BIBLIOGRAPHY OF REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM OF THE U.S. GEOLOGICAL SURVEY, 1978-96

By Ren Jen Sun, John B. Weeks, and Hayes F. Grubb

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY WATER-RESOURCES INVESTIGATIONS REPORT 97-4074

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U.S. GEOLOGICAL SURVEY

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FIGURES

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
Volume		
acre foot (acre-ft)	1,233	cubic meter
Flow		
foot per year (ft/yr)	0.3048	meter per year
inch per year (in/yr)	25.40	millimeter per year
cubic foot per second (ft^3 /s)	0.2832	cubic meter per second
gallon per minute (gal/mi^n)	0.063098	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
billion gallons per day (Ggal/d)	43.81	cubic meter per second

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

BIBLIOGRAPHY OF REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM OF THE U.S. GEOLOGICAL SURVEY, 1978-96

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ABSTRACT

The Regional Aquifer-System Analysis (RASA) Program of the U.S. Geological Survey was initiated in 1978 and was completed in 1995. The purpose of this program was to define the regional geohydrology and establish a framework of background information on geology, hydrology, and geochemistry of the Nation's important aquifer systems. This information is critically needed to develop an understanding of the Nation's major ground-water flow systems and to support better management of ground-water resources.

Twenty-five of the Nation's major aquifer systems were studied under this program. Starting in 1988, the program devoted part of its resources to compilation of a National Ground Water Atlas that presents a comprehensive summary of the Nation's major ground-water resources. The atlas, which is designed in a graphical format supported by descriptive text, serves as a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation.

This bibliography lists 1,105 reports that result from various studies of the program. The list of reports for each study follows a brief description of that study.

INTRODUCTION

The U.S. Geological Survey initiated the Regional Aquifer-System Analysis (RASA) Program in 1978 in response to Federal and State needs for information to improve management of the Nation's ground-water resources. The objective of the RASA Program is to define the regional geohydrology and establish a framework of background information--geologic, hydrologic, and geochemical--that can be used for regional assessment of ground-water resources and in support of detailed local studies. The program was completed in 1995.

A total of 25 aquifer systems were studied under the RASA Program (fig. 1). Studies of three other aquifer systems--the Pecos River Basin in New Mexico and Texas; the Alluvial Basins in Oregon, California, and Nevada; and the Illinois Basin in Illinois--were not started due to changes in national priorities, such as the emphasis on ground-water and surface-water relations and the hydrogeology of critical aquifers. This report provides synopses of these 25 regional aquifer systems and lists reports resulting from studies of each of these systems.

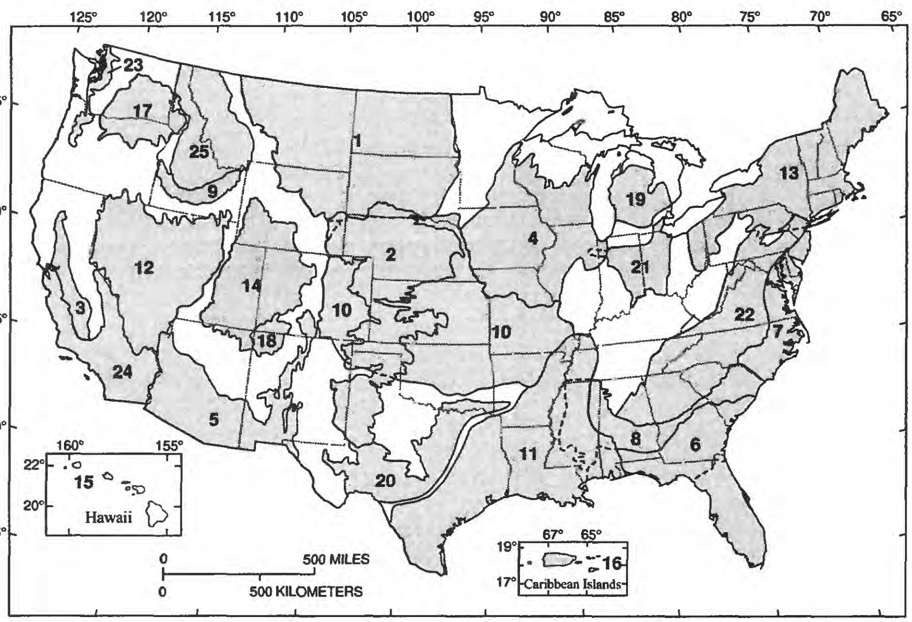
Because of the critical need for a unified summary of ground-water information on a nationwide scale, a ground-water atlas of the United States was compiled. The atlas summarizes RASA study results and other reports of the U.S. Geological Survey, various States and local agencies, and articles published in scientific journals. The atlas project is discussed in the last section of this report.

The U.S. Geological Survey has a National Research Program (NRP) that conducts basic and problem-oriented research. Basic research explores the scientific processes that control the quantity and quality of the Nation's water resources. Problem-oriented research develops operational and interpretative methods useful for water-resources investigations inside and outside of the Survey. The RASA Program has benefited from both the basic and problem-oriented research conducted through NRP. Each year the RASA Program has contributed funds to the NRP. These funds were used for research in all phases of the hydrologic cycle, not just those directly related to the RASA Program. The purpose of that support was to build for the future by providing funds for continued research and development of theoretical and operational procedures for hydrologic investigations. Reports published by NRP that are directly related to the RASA Program studies are included in this bibliography.

