Strategic Directions for the U.S. Geological Survey Ground-Water Resources Program

A Report to Congress

November 30, 1998

U.S. Department of the Interior
U.S. Geological Survey

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U.S. DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

U.S. GEOLOGICAL SURVEY
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INTRODUCTION

The U.S. Geological Survey (USGS) has been collecting and interpreting ground-water data since the late 1800’s. Ground-water issues have increased in scope and complexity as competing demands on the resource have grown. Moreover, ground-water systems change over time in response to residential, industrial, and agricultural development, and in response to natural stresses such as droughts. Aquifers cross State lines and other political boundaries, creating the need for impartial regional and national ground-water information. The USGS Ground-Water Resources Program responds to these driving forces through ongoing efforts to examine and report on critical issues affecting the sustainability of the Nation’s ground-water resources.

This report discusses strategic directions of the Ground-Water Resources Program. The report is in response to a request from the U.S. House of Representatives Subcommittee on Interior Appropriations in its report to accompany H.R. 4193.

THE IMPORTANCE OF GROUND WATER TO THE NATION

Ground water is one of the Nation’s most important natural resources. Underground aquifers supply drinking water to about 130 million United States residents (about 50 percent of the population), and ground water is used in all 50 States (Figure 1). About 40 percent of the Nation’s public water supply, and much of the water used for irrigation, is provided by ground water. About 42 million people, including most of the rural population, supply their own drinking water from individual wells.

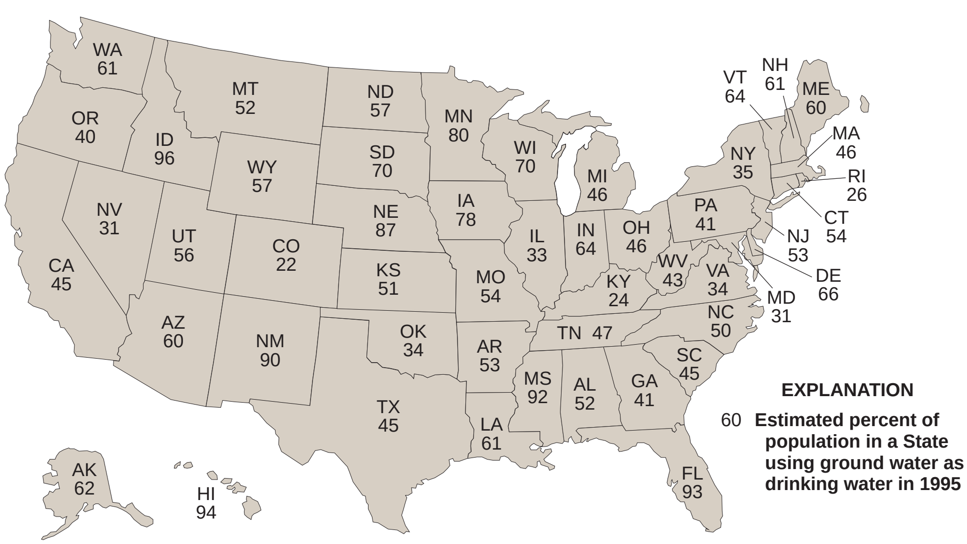


Figure 1. *Ground water is an important source of drinking water in every State. (Data from U.S. Geological Survey Circular 1200.)*

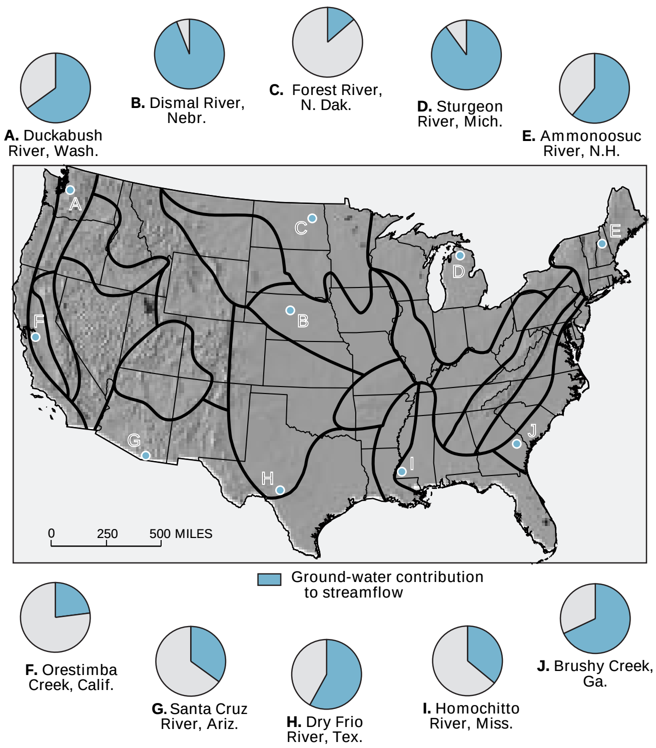


Figure 2. *In the conterminous United States, 24 regions were delineated where the interactions of ground water and surface water are considered to have similar characteristics. Pie diagrams for streams in 10 of the regions show the estimated ground-water contribution to streamflow. The pie diagrams illustrate the importance of ground water as a source of streamflow and the variability of the relation between ground water and surface water across the country. (Modified from U.S. Geological Survey Circular 1139.)*

Ground water also plays a crucial role in sustaining streamflow (Figure 2). During low-flow periods, most streamflow is derived from ground water. Ground-water pumping decreases the amount of ground water that flows to streams, or alternately, causes streams to seep to ground water. As a result, ground-water and surface-water users commonly compete for the same resource. Ground water also is vital to the health of lakes and wetlands. Moreover, plants and aquatic animals greatly depend upon the ground water that discharges to the streams, lakes, and wetlands in which they live.

