtech.edu/

Nebraska Conservation and Survey Division
http://csd.unl.edu/csd.htm

Nevada Bureau of Mines and Geology
www.nbmg.unr.edu

New Hampshire Geological Survey
www.des.state.nh.us/descover.htm

New Jersey Geological Survey
www.state.nj.us/dep/njgs/

New Mexico Bureau of Geology and Mineral Resources
www.geoinfo.nmt.edu

New York State Geological Survey
www.nysm.nysed.gov/geology.html

North Carolina Geological Survey
www.geology.enr.state.nc.us/

North Dakota Geological Survey
www.state.nd.us/ndgs/

Ohio Division of Geological Survey
www.ohiodnr.com/geosurvey/

Oklahoma Geological Survey
www.ou.edu/special/ogs-pttc/

Oregon Department of Geology and Mineral Industries
www.oregongeology.com/

Pennsylvania Bureau of Topographic and Geologic Survey
www.dcnr.state.pa.us/topogeo

Puerto Rico Departamento de Recursos Naturales
www.kgs.edu/AASG/puertorico.html

Rhode Island Geological Survey
www.uri.edu/cels/gel_home/ri_geological_survey.htm

South Carolina Geological Survey
water.dnr.state.sc.us/geology/geohome.htm

South Dakota Geological Survey
www.sdgs.usd.edu/

Tennessee Division of Geology
www.state.tn.us/environment/tdg/

Texas Bureau of Economic Geology
www.beg.utexas.edu/

Utah Geological Survey
http://geology.utah.gov/

Vermont Geological Survey
www.anr.state.vt.us/geology/vgshmpg.htm

Virginia Division of Mineral Resources
www.geology.state.va.us

Washington Division of Geology and Earth Resources
www.wa.gov/dnr/htdocs/ger/ger.html

West Virginia Geological and Economic Survey
www.wvgs.wvnet.edu/

Wisconsin Geological and Natural History Survey
www.uwex.edu/wgnhs/

Wyoming State Geological Survey
www.wsgsweb.uwyo.edu/

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