Upon completion of each RASA study, a U.S. Geological Survey Professional Paper or a series of Professional Papers are published to summarize and synthesize the results of that study. The Professional Papers associated with each RASA study have a unique number. Those with a series of chapters are designated by the study's unique number and a letter; the letter A commonly is reserved for the chapter that summarizes the major findings of the particular aquifer system. Professional Papers derived from the RASA Program are identified by a Professional Paper number between 1400 and 1425.

Scientific journal articles and symposium proceedings must be obtained from the journals or sponsoring organizations. The RASA Program has also produced many abstracts for presentations made at scientific meetings; these abstracts are not listed in this report.

This bibliography updates an earlier report (see report 8 in the list immediately below) by including the 876 references of the earlier work plus the additional 229 reports completed since. Some reports from the last few studies undertaken are currently (1996) in preparation.



EXPLANATION

Regional aquifer study areas

1 Northern Great Plains
2 High Plains
3 Central Valley, California
4 Northern Midwest
5 Southwest alluvial basins
6 Floridan
7 Northern Atlantic Coastal Plain
8 Southeastern Coastal Plain
9 Snake River Plain
10 Central Midwest
11 Gulf Coastal Plain
12 Great Basin
13 Northeast glacial aquifers
14 Upper Colorado River basin
15 Oahu, Hawaii
16 Caribbean Islands
17 Columbia Plateau
18 San Juan Basin
19 Michigan Basin
20 Edwards–Trinity
21 Midwestern basins and arches
22 Appalachian valleys and piedmont
23 Puget–Willamette Lowland
24 Southern California alluvial basins
25 Northern Rocky Mountain intermontane basins

Figure 1.--Location of regional aquifer-system studies.

The RASA Program produced 1,105 reports. Nine of these reports, listed below, explain and summarize the RASA Program. The other 1,096 reports are listed at the end of each section that briefly describes the study that produced the reports.

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ACKNOWLEDGMENTS

The authors thank the Regional Aquifer-System Analysis (RASA) Project Chiefs and their staffs, and the District Chiefs and their staffs who worked on the RASA studies and who reviewed a draft of this bibliography. Their assistance made the initial compilation of this report possible within a short period of time.

APPALACHIAN VALLEYS AND PIEDMONT

The study area of the Appalachian Valleys and Piedmont regional aquifer-system analysis is about 145,000 square miles, covering parts of New Jersey, Pennsylvania, Delaware, Maryland, the District of Columbia, West Virginia, Virginia, Tennessee, North Carolina, South Carolina, Georgia, and Alabama. The study area lies within parts of the Valley and Ridge, Blue Ridge, and Piedmont physiographic provinces in the Appalachian Highlands of the eastern United States.

Geologically and structurally, the study area can be divided into two distinct hydrogeological areas. The first area includes the Valley and Ridge physiographic province and the extreme western part of the Blue Ridge physiographic province. This area mostly consists of Paleozoic carbonate rocks (dolomite and limestone), sandstone, siltstone and shale. Ground-water flow in these rocks is predominantly through fractures or solution channels. The second area includes the Piedmont physiographic province and a larger part of the Blue Ridge physiographic province where often highly deformed Precambrian and lower Paleozoic metamorphic rocks are intruded by granite or other igneous intrusions. Ground-water flow in these rocks is predominantly through fractures that tend to decrease in size and number of openings with depth. Openings may extend several hundreds or thousands of feet down into the rocks.

Approximately 15 large rift basins, locally called early Mesozoic basins, are filled with sedimentary rocks intruded with basaltic lava flows. These basins occur within a 600 mile long area of the Piedmont. Permeability of the sandstones and other continental deposits is mostly in primary pore spaces, but fractures, joints, and bedding planes are additional avenues for ground water flow. Ground water is stored mostly in the regolith that mantles the fractured rocks in these physiographic provinces. The regolith includes soil, saprolite and partly weathered rocks. The thicker the regolith, the greater is the storage capacity for ground water.

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CARIBBEAN ISLANDS

The study area of the Caribbean Islands regional aquifer-system analysis covers Puerto Rico, its adjacent islands (Vieques, Culebra, and Mona), and the U.S. Virgin Islands (St. Croix, St. Thomas, and St. John). The most important ground-water areas in Puerto Rico are the limestone aquifers of the north coast and the alluvial/fan delta aquifers of the south coast. The Kingshill aquifer of St. Croix is the only aquifer of significant extent in the U.S. Virgin Islands and consists of the Kingshill Limestone and unnamed limestone of Pliocene age. The investigation of the Caribbean Islands regional aquifer-system analysis study, therefore, was concentrated on these aquifers.

The geology of Puerto Rico is complex and varied. The central core of the island consists largely of volcanic and intrusive rocks of Cretaceous and early Tertiary age. Limestones, minor dolomite and clastic sediments of Oligocene to Pliocene age were deposited to the north and south of the central mountain core. The clastic sediments consist of poorly sorted mixtures of gravel, sand, and fine-grained materials. On the north coast, minor clastic sediments grade upward into thick beds of relatively pure limestone. Ground water moving through joints and fractures in the limestone has formed solution cavities. In outcrop areas along the north coast, a mature karst topography has developed. Along the south coast, gravel, sand and silt fan delta (coastal alluvial fan) deposits and river alluvium of

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CENTRAL MIDWEST

The Central Midwest regional aquifer-system analysis study covers an area of 370,000 square miles in parts of Arkansas, Colorado, Kansas, Missouri, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The sedimentary rocks underlying the study area are generally water-yielding formations that range in thickness from a featheredge in Missouri to more than 40,000 feet in central Oklahoma. The igneous and metamorphic basement rocks that underlie the water-yielding formations generally do not yield significant quantities of water to wells. Therefore, the surface of the basement rock forms the lower limit of the ground-water flow system in the study area.