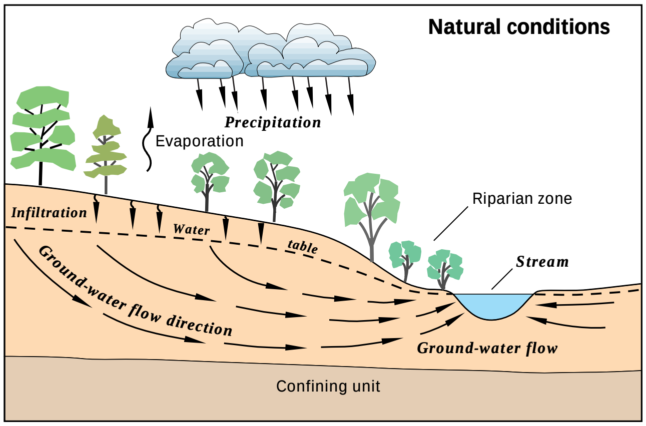
The USGS has had a central role in the development of ground-water hydrology to address these varied issues. The contributions have been of two kinds: (1) Development of the methods and principles underlying the science, and (2) characterization of major aquifers of the Nation to aid in the wise use and protection of these systems. Among federal agencies, only the USGS has the established mission and expertise to conduct a national effort to assess the status and trends of the whole resource. Other federal agencies contribute to basic research on ground water (e.g., National Science Foundation); have a role in technology for protection, artificial recharge, and cleanup of aquifers (Department of Energy, Bureau of Reclamation, Army Corps of Engineers, Environmental Protection Agency (EPA), and Department of Agriculture); and carry out investigations and research in support of regulatory responsibilities (EPA and Nuclear Regulatory Commission).

Many federal, State, and local agencies use the results of USGS studies. Users of ground-water information provided by the USGS rely on its unbiased scientific accuracy for purposes ranging from development of water-management plans to economic forecasts. The next section describes how ground-water issues have changed with time, and how the scientific programs and future plans of the USGS respond to those changing information needs.

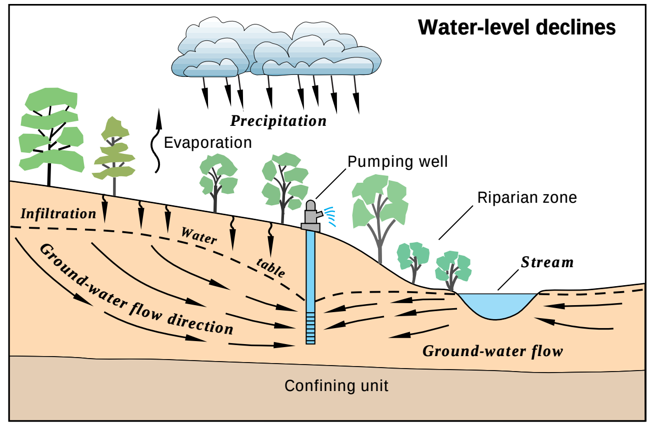
EVOLVING GROUND-WATER ISSUES AND USGS PROGRAMS

Initial concerns about ground water in the United States were largely focused on development of the resource. As development intensified, issues such as overpumping, equitable sharing of ground-water resources, and degradation of ground-water quality became increasingly important. Further development led to wider recognition of the effects of ground-water withdrawals on surface water and on the biological resources associated with lakes, wetlands, riparian areas, and estuaries.

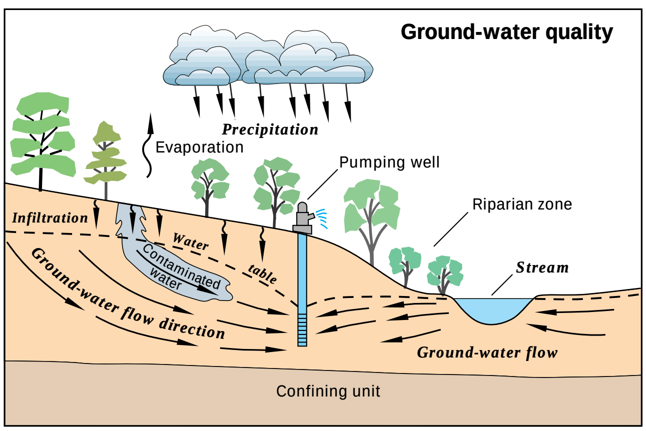
Ground-water programs of the USGS are an integral part of the Department of Interior and USGS Government Performance and Review Act (GPRA) strategic goal to "provide science for a changing world in response to present and anticipated needs." Further, the USGS has a goal to "ensure the continued availability of long-term environmental and natural resource information and systematic analysis and investigations needed by our customers."



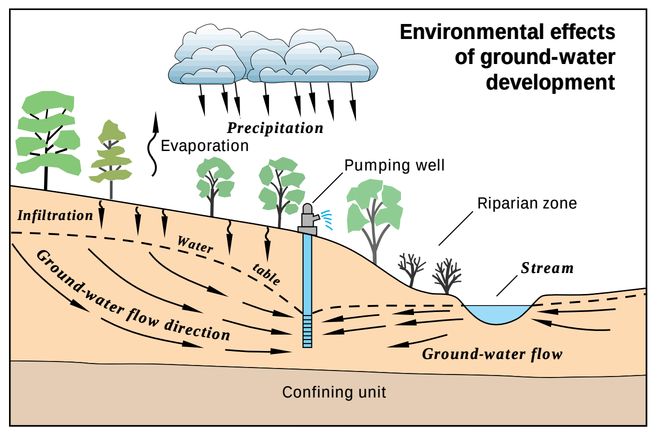
Water is recharged to the ground-water system by percolation of water from precipitation and then flows to the stream through the ground-water system.



Water pumped from the ground-water system causes the water table to lower and alters the direction of ground-water movement. Some water that flowed to the stream no longer does so and some water may be drawn in from the stream into the ground-water system, thereby reducing the amount of streamflow.



Contaminants introduced at the land surface may infiltrate to the water table and flow towards a point of discharge, either the well or the stream. (Not shown, but also important, is the potential movement of contaminants from the stream into the ground-water system.)



Water-level declines may affect the environment for plants and animals. For example, plants in the riparian zone that grew because of the close proximity of the water table to the land surface may not survive as the depth to water increases. The environment for fish and other aquatic species also may be altered as the stream level drops.

Figure 3. *Diagram of a cross section of ground-water flow to a stream illustrating various effects of ground-water development.*

Today, concerns about the sustainability of our ground-water resources involve:

1. Long-term availability of ground-water supply (and surface-water supply),
2. Protection of ground-water quality, and
3. Environmental effects of ground-water development.

Thus, ensuring sustainable ground-water development depends not only on understanding subsurface processes in aquifers, but also understanding the interaction of ground water with land and surface-water resources (Figure 3).

The USGS has continuously responded to changing ground-water issues. Four programs that should be mentioned in this regard are discussed here as background to their interplay with the Ground-Water Resources Program.

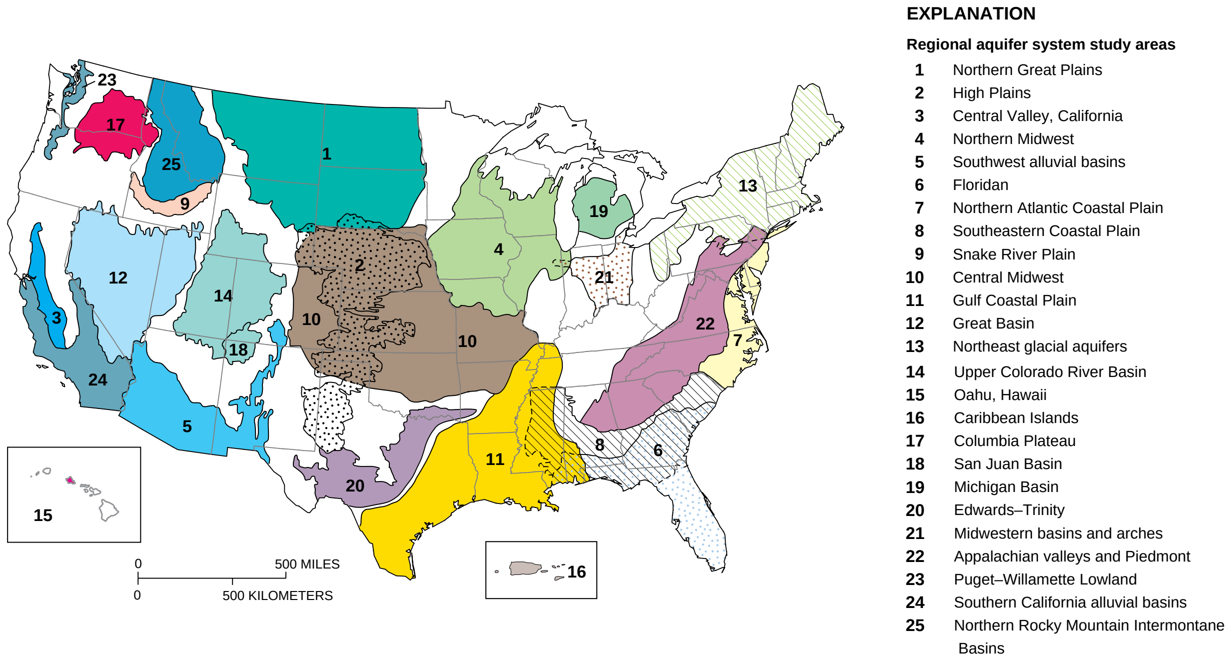


Figure 4. *From 1978–95, the USGS intensively studied 25 regional aquifers as part of the Regional Aquifer-System Analysis (RASA) Program.*

The **Regional Aquifer-System Analysis (RASA) Program** began in response to the 1977 drought and recommendations by the U.S. National Water Commission and the U.S. Comptroller General. From 1978 to 1995, the RASA Program systematically evaluated 25 of the Nation's most important ground-water systems (Figure 4). Computer models were used to develop estimates of current and future water availability for many of these systems. In addition, a National Ground-Water Atlas was compiled as a general source of information on ground-water resources.

The RASA Program provided a baseline of knowledge on the aquifer systems studied that will prove useful for many decades to come. However, as valuable as the RASA Program was, it leaves some important needs unfulfilled. The program did not examine many of the shallower or less productive aquifers that are very important to rural and small community water users and in sustaining flow in streams. The RASA Program also was static, describing the aquifers at a point in time. Virtually all of the information used in the RASA ground-water studies is now at least 10 to 20 years old. Ground water is dynamic, and aquifers must be re-examined over time as conditions and issues change.

The **National Water-Quality Assessment (NAWQA) Program** was started in 1991 to provide information about the status and trends in the quality of the Nation's ground-water and surface-water resources. The focus of the ground-water component of the NAWQA Program has been on the effects of human activities on the quality of ground water in agricultural and urban areas. The NAWQA Program provides critical information on the overall status and trends in ground-water quality, but was never intended to evaluate issues such as ground-water depletion and saltwater intrusion, nor to address many complex issues associated with the interactions of ground water with streams, lakes, wetlands, and other surface-water bodies.

The **National Cooperative Geologic Mapping Program (NCGMP)** was created as a partnership with State Geological Surveys and universities in 1992 by the National Geologic Mapping Act and reauthorized in 1997 as P.L. 105–36. Since 1992, the NCGMP has produced geologic maps and data bases as the framework for ground-water assessments of regional aquifers in the southwest and in the southeastern Coastal Plain and has funded many geologic mapping projects by State Geological Surveys and universities. On average, 35 percent of these projects cite ground-water issues as one of the principal reasons for mapping. For example, geologic map information for ground-water modeling, aquifer delineation, and well-head protection was cited as the highest priority need by public and private-sector participants at the 1997 Great Lakes Geologic Mapping Forum in Indianapolis.

The **Federal-State Cooperative (Coop) Water Program** matches funds from State and local agencies to support data collection and investigations that serve both federal interests and the needs of the State and local agencies. For over 100 years, this arrangement has been a valuable means to build a national data base and understanding of ground water. The RASA and NAWQA Programs have depended greatly on previous work in the Coop Program as the starting point to their efforts. A limitation of the Coop Program is that the studies rarely cross State lines because of the difficulty of aligning the funding plans of multiple States. A strength of the Coop Program is that close interaction with water managers at the State and local level ensures continuing relevance of the ground-water studies to address the most pressing issues. As new needs and issues emerge, the USGS works with its partners to provide the science to resolve them.

Cooperators and other stakeholders responding to strategic-plan development by the USGS have strongly highlighted the importance of improved unbiased, long-term assessments of the quantity of water in the Nation's aquifers. They point out the importance of these assessments to economic development, to resolution of interstate conflict, and to resolution of conflicts between development and environmental protection. Interactions with the Western Water Policy Review Advisory Commission (WWPRAC) further highlighted the inadequacies of current assessments. Questions about the status and trends of ground-water resources were central to their ability to envision the future of water in the West. The data assessments the USGS could provide were not equal to the task, and the WWPRAC report expresses the need for assessments that look at large scales over time scales of many decades.

RELATIONSHIP OF GROUND-WATER RESOURCES PROGRAM TO OTHER USGS PROGRAMS

The Ground-Water Resources Program (GWRP) has evolved from the RASA Program. The GWRP builds upon the Coop Program and other more localized studies to provide a more complete picture of the Nation's ground-water resources. The program is intended to update information from the RASA Program about the long-term availability of ground-water supply and also to address the environmental effects of ground-water development on land and surface-water resources. Geologic mapping capability by the NCGMP provides essential information on the geologic framework of ground-water systems, including development of new three-dimensional geohydrologic maps.