Hydraulic properties of the various rocks in the study area differ greatly. In most of the study area, the water-yielding rocks are deeply buried, and ground-water-related data are scarce except for data collected incidentally by the petroleum industry. Because the cost of collecting additional hydrologic data from the deep subsurface is prohibitive, special efforts and techniques were used to evaluate and analyze existing data.

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CENTRAL VALLEY, CALIFORNIA

The Central Valley of California is approximately 20,000 square miles. The northern part is drained by the Sacramento River, and the southern part is drained partly by the San Joaquin River and also contains an internally drained basin--the Tulare Basin. The aquifer system of the Central Valley is composed of a heterogeneous mixture of continental alluvial materials derived from the surrounding mountains. Thickness of the sediments averages about 1,500 feet in the Sacramento Valley and 2,900 feet in the San Joaquin Valley. About 50 percent of the thickness of continental sediments in the Central Valley is composed of clay and silt.

Annual pumpage in the Central Valley has increased from about 362,000 acre-feet during 1912-13 to about 15 million acre-feet during the drought in 1977. In parts of the Central Valley, pumping has caused water-level declines of nearly 400 feet. As water levels decline in aquifers, water stored in the pores of the fine-grained confining layers start to drain into the adjacent aquifers where heads have been reduced by pumping. As a result, the land surface has subsided due to inelastic compaction of the fine-grained sediments. By 1970, subsidence exceeded 29 feet in one place in the San Joaquin Valley, and more than 5,000 square miles of land surface in the Central Valley had subsided more than 1 foot.

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COLUMBIA PLATEAU, WASHINGTON, OREGON, AND IDAHO

The Columbia Plateau is located in central and eastern Washington, northern Oregon, and a small part of northwestern Idaho. The plateau covers about 63,200 square miles entirely within the drainage of the Columbia River. The Columbia Plateau regional aquifer-system analysis study consists of unconsolidated sediments, basaltic rocks, and intercalated sediments. Where saturated unconsolidated sediments overlie the basalts, they form a water-table aquifer that is termed the overburden aquifer. This aquifer is the uppermost unit in the Columbia Plateau aquifer system. Rocks of the Miocene Columbia River Basalt Group make up most of the aquifer system underlying the Columbia Plateau. The many layers of lava beds and sedimentary interbeds form a multilayered aquifer system, which for study purposes has been divided into three units. The units, including intercalated sediments, correspond to three basalt formations in the Columbia River Basalt Group--the Saddle Mountains, Wanapum, and Grande Ronde Basalts. The three basalt units are connected hydraulically either directly or through leaking confining sedimentary interbeds. The sedimentary interbeds between the units generally are fine grained and laterally extensive; the thickness of the interbeds is small compared to the thickness of the basalt units.

The four geohydrologic units (overburden aquifer and 3 basalt units) form the aquifer system underlying the Columbia Plateau and provide water for most municipal, industrial, and domestic needs; the units also provide water for most of the irrigated lands outside the Columbia Basin Irrigation Project area and the Yakima River Basin. Ground-water withdrawals were estimated at 56,000 acre-ft in 1945 and 838,000 acre-ft in 1984. About 80 percent of the water withdrawn is used for irrigation.

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EDWARDS-TRINITY AQUIFER SYSTEM, TEXAS

The approximately 95,000-square-mile study area of the Edwards-Trinity regional aquifer-system analysis study consists of the Edwards-Trinity aquifer system of central Texas, southeastern Oklahoma, and southwestern Arkansas, plus contiguous hydraulically-connected units. The Edwards-Trinity aquifer system includes three major aquifers that occur in rocks of Cretaceous age. The three aquifers of the system, named the Edwards aquifer, the Trinity aquifer, and the Edwards-Trinity aquifer, together extend over an area of about 80,000 square miles. The Edwards aquifer is composed mostly of extensively fractured and solutioned limestone that yields large quantities of water to wells and springs. The Trinity aquifer consists primarily of dolomitic limestone with interbedded sand, shale, and clay; and the Edwards-Trinity aquifer generally is composed of limestone and dolomite in its upper part, and quartz-rich sand in its lower part. In the southern half of the study area, south and west of the Colorado River, much of the aquifer system is near the surface and unconfined.

During the late 1980's, an estimated 1,200,000 acre-feet per year of water was withdrawn from the study area for all uses. More than 80 percent of the withdrawals (1,000,000 acre-feet per year) occurred in the southern one-half of the study area. Within that area, the major withdrawals are concentrated in the highly productive Edwards aquifer, which underlies an area of approximately 3,000 square miles. An estimated 545,000 acre-feet of water was withdrawn from the Edwards in 1988, primarily to supply municipal and industrial water to the San Antonio metropolitan area and irrigation water to farms west of the San Antonio area. Nearly one-half of the ground-water supplies were withdrawn from about 3 percent of the study area.

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FLORIDAN AQUIFER SYSTEM

The Floridan aquifer system is one of the major sources of ground water in the United States. This highly productive aquifer system underlies all of Florida, southern Georgia, and small parts of adjacent Alabama and South Carolina; a total area of about 100,000 square miles.

The Floridan aquifer system is a thick sequence of carbonate rocks of Tertiary age that are hydraulically connected in various degrees to form a regional aquifer system. The rocks range in thickness from a featheredge in outcrop areas to more than 3,500 feet in coastal areas. The aquifer system generally consists of an upper and lower aquifer separated by a less-permeable confining unit of highly variable properties.