The GWRP is primarily focused on ground-water quantity and the effects of ground-water withdrawals on ground water and surface water, but also provides key information to complement NAWQA and other water-quality programs, particularly in the area of ground-water/surface-water interactions. For example, enhanced understanding of ground-water/surface-water interactions could lead to significant improvements in the design of water-quality monitoring networks and is needed to help identify when wells near streams are vulnerable to contamination by surface water (commonly referred to by EPA as "ground water under the influence of surface water").

In addition to the four programs highlighted above, the USGS has a wide range of capabilities in hydrology, biology, geology, and mapping to address ground-water resources in a fully integrated manner. For example, expertise in coastal geology enhances characterization of near-shore geologic environments for better understanding of saltwater intrusion and the discharge of fresh ground water to marine environments. Capabilities in remote sensing and land characterization provide key information for computer models and decision-support systems. Biological capabilities in habitats, wetlands, and instream-flow requirements are needed to assess the effects of ground-water development on surface-water systems. Expertise in climate improves understanding of the role of climate variability and climate change on ground-water resources.

CURRENT ACTIVITIES OF THE GROUND-WATER RESOURCES PROGRAM

Currently (1998), the Ground-Water Resources Program consists of five primary activities, briefly described below:

1. *Middle Rio Grande Basin, New Mexico*.—Studies by the New Mexico Bureau of Mines and Mineral Resources and the USGS in cooperation with the City of Albuquerque have shown that ground water is not as plentiful as once thought. Work is underway by the USGS to improve the understanding and the accuracy of estimates of the quantities and distribution of water moving into and through the ground-water system of the entire Middle Rio Grande Basin.

2. *Southwestern United States*.—Surface water in the southwestern United States is generally fully appropriated, and considerable ground-water development has taken place. New water supplies increasingly rely on conjunctive use of surface water and ground water. The dependence of sensitive ecosystems on ground water creates further competition for scarce water resources. To address these concerns, the USGS has begun a study of the interaction of ground water and surface water in the Southwest (Figure 5).

3. *South Florida*.—Analysis of options for restoration of the Everglades and Florida Bay depends on improved understanding of ground water and its interactions with surface water. The U.S. Army Corps of Engineers, National Park Service, and South Florida Water Management District are using information from USGS studies as they move toward restoration plans for the Everglades.

4. *Atlantic Coast*.—Development of ground-water resources along the Atlantic coast has caused saltwater to intrude many highly productive aquifers. Related concerns exist about the effects of changes in ground-water discharge to coastal ecosystems. A project to review what is known about these freshwater-saltwater issues along the Atlantic coast has recently begun.

5. *National Aquifer Data Base*.—Preliminary planning is underway for a digital data base on principal aquifer systems as a follow-up to the National Ground-Water Atlas.

The Ground-Water Resources Program thus addresses a variety of information needs. As the program transitions from its exclusive focus on the 25 RASA aquifer systems to broader issues, the above activities serve as prototypes for the possible future activities described below.

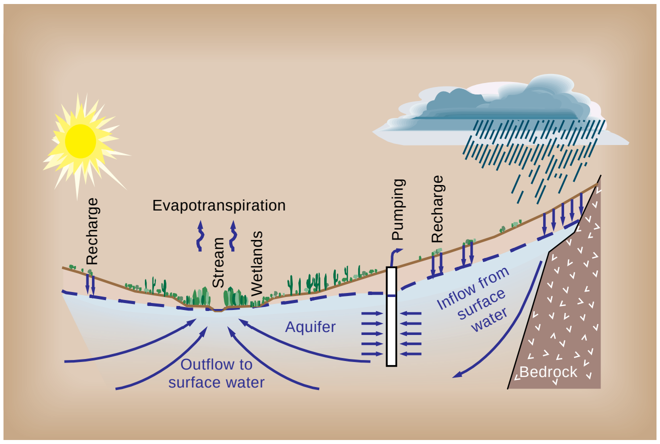


Figure 5. *Availability of an adequate supply of freshwater is a significant issue affecting continued economic growth of cities and towns in the Southwest, which also contains some of the most productive agricultural lands in the United States. Environmental considerations create increasing constraints on water development. For example, perennial streams, springs, and wetlands depend on ground-water discharge for their existence. In addition, the effects of climatic variability on water resources, particularly on ground-water recharge, are not well understood and are a major deficiency in current models used in water management.*

"The western states need good information about groundwater to make informed water management decisions. The resources to perform these studies vary by state, and the federal government's role in providing information can be critical. The USGS, in conjunction with state officials, should help quantify existing data bases and should make available any computer models, geophysical methodology, seismic information, or other tools that could be used to assist decisionmakers. The USGS should also engage in analysis of groundwater resources and provide policy relevant information such as forecasts of aquifer life to the water resources community."

From: Western Water Policy Review Advisory Commission, 1998, Final Report—Water in the West: Challenge for the Next Century: Western Water Policy Review Advisory Commission, Denver, Colorado, p. xxx.

FUTURE PRIORITIES FOR THE GROUND-WATER RESOURCES PROGRAM

Future plans and proposals considered for the program emphasize four themes: scientific assessments of critical ground-water issues, regional and national overviews, improved access to ground-water data, and research and methods development. These themes are discussed in the following sections.

Scientific Assessments of Critical Ground-Water Issues

A flexible approach is needed to address diverse issues. In some cases, studies are undertaken for major aquifer systems, such as those ongoing for the Middle Rio Grande Basin and in south Florida. In other cases, issue-based studies focus on multiple aquifer systems over a broad geographic area, such as the ongoing studies of the southwestern United States and Atlantic coast.

For discussion purposes, key issues considered by the program are grouped according to five topical areas: ground-water depletion, ground-water/surface-water interactions, freshwater/saltwater relations, subsidence, and ground water in complex geologic environments. A brief background on each issue, with selected examples from across the United States, is given below. Examples cited are for illustrative purposes and are neither exhaustive nor prioritized.

Ground-Water Depletion

Widespread pumping that is sufficient to cause regional declines in ground-water levels can have several consequences. Wells can become dry or have greatly reduced yields as water levels decline. Pumping costs increase as the distance that ground water must be pumped to the land surface increases. Large decreases in aquifer storage can result in substantial ground-water mining with less water available for future users. Areas of significant ground-water depletion in the United States include, among others, the High Plains aquifer, many areas in the southwestern United States (e.g., AZ, CA, NM, NV, and TX), the Sparta aquifer in the southeastern United States (AR, LA, and MS), and the Chicago-Milwaukee area.