Development of the Floridan aquifer system has proceeded unevenly with large withdrawals concentrated in a few areas. A total of about 3 billion gallons per day was withdrawn from the aquifer system as of the early 1980's. In many areas, the aquifer system is the sole source of freshwater. A considerable area of the Floridan aquifer system remains highly favorable for development of large ground-water supplies. This favorable area for development of large ground-water supplies is largely inland from the coast and is characterized by high transmissivity as well as minimal development in 1985. The major constraint on future development is potential for degradation of water quality. The possibility of saltwater encroachment in coastal areas and upconing of deep saltwater in some inland areas are important factors to be considered for future development.

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GREAT BASIN, NEVADA AND UTAH

The Great Basin regional aquifer-system analysis study covers an area of about 140,000 square miles in parts of Nevada, Utah, and adjacent states. The area is characterized by generally north-trending mountain ranges that range in width from 5 to 15 miles and rise 1,000 to 5,000 feet above the adjoining valleys. The widths of the valleys are about the same as widths of the adjacent mountain ranges. The valleys are typically elongated, and many extend more than 50 miles in a north or northeast direction.

The area has a complex geologic history that includes major episodes of sedimentation, igneous activity, orogenic deformation, and continental rifting. A major tectonic change occurred about 17 million years ago with the onset of extensional faulting, which has formed the major basins and ranges that characterize the topography. The Great Basin contains a regional aquifer system in a sense that most of its separate valley basins share common geologic and hydrologic characteristics. Currently, some 242 hydrographic areas are recognized within the study area; most include one or more structural basins and associated basin-fill aquifers. A special situation exists in eastern Nevada and western Utah, where permeable carbonate rocks underlying the basin-fill deposits form a complex ground-water flow system with the characteristics of both basin-fill and carbonate rock aquifers.

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GULF COASTAL PLAIN

The Gulf Coastal Plain regional aquifer-system analysis study covers an area of about 230,000 square miles onshore in parts of Alabama, Arkansas, Florida, Illinois, Kentucky, Mississippi, Missouri, Tennessee, Texas, and all of Louisiana. The study area also includes 60,000 square miles offshore between the coast and the edge of the continental shelf. The study is limited to the coastal plain sediments of Tertiary and younger age except for an area in the Mississippi embayment where Upper Cretaceous sediments supply ground water in parts of several States. The bottom of the aquifer system is either the top of the Paleocene Midway Group that consists of low permeable sediments, or at the top of the geopressured zone. The sediments are thin in and near the outcrop areas but attain thicknesses of several thousand feet downdip. None of the individual aquifers are continuous throughout the study area; some cover only a few hundred square miles. Some of the aquifers in sediments of Eocene age are present in as many as 8 of the 10 States and supply large quantities of freshwater for municipal, industrial, and agricultural use. Withdrawals increased from about 4,000 Mgal/d during 1960, to about 11,000 Mgal/d during 1990.

The sediments within the study area are composed predominantly of alternating beds of sand and clay with some interbedded gravel, silt, lignite, and limestone. The sediments that comprise the individual aquifers and associated confining units are exposed at land surface in narrow bands several miles wide that roughly parallel the present Gulf of Mexico coastline or the axis of major embayments. The sediments in the study area generally dip toward the Gulf of Mexico and generally become thicker and less permeable downdip. The regional ground-water flow pattern in these sediments is interrupted downdip by faulting or by the geopressured zone.

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HIGH PLAINS

The area of the High Plains regional aquifer-system analysis study is 174,000 square miles of flat to gently rolling terrain in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Ground water from the High Plains aquifer is the primary source of water supply in this area with few perennial streams. More than 90 percent of water used in the High Plains is obtained from the High Plains aquifer. About 95 percent of water used for irrigation is from the aquifer. Because of a plentiful supply of suitable-quality ground water, irrigation has transformed the High Plains into one of the Nation's major agricultural areas.

The High Plains aquifer consists mainly of near-surface sand and gravel deposits. The Tertiary Ogallala Formation, which underlies about 80 percent of the High Plains, is the principal geologic unit of the aquifer. The saturated thickness of the High Plains aquifer averages about 200 feet, and the maximum thickness is about 1,000 feet in central Nebraska. Ground water generally flows from west to east and discharges naturally to streams and springs and by evapotranspiration in areas where the water table is near land surface. Infiltration of precipitation and seepage from streams are the principal sources of recharge to the aquifer. Because the High Plains is located in a semi-arid region, recharge to the aquifer is small. This small recharge coupled with relatively large pumpage in parts of Texas, New Mexico, and Kansas have caused severe depletion of water in aquifer storage and declining water levels in these areas.

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MICHIGAN BASIN

The Michigan basin regional aquifer-system analysis study covers about 29,000 square miles of the Lower Peninsula of Michigan. The study is limited to Mississippian and younger consolidated and unconsolidated sediments in the Michigan Basin. The Marshall Sandstone (Mississippian), sandstones within the Grand River and Saginaw Formations (Pennsylvanian), and glacial deposits (Pleistocene) are the major aquifers in the Michigan Basin. The lower limit for the study has been defined as the contact between the Coldwater Shale (Mississippian) and the overlying Marshall Sandstone. Glacial deposits overlie nearly all of the study area.

Ground water has increasingly become an important source of water in Michigan. As of 1985, reported use of ground water averaged 220 Mgal/d (million gallons per day) for the entire State. Of this total, about 80 Mgal/d was from the Marshall and Grand River-Saginaw aquifers. About 40 Mgal/d was pumped from the glacial deposits in the study area.