Long-term observation-well networks are needed to provide data to monitor areas of ground-water depletion. Water allocation and development decisions must be based on an accurate set of facts about the changing status of the resource. Water-level monitoring takes place for many aquifer systems within States, but with the exception of the High Plains aquifer (Figure 6), coordinated water-level monitoring generally has not been done for ground-water systems that cross State boundaries. In order to provide the information needed on large aquifers, a rotational assessment of water-level changes on these major systems should take place at least every 5 to 10 years.

Information on the amounts of ground water pumped from different aquifers is needed to characterize areas of overdraft. This water-use information

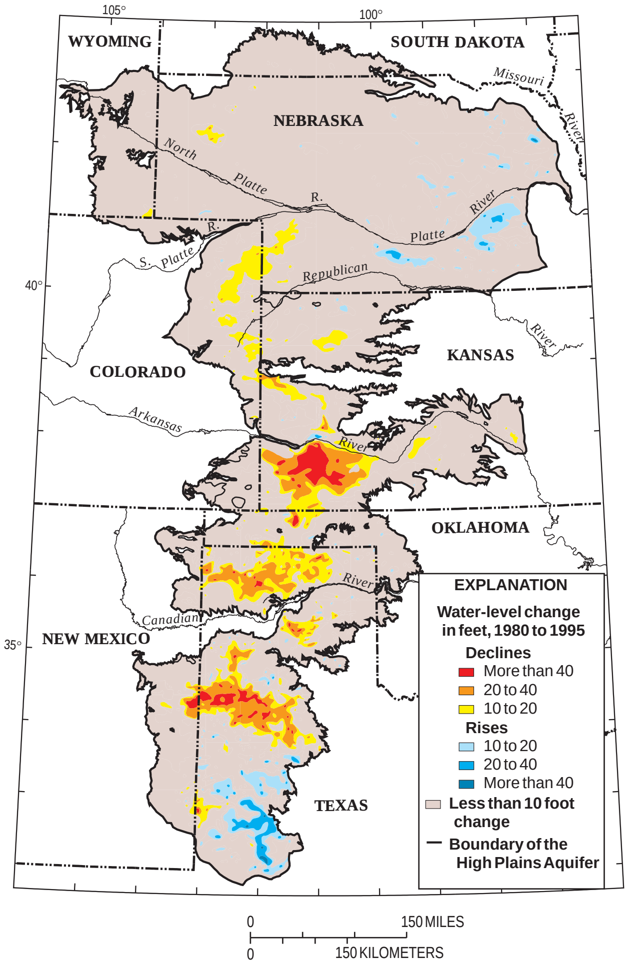


Figure 6. *The High Plains aquifer covers eight States in the central United States. Irrigation has made the High Plains one of the Nation's most important agricultural areas. Extensive pumping has depleted ground-water storage in the aquifer, as indicated by this map of water-level change from 1980 to 1995. Although ground-water pumping has decreased over the past decade in much of the High Plains, water levels have continued to decline significantly in some areas because withdrawals still exceed recharge. Ground-water levels have risen in other areas as a result of decreased pumping or recharge from surface-water irrigation. (Modified from U.S. Geological Survey Water-Resources Investigations Report 97–4081.)*

is critical to the development of predictive models and decision-support systems to make realistic projections of the effects of alternative management strategies. Currently, the USGS works with State agencies to provide water-use data on a geographic basis such as was shown in Figure 1. Significant advances in the prediction of water-level declines depend on obtaining more accurate data on pumping, consumptive use, recharge, and surface-water return flow using remote sensing and other advanced techniques.

Ground-Water/Surface-Water Interactions

Traditionally, management of water resources has focused on surface water or ground water as if they were separate entities. Yet, nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with ground water. Actions taken with one part of the system often have had unintended consequences with the other parts of the system. As development of land and water resources intensifies, it becomes increasingly important to manage ground water and surface water as a single entity.

The nature and degree of the hydraulic connection between ground water and surface water varies considerably from place to place and from terrane to terrane. For example, the interaction in the arid southwest, which has few perennial streams, is usually quite different from the interaction in the humid northeast where perennial streams are more commonplace (Figure 7).

"Assuring long-term ground-water supplies is one of the most significant natural resource issues facing the Nation today."

"Those responsible for providing water supplies to municipalities, irrigation districts, industries, or entire regions or States are increasingly taking the view that ground water is simply one part of an overall system of water storage and delivery and should be considered along with the visible parts of that system—the rivers, reservoirs, canals, and pipelines."

From: Federal Coordinating Council for Science, Engineering, and Technology, 1992, Federal Ground-Water Science and Technology Programs: A Report by the Subcommittee on Water Resources, Office of Science and Technology Policy, Washington, D.C., 82 p.

“Ground water often makes significant contributions to valuable ecological services. For example, in the Southwest, many flowing streams have been eliminated by overpumping. Because the ground water processes that affect ecosystems and base stream flow are not well understood, combined hydrologic/ecologic research should be pursued to clarify these connections and better define the extent to which changes in ground water quality or quantity contribute to the change in ecologic values.”

From: National Research Council, 1997,Valuing Ground Water—Economic Concepts and Approaches: National Academy Press, Washington, D.C., p. 5.

Ground-water/surface-water interaction is a particularly complicated aspect of wetland hydrology (Figure 8). Long-term ground-water studies in wetland environments are needed to support effective management of natural, restored, and newly created wetlands. Likewise, riparian zones adjacent to waterways where vegetation is strongly influenced by the presence of water also require special attention. The status of ground water near streams is critical to determine how riparian zones protect water quality and biodiversity, and how they buffer lands from flood damage. The need for a federal effort is reinforced because of the important trust responsibilities for threatened and endangered species that rely on the streams, wetlands, and riparian zones. Tools also are required to aid in quantifying the influence of ground-water development on changes in the interstate movement of water in rivers and in supporting watershed programs of various management agencies.