Saline water underlies the entire Lower Peninsula of Michigan. In the center of the Michigan Basin, the Marshall Sandstone and the deeper parts of the Saginaw Formation contain brine or saline water. In the Saginaw Lowlands, saline water is present in glacial deposits. In the Lansing area, a cone of depression that extends over 100 square miles has developed in the Grand River-Saginaw aquifer. Water levels near the center of the cone have declined about 160 feet below the prepumping level. In the Flint area, where both the Marshall and Grand River-Saginaw aquifers were used for public supply, heavy pumping caused upconing of saline water. The ground-water supply was replaced by sources of surface water.

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MIDWESTERN BASINS AND ARCHES, OHIO, INDIANA, ILLINOIS, AND MICHIGAN

The Midwestern Basins and Arches study area includes about 43,000 square miles and extends approximately from Columbus, Ohio, to Indianapolis, Indiana, and from Lake Erie to the Ohio River. The major aquifers are in carbonate bedrock of Silurian and Devonian age, and saturated glacial deposits of Quaternary age. The bedrock subcrops beneath the Quaternary glacial deposits in western Ohio and eastern Indiana and receives recharge from the glacial deposits, which are normally under unconfined conditions, except where outwash deposits or basal material in buried valleys are covered by till or fine-grained lake deposits.

Most of the water in the glacial deposits locally discharges to streams after being recharged. However, a small amount of the recharge infiltrates downward from the glacial deposits to the underlying carbonate rocks. Water in the carbonate rocks is mostly under confined conditions, except where the bedrock is close to, or exposed at, the surface. The direction of ground-water flow in the carbonate rocks is generally toward major streams, such as the Ohio, Iroquois, Kankakee, and Scioto rivers, and to Lake Erie, and toward subcrop areas along the Scioto Valley and the Illinois structural basin.

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NORTHEAST GLACIAL AQUIFERS

The Northeast Glacial-Aquifers study includes most of the glaciated parts of the northeastern United States and extends as far west as Ohio. Long Island, New York, and Cape Cod, Massachusetts, are excluded from the study because the ground-water hydrology of these areas has been extensively studied. The study area includes (1) mountainous areas of New Hampshire, Maine, Vermont, and New York; and (2) low-lying areas along the Great Lakes, major rivers, and the Coast.

The study area has been divided into three major types of geohydrologic terrains within which aquifer systems have similar characteristics. These divisions are based largely on the geology of glacial deposits and on physiography. In 70 percent of the study area, major valley's sloped away from the ice sheet and generally contain productive aquifers, although silt and clay are relatively abundant in deep valleys. In 10 percent of the area, deep valleys that sloped toward the ice now contain mostly diamicton, silt, and clay with discontinuous buried aquifers. About 20 percent of the area consists of broad lowlands where surficial aquifers are widely scattered beneath extensive silt or clay, thin surficial aquifers are commnon near lowland margins and induced infiltration is generally not feasible

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NORTHERN ATLANTIC COASTAL PLAIN

The Northern Atlantic Coastal Plain is a gently rolling to flat region of about 50,000 square miles that extends along the coast from Long Island, New York, to the North Carolina-South Carolina State boundary. It is underlain by a seaward thickening wedge of predominantly unconsolidated sediments that thickens from a featheredge at the Fall Line in the west to more than 8,000 feet along the Coast of Maryland and 10,000 feet at Cape Hatteras, North Carolina. The sediments consist mostly of gravel, sand, silt, and clay of Jurassic to Holocene age. Limestone occurs principally in North Carolina. This sedimentary wedge forms a complex aquifer system in which the sand, gravel, and limestone function as aquifers, and the clay and silt function as confining units.

Ground-water recharge to the Northern Atlantic Coastal Plain aquifer system is derived from precipitation and occurs chiefly in upland and interfluvial areas. A small amount of the recharge water, generally less than 1 inch per year, replenishes the deeper confined part of the aquifers. Under natural conditions, discharge from the confined aquifers is primarily upward across the confining units into shallower aquifers and ultimately into major rivers, the sea, or coastal estuaries, sounds, and bays. Saltwater underlies freshwater in the seaward part of the Coastal Plain. Areas of shallow saltwater generally coincide with areas of natural ground-water discharge.

Withdrawal of water from the confined part of this aquifer system, principally for municipal and industrial use, has grown from about 100 million gallons per day in 1900 to about 1,200 million gallons per day in 1980. Pumping from the confined aquifer system has caused widespread potentiometric head declines that have significantly altered ground-water recharge, discharge, and flow patterns.

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NORTHERN GREAT PLAINS

The area of the Northern Great Plains regional aquifer-system study is about 300,000 square miles and includes North Dakota and parts of South Dakota, Montana, Wyoming, and Nebraska. The Northern Great Plains mostly is underlain by sandstone, limestone, shale, and some evaporite deposits. Ground water generally flows northeastward across the area. The source of recharge is precipitation in topographically high areas. Ground water generally travels hundreds of miles and discharges into topographically low areas of eastern North Dakota and South Dakota and occurs as subsurface outflow into Canada. Some ground-water discharge also occurs as diffuse upward leakage into overlying shallower aquifers.

Flow characteristics vary significantly between the predominantly carbonate aquifers in Paleozoic rocks (such as the Madison Limestone) and the predominantly clastic aquifers in Mesozoic rocks (such as the Dakota Sandstone). Potential for flow between aquifers exists near recharge and discharge areas and in the interior part of the study area, where hydraulic heads differ significantly between aquifers.

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NORTHERN MIDWEST

The Northern Midwest regional aquifer-system analysis study area is about 161,000 square miles in parts of Illinois, Indiana, Iowa, Minnesota, Missouri, and Wisconsin. Sandstones of Cambrian and Ordovician age are the most permeable rocks in the area and constitute a regional aquifer system known as the Cambrian-Ordovician aquifer system. The aquifer system contains three major aquifers--the St. Peter-Prairie du Chien-Jordan aquifer, the Ironton-Galesville aquifer, and the Mount Simon aquifer. The aquifers are separated by low permeability shale, shaly dolomite, or siltstone.