Freshwater/Saltwater Relations

The fresh ground-water resource of the United States is virtually surrounded by saltwater. The problem of saltwater intrusion is associated most commonly with excessive withdrawals of ground water from aquifers that lie adjacent to the ocean or tidal waters. Ground-water pumping can reduce freshwater flow toward coastal discharge areas and cause saltwater to be drawn landward. In extreme cases, such landward movement can result in supply wells being abandoned where saltwater reaches pumping centers. In addition, the decrease of freshwater flow to the coastal environment can change the salinity of coastal waterways and wetlands, thereby affecting the habitat of plants, fish, and wildlife. Significant water-level drawdowns also can cause saline water that underlies freshwater in much of the interior of the country to move vertically upward into wells.

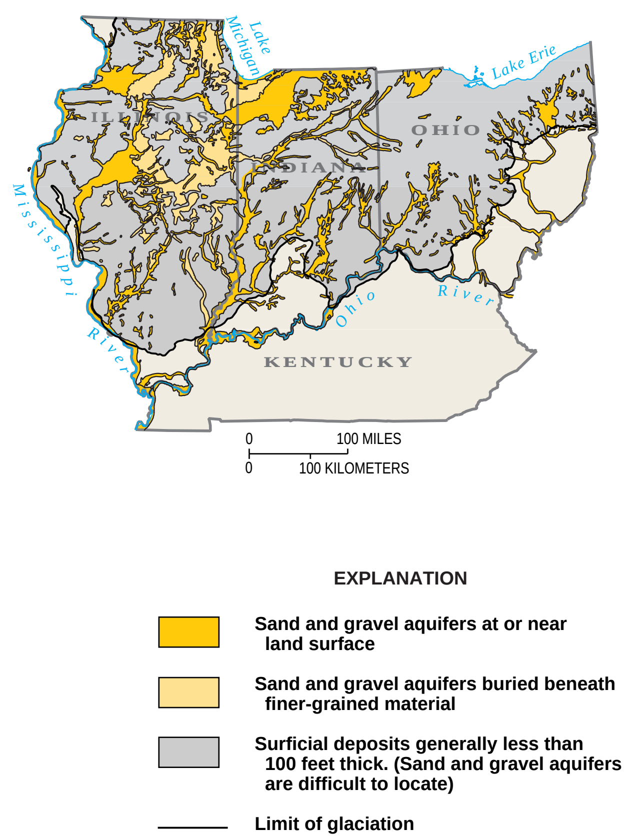


Figure 7. *Sand and gravel aquifers in areas that underwent continental glaciation (such as much of Illinois, Indiana, and Ohio) and in alluvium along rivers (such as the Ohio River) are important sources of ground water. Pumping from these aquifers near streams can induce water from the stream into wells and change the quality of water supplied for drinking. The amount and type of ground-water/surface-water interactions vary in complex ways that depend on factors such as geologic properties, pumping rates, stream stage, and streambed material. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 730–K.)*

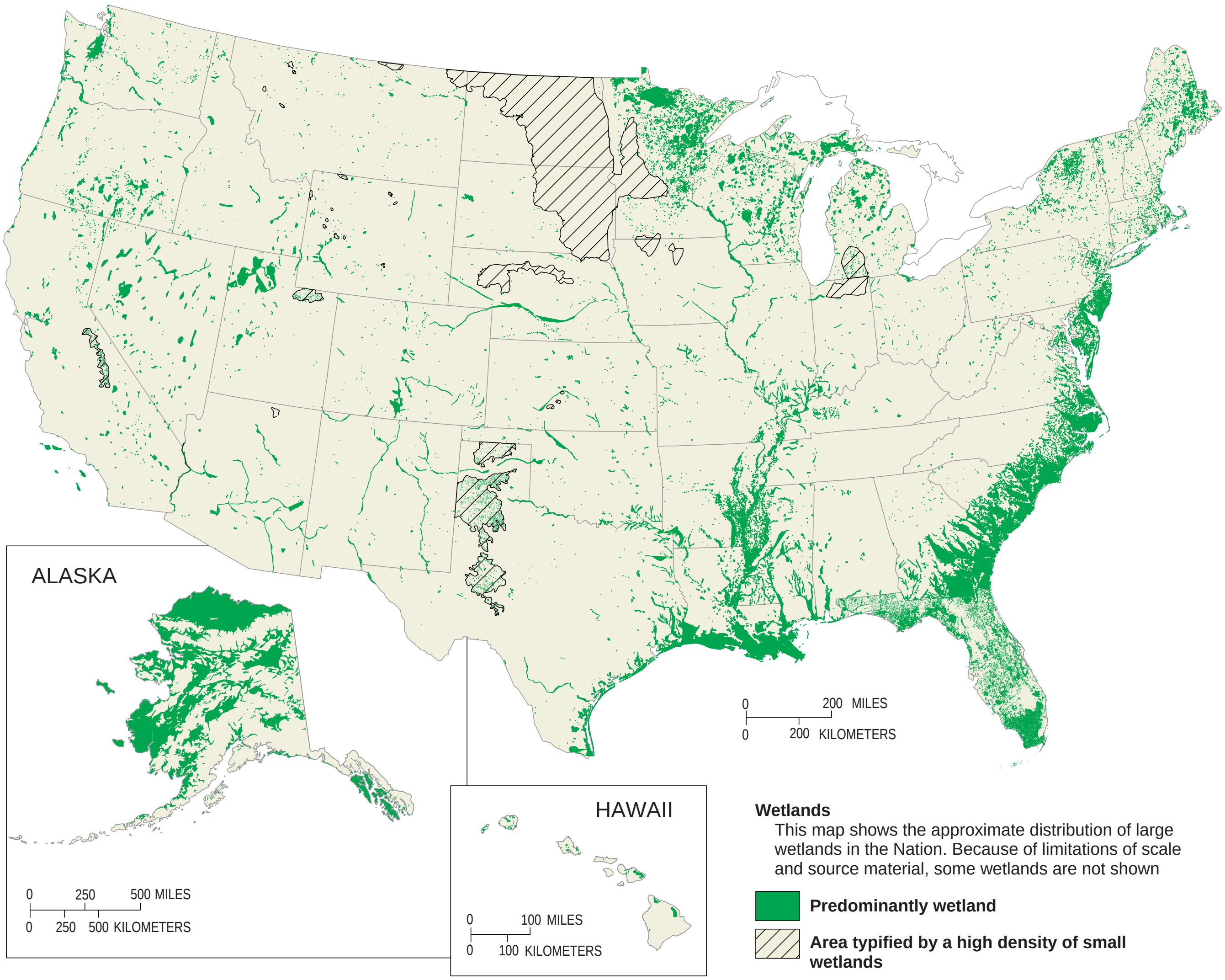


Figure 8. *Understanding wetland hydrology will be improved if the relationships between ground water and wetlands are more clearly established. Wetlands occur throughout the United States and cover large areas in the north-central and northeastern United States, coastal areas along the Atlantic and Gulf coasts, riverine terrane in the lower Mississippi River valley, and Alaska. (Modified from U.S. Geological Survey Water-Supply Paper 2425.)*

Incidences of saltwater intrusion into freshwater aquifers have been documented in almost all of the coastal States. In some areas, water-management techniques have been developed to help control saltwater intrusion; for example, Los Angeles and Orange Counties in California operate artificial recharge programs, and the Miami area in Florida has a program to adjust the freshwater levels in canals. Along the eastern seaboard States (Figure 9), saltwater intrusion has been documented in many of the aquifers at various depths. The severity of saltwater-intrusion problems varies substantially among localities and hydrogeologic settings. Effective regionwide planning of ground-water and surface-water development depends on knowledge of the location of the saltwater interface and ability to predict its future movement based on factors such as ground-water pumping, surface-water withdrawals, and sea-level change. Freshwater inputs to coastal wetlands and estuaries are important national issues because of the habitats these areas provide. Examples of areas where the freshwater inputs are a concern are Chesapeake Bay, Florida Bay, and Great South Bay, Long Island.

Subsidence

In some areas of the country, land subsidence can result from a decrease in subsurface support caused by the withdrawal of ground water. Subsidence can severely damage wells, buildings, and highways, and create problems in the design and operation of structures for drainage, flood protection, and water conveyance. Subsidence in response to ground-water withdrawals can continue over months or years after water levels stabilize and can cause an irreversible loss of storage capacity in aquifer systems. Subsidence from ground-water withdrawals occurs throughout the United States. It is most common in heavily developed aquifers in the southwestern United States and from sinkhole collapse in limestone aquifers in the southeastern United States.

There is a strong federal interest in subsidence because subsidence problems pose significant threats to federally funded infrastructure, such as highways, runways (e.g., the runway used for the Space Shuttle at Edwards Air Force Base), and canals (e.g., the Central Arizona Project). Also, in areas near coastlines, subsidence can increase coastal flood risks, which entail potential economic losses that will create demands for federal disaster mitigation or recovery funds. An ongoing appraisal of the status of ground-water systems that are at risk from subsidence is needed.

Ground Water in Complex Geologic Environments

Geologic environments that are extensive areally, but have unique common physical characteristics that govern the movement of ground water, require special attention when assessing the Nation's ground-water resources. For example, traditional hydrologic methods are mostly ineffective in limestone and other "karst" areas characterized by sinkholes, caves, and underground drainage from dissolution of rocks (Figure 10). Karst systems are highly susceptible to contamination. Aquifers in karst regions supply much of the Nation's ground water for drinking-water supply. Many National and State Parks are located in karst regions because of the existence of caves. Similar difficulties exist in characterizing many other types of geologic settings in which the presence of fractures, faults, and other geologic features adds a significant complexity to understanding the availability and sustainability of ground water (Figure 11). Permafrost, which underlies about 80 percent of Alaska, is another poorly understood, but widespread, environment. Permafrost changes the hydraulic properties of the materials in ground-water systems because the frozen parts of the system do not transmit water easily. At the present time, the potential importance of permafrost in Alaska has increased because it has been suggested that much of the permafrost is warming or thawing because of recent climatic conditions.

Figure 9. *Development of ground-water resources along the Atlantic coast has caused saltwater to intrude many highly productive freshwater aquifers. Projected future growth in population along the coastal areas of the United States will likely increase stresses on coastal aquifers and ecosystems that depend on freshwater discharges from these aquifers. Selected areas along the Atlantic coast where saltwater has intruded freshwater aquifers are shown. During the next 2 years, the USGS will prepare an assessment of freshwater-saltwater relations along the Atlantic coast.*

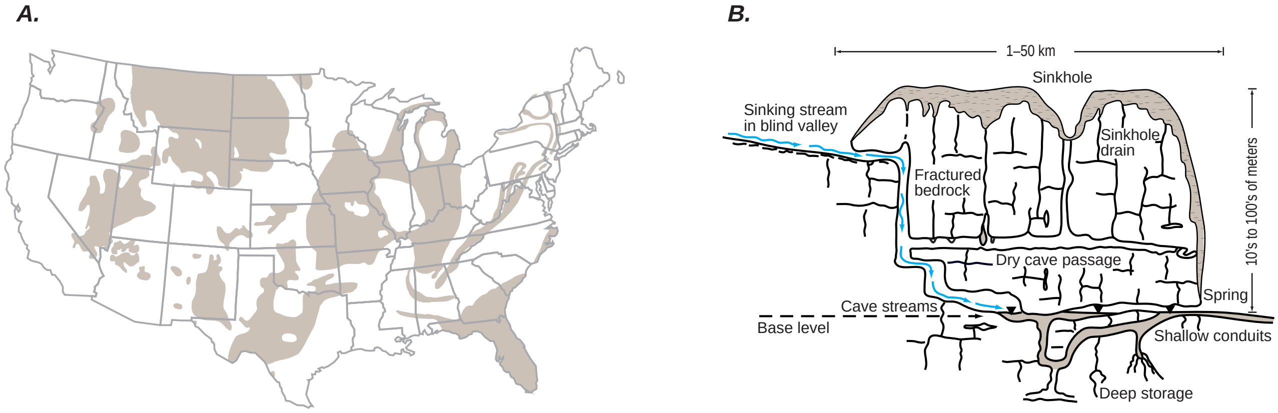


Figure 10. *(A) Much of the Nation is underlain by carbonate rocks or gypsum that are exposed at the land surface or are in the zone of active ground-water circulation. (B) In many areas, these rocks, which are slowly soluble to ground water, develop caves and other karst features, making it particularly difficult to evaluate ground-water conditions. (Modified from Back, W., Rosenshein, J.S., and Seaber, P.R., eds., 1988, Hydrogeology: The Geology of North America, v. O–2, Geological Society of America, and White, W.B., 1993, Analysis of Karst Aquifers in Alley, W.M., ed., Regional Ground-Water Quality: Van Nostrand Reinhold.)*

Regional assessments of ground-water resources and development of better predictive tools are needed by public agencies and by those in the private sector who are attempting to address water availability and contamination issues in these complex geologic environments. Recent efforts of the USGS joining the talents of the Water Resources Division and the Geologic Division (such as the ongoing work in the Middle Rio Grande Basin, NM) have led to significant advancements in ground-water science that can be expected to produce better decision-support systems for aquifer management. A long-term goal is to capitalize on recent geologic and geophysical research in geologically complex environments and use it to improve understanding and management of ground-water systems.