The Cambrian-Ordovician aquifer system is a leaky-artesian system. Movement of ground water is partly controlled by low permeability confining units of shale, shaly dolomite, or siltstone. In the upland and outcrop areas where the system is thin, water-table conditions exist. Much of the recharge occurs in those areas. Most of the recharge water flows locally, less than a few miles, and discharges into nearby streams. The remainder of the recharge moves slowly downward to deeper formations which are part of the regional confined ground-water flow system.

The aquifer system is used extensively for industrial, municipal, and rural water supplies in the six States. Hydraulic heads in the aquifer system in the heavily pumped Chicago-Milwaukee area have declined hundreds of feet since the late 1800's and to a lesser extent in other major metropolitan areas.

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NORTHERN ROCKY MOUNTAINS INTERMONTANE BASINS, MONTANA AND IDAHO

The Northern Rocky Mountains Intermontane Basins study area encompasses about 80,000 mi^2. The study area extends westward from the Northern Great Plains in Montana to the Columbia Plateau in western Idaho, and northward from the Snake River Plain in Idaho to the United States-Canada border. Basin-fill deposits of Tertiary and Quaternary age may be as much as 16,000 feet thick. Aquifers within basin-fill deposits in western Montana and central and northern Idaho were the focus ot this study. The term "basin" is used to refer to structurally defined areas and features that contain unconsolidated to poorly consolidated deposits. About 70 basins were delineated and data were collected and compiled for about 54 basins.

The basin-fill aquifers supply water for many purposes; the largest use of ground water is for irrigation and public supply. Total ground-water withdrawals during 1985 were estimated at 400 Mgal/d.

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OAHU, HAWAII

The Island of Oahu has a land area of 604 square miles and was formed through building and subsequent coalescence of two shield volcanoes, the Waianae and Koolau Volcanoes. The Waianae Volcano forms the western part of Oahu, and the Koolau Volcano forms the eastern part. A long period of quiescence followed the initial mountain building. During the quiescence, both volcanoes were deeply eroded. The Waianae Volcano became dormant first, and the westward dipping flows of the Koolau Volcano overlapped the eroded surface of the Waianae Volcano in the central part of the island. Subsidence of Oahu submerged permeable lava flows and placed them in hydraulic contact with the surrounding ocean water. Shifts in sea level and erosion allowed deposits of marine and terrestrial sediments to accumulate behind barrier reefs, forming coastal plains in some areas.

A regional aquifer system in volcanic rocks derived from the Waianae and Koolau Volcanoes is subdivided areally by geohydrologic barriers such as dikes. Fresh ground water occurs on Oahu as a basal lens floating on saltwater, as dike-impounded water, and as water perched above the basal aquifer. The first well was drilled near Honolulu in 1879. Ground-water withdrawals for 1901 are estimated at about 18 Mgal/d and by 1915 exceeded 200 Mgal/d. Ground-water withdrawals averaged about 340 Mgal/d for the period 1961-85 and ranged from about 160 to 413 Mgal/d.

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PUGET-WILLAMETTE LOWLAND, WASHINGTON AND OREGON

The Puget-Willamette Lowland is located in western Washington, western Oregon, and a small part of southwestern British Columbia, Canada. The study area extends from near the Fraser River in British Columbia to just south of Cottage Grove in Oregon. The Puget-Willamette Lowland consists of two distinct aquifer systems, the Puget Sound Lowland aquifer system in Washington and Canada and the Willamette Lowland aquifer system in Oregon. The study covers an area of about 27,400 square miles, of which the Puget Sound Lowland covers about 16,200 square miles (including about 2,500 square miles of saltwater area) and the Willamette Lowland is about 11,200 square miles.

Alluvium, glacial, and interglacial sediments comprise the aquifer system in the Puget Sound Lowland area. These deposits consist principally of river alluvial, recessional and advance outwash, till, and other glaciofluvial and interglacial sediments. In the Willamette Lowland, alluvial basin-fill sediments and basalt comprise the aquifer system. Tertiary sedimentary, volcanic and metamorphic rocks form the lateral and basal boundaries of both aquifer systems. Recent, large increases in population are increasing the demands for water supplies. Ground water is an important source of supply in the study area, but some problems--such as saltwater intrusion from Puget Sound and upconing of salt water in the Willamette Lowland--have been associated with increases in ground-water withdrawals.

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SAN JUAN BASIN, ARIZONA, COLORADO, NEW MEXICO, AND UTAH

The San Juan structural basin, in New Mexico, Colorado, Arizona, and Utah, has an area of about 21,600 square miles. The regional aquifer-system analysis study of the San Juan Basin includes rocks of Triassic or younger age which underlie about 19,400 square miles of the structural basin. Annual precipitation in the mountainous areas along the northern and eastern margins of the basin ranges from 20 to 30 inches, whereas the lower-altitude central part of the basin receives 10 or fewer inches per year. Altitudes in the study area range from about 4,500 feet in the northwest to about 11,000 feet in the southeast.

The San Juan structural basin contains a thick sequence (more than 14,000 feet) of sedimentary rocks ranging in age from Cambrian through Tertiary. These sedimentary rocks dip from the basin margins toward the trough-like structural center of the basin. The older sedimentary rocks crop out around the basin margins and are successively overlain by younger rocks toward the structural center of the basin. Tertiary volcanic rocks and various Quaternary deposits also are present in the basin.

The most important of the eight regional aquifers in the study area are in permeable rocks of the Morrison Formation, Gallup Sandstone, and Dakota Sandstone. Ground water is an important resource in much of the San Juan Basin, because surface water has been fully appropriated or is not available. Historically, the main uses of ground water were for municipal, domestic, and stock purposes. However, since the late 1970's competition has been great among electric-power companies, municipalities, Indian communities, and mining companies for rights to use the limited ground-water resource in the basin.

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SNAKE RIVER PLAIN, IDAHO

The Snake River Plain covers an area of about 15,600 square miles that extends across southern Idaho into eastern Oregon. The Snake River descends 2,930 feet along its 502-mile course through the study area. The surface of the plain decreases in altitude from about 6,000 feet above sea level in the northeast to 2,100 feet in the west. Average annual precipitation on much of the plain is less than 10 inches, one-third to one-half of which falls during the growing season from April through September. Most water available to the plain originates as snow on surrounding mountains, which are as much as 12,000 feet above sea level. Annual precipitation in the mountains is as much as 60 inches.

The eastern part of the Snake River Plain is basically a downwarped basin filled with basalt rocks of Quaternary age. Near the margins, unconsolidated sedimentary rocks overlie and are intercalated with the basalt. The tops of basalt flows are typically broken and have large values of hydraulic conductivity. Consequently, thick sections of basalt, which include many separate flows, store and yield large quantities of water. In places, the basalt aquifer may be several thousand feet thick. About two-thirds of the ground water discharged from the eastern plain is through a series of springs that flow to the Snake River, including 11 that discharge an average of more than 100 cubic feet per second.

The western part of the plain is a graben bounded by well-defined high-angle faults. Tertiary and Quaternary sedimentary rocks of variable thickness are the predominant fill material. Ground-water discharge to the Snake River in the western plain is small relative to that in the eastern plain.

The economy of southern Idaho is based largely on agriculture, which is dependent on an adequate supply of water for irrigation. In the past, most water for irrigation was obtained from the Snake River. By the early 1950's, ground water was also a major source of water for irrigation. About 2 million acre-ft of ground water was withdrawn during 1980.

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SOUTHEASTERN COASTAL PLAIN

The Southeastern Coastal Plain aquifer system underlies an area of about 130,000 square miles in parts of South Carolina, Georgia, Alabama, Mississippi, and adjacent areas of northern Florida and southwestern North Carolina. The Southeastern Coastal Plain aquifer system is located among the three adjacent studied regional aquifer systems: the Northern Atlantic Coastal Plain to the northeast, the Floridan to the south and southeast, and the Gulf Coastal Plain to the west.

The Southeastern Coastal Plain aquifer system consists of a thick wedge of unconsolidated to consolidated clastic and carbonate rocks of Cretaceous to Holocene age. These rocks extend and thicken seaward from the inner Coastal Plain margin to the Atlantic Ocean, Gulf of Mexico, or Florida peninsula. Except where they are covered by younger strata, the aquifers and confining units that comprise the Southeastern Coastal Plain regional aquifer system crop out in adjacent bands from Mississippi to South Carolina. In outcrop areas, most of the water that enters the aquifer system discharges to nearby streams. The remainder of the recharge moves downgradient and enters the deeper, confined aquifer system. The lower limit of the Southeastern Coastal Plain aquifer system is delineated at the freshwater-saltwater interface in gulfward areas, and by low permeability rocks of Paleozoic and early Mesozoic age in landward areas.

Pumping from the Southeastern Coastal Plain aquifer system has caused only local water-level declines, and degradation of ground-water quality due to upconing or saltwater encroachment occurs only in restricted areas.

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SOUTHERN CALIFORNIA BASINS

The regional aquifer-system analysis study of the southern California basins covers an area of 75,000 square miles. The area includes 89 drainage basins that can be grouped according to common characteristics and relations into coastal and desert basins. Because of the large size of the study area and the large number of basins involved, it is impractical to study each basin in detail. Therefore, a coastal basin and a desert basin were selected for intensive study.

The coastal basin selected for intensive study is the Santa Clara-Calleguas basin, and the desert basin is the Mojave basin.

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SOUTHWEST ALLUVIAL BASINS, ARIZONA

The study includes an area of about 82,000 square miles in southern and central Arizona and parts of California, Nevada, and New Mexico and contains 72 basins that generally are separate hydrologic entities. The boundaries between basins generally correspond to surface-water drainage divides, ground-water divides, or areas of minimal interbasin connection. The study area is characterized by sharply rising mountains that separate wide, flat basins filled with varying amounts of alluvial deposits. These alluvial deposits form the major aquifers and store large amounts of water.

The basins were formed 10 to 15 million years ago when movement along high-angle normal faults down-dropped the basins in relation to the mountain masses. The result was a series of generally northwest-trending basins. The formation of basins was a gradual process that was accompanied by deposition of locally derived sediments. The alluvial deposits range in thickness from a few thousand feet to more than 10,000 feet.

Ground-water withdrawals during 1915 are estimated at about 120 thousand acre-ft. Withdrawals increased to almost 4 million acre-ft by 1953 and ranged between 4 and 6 million acre-ft for the period 1954-83.

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SOUTHWEST ALLUVIAL BASINS, NEW MEXICO

The study of alluvial basins in central and southern New Mexico and adjacent parts of Colorado and Texas covers a total area of 70,000 square miles. The basins are bounded on the north, east, and west mainly by Precambrian crystalline rocks, Paleozoic and Mesozoic sedimentary rocks, and Tertiary volcanic rocks. The southern boundary of the study area is the Mexico-United States International Boundary.

Alluvial sediments in the basins were derived from surrounding highlands and mountains. The alluvial sediments are composed of flood-plain deposits and sediments of the Tertiary and Quaternary Santa Fe Group. The Santa Fe Group consists of unconsolidated to moderately consolidated lenticular deposits of gravel, sand, and clay interbedded in some places with volcanics.

Precipitation in the uplifted mountainous blocks east and west of the basins is the source of the surface water which eventually recharges the aquifers near the base of the mountains where infiltration rates are high. The other source of recharge is seepage from the Rio Grande. Most municipal and industrial wells in the study area are completed in the Santa Fe Group.

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UPPER COLORADO RIVER BASIN

The Upper Colorado River Basin has a drainage area of about 113,500 square miles in western Colorado, eastern Utah, southwestern Wyoming, northeastern Arizona, and northwestern New Mexico. The area contains a variety of landforms including rugged mountains, broad plains, deeply dissected canyons, relatively flat flood plains, and many erosional features. The area has been subjected to repeated tectonism. The predominant tectonic features are numerous basins and uplifts. The resulting structural relief is nearly 30,000 feet.

Consolidated sedimentary rocks of Paleozoic, Mesozoic, and Tertiary age attain a maximum thickness of tens of thousands of feet. Those rocks include fractured limestone, dolomite, and sandstone aquifers. Annual precipitation ranges from about 6 inches on the plains of Utah to about 40 inches in the mountains. Precipitation, in the form of snow and rainfall, is the major source of recharge to the aquifers. Several aquifers that are deeply buried in basins are exposed on margins of uplifts, where precipitation recharges the aquifers. Some aquifers in Tertiary rocks tend to be exposed and recharged over extensive areas.

Aquifer systems in the Upper Colorado River Basin have been grouped into three major groups. In descending order, they are the: (1) Tertiary-rock aquifers, (2) Mesozoic-rock aquifers, and (3) Paleozoic-rock aquifers. Within each aquifer group, rocks are further divided into aquifers and confining units on the basis of lithology, depositional environment, and hydrologic characteristics. Twenty-five aquifers and confining units have been identified for the Upper Colorado River Basin regional aquifer system.

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NATIONAL GROUND WATER ATLAS

The Ground Water Atlas of the United States is a unified, comprehensive summary of the Nation's ground-water resources and serves as a basic reference for the location, geography, geology, and hydrology of the major aquifers of the Nation. The atlas was compiled as part of the Regional Aquifer-System Analysis (RASA) Program.

The atlas, which is designed in a graphical format, is supported by descriptive discussions and is composed of 14 chapters. The introductory chapter presents a national overview of the ground-water conditions, describes effects of development such as saltwater encroachment and land subsidence on the ground-water flow system, and includes a map that shows locations of major aquifers. The remaining 13 chapters describe ground-water conditions in regional segments (fig. 2). The 13 regional segments collectively cover the 50 States and Puerto Rico and describe geologic and hydrologic conditions for the major aquifers in each regional area. The scale of the atlas does not allow portrayal of local features of the geology and hydrology of the aquifers described, nor does it include discussion of minor aquifers in the region. However, readers who seek detailed, local information on specific aquifers can find extensive lists of references at the end of each chapter.

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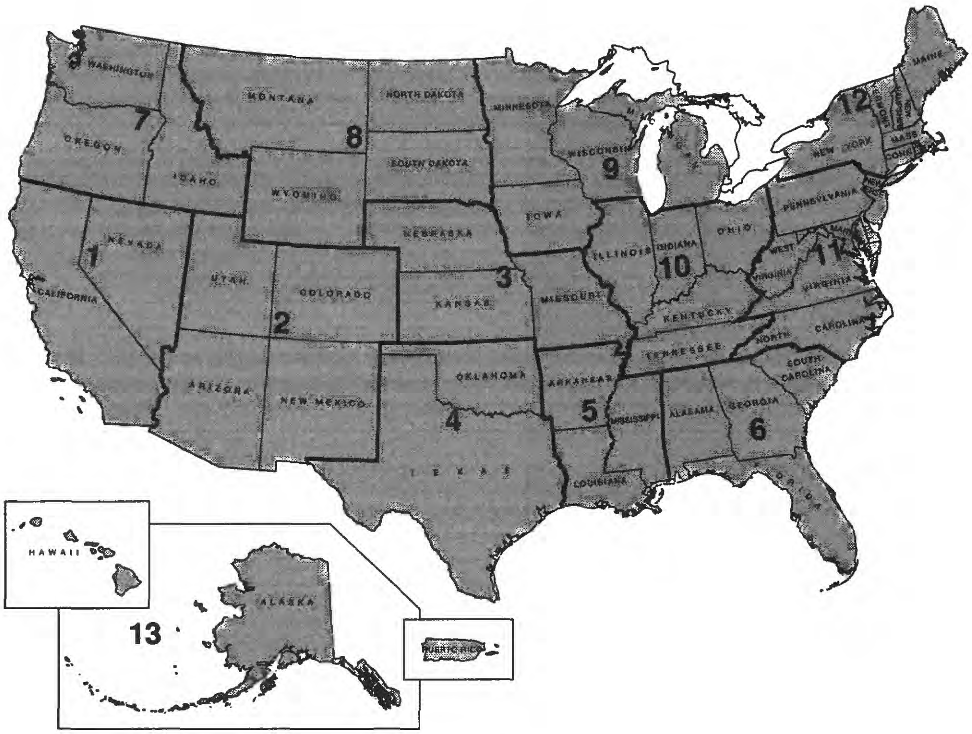

EXPLANATION

SEGMENT	CONTENT	ATLAS CHAPTER
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12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730-M
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Figure 2.--States contained in each segment of the Ground Water Atlas of the United States.