Regional and National Overviews

During the past 75 years, several summaries of the state of the Nation's ground water have been completed by the USGS. O.E. Meinzer, who has been called the "father of ground-water hydrology in the United States," published the first of these summaries in 1923. Meinzer's publication was followed by State-by-State and regional summaries on ground-water resources in the 1950's, 1960's, and 1970's. These national and regional overviews have increased our knowledge about the Nation's ground-water resources. Each has been followed by another as the places ground water is used, the amounts needed for supply, and the issues of concern all change.

Regional and national overviews on a continuing basis would provide an ongoing status report of the Nation's ground-water resources. Such a status report would serve as a central source of information for policymakers who are addressing development and environmental issues that involve ground-water resources. Long-term consideration is being given to ways of producing a national overview on a decadal basis by rotating among a set of regional overviews. Close coordination would be required with the NAWQA and Coop Programs to maximize the effectiveness of such national overviews by taking advantage of the important data these programs can provide.

Access to Ground-Water Data

Data are the foundation for scientific work and are an essential underpinning of attempts to evaluate alternative water-management plans. Several forces are shaping future needs for ground-water data. The types of data needed are expanding as new issues arise. New types of interpretive studies are using data in many ways not previously anticipated. Because of the ability to merge data from many different sources, the sharing of data for multipurpose needs is becoming more commonplace and essential.

Data needed to characterize a ground-water system include both site data on the characteristics of wells and geospatial data on the characteristics of aquifers (e.g., three-dimensional extent and hydrologic and geochemical characteristics over a region). Easy-to-use interfaces are needed to provide ground-water data from wells on the Internet, but considerable effort remains to carefully evaluate and ensure the quality of ground-water data bases for a broad range of possible uses. Preliminary planning also is being done for a National Aquifer Data Base that would serve as a central and readily available source of geospatial information on ground water. Development of the data base will be coordinated with other data bases within the USGS, the State Geological Surveys, and other agencies, as well as guidelines established by the Federal Geographic Data Committee (FGDC).

Collectively, these activities could lead to much greater availability of ground-water data for a multitude of purposes ranging from the individual land owner siting a well to persons developing decision-support systems for regional water management to policymakers at the national scale. Users include a diverse set of local, State, and federal government agencies; universities; nongovernmental organizations; and private-sector firms.

Research and Methods Development

The USGS has been in the forefront of devising new analytical techniques to solve practical problems in the study of ground water. Predictive models are needed for informed decisionmaking in many emerging areas related to the environmental effects of ground-water development. For example, new methods are needed to better address how shallow aquifer systems interact with streams, lakes, and wetlands. Also, complex geologic environments require new methods of data collection and analysis. New models and methods developed will enhance USGS programs, but they also become the tools employed by State and local governments and ground-water scientists and engineers in the private sector. Research and methods development is an important part of the ongoing studies in the Middle Rio Grande Basin, south Florida, and the southwestern United States.

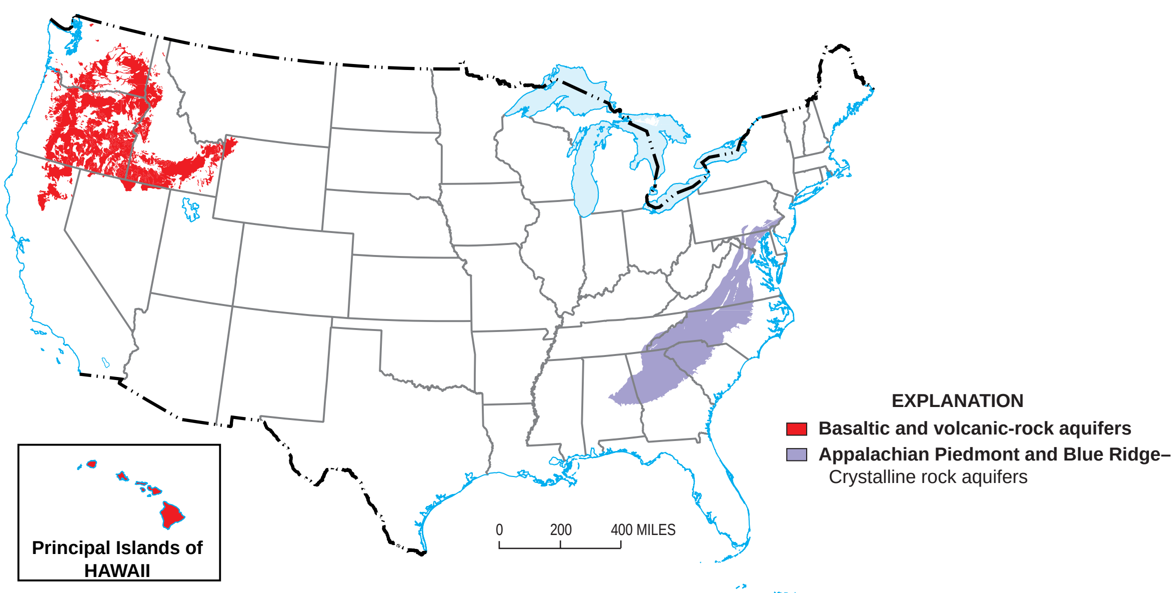


Figure 11. *Hydrogeologic environments throughout the United States are highly varied and include many complex settings in which it is difficult to characterize the availability and sustainability of ground-water resources. For example, areas that were subject to large sequences of lava flows, such as the Columbia Plateau, the Snake River Plain in Idaho, and the Hawaiian Islands, commonly have very productive ground-water systems. Aquifers in this terrane yield water mainly from zones between lava flows and are controlled by fracturing and weathering. A second example are crystalline rocks of the Appalachian Piedmont and Blue Ridge in which the ground-water system is comprised of bedrock and an overlying layer of loose unconsolidated rocks, referred to as the regolith. The hydraulic connection between the regolith and fractures in the bedrock controls the water-supply potential of many aquifers in this rapidly growing, highly urbanized and farmed region.*

"The USGS has been investigating water resources for more than 100 years. Thus, it has developed a broad picture of the nation's water supplies."

From: National Research Council, 1991, Preparing for the Twenty-First Century—A Report to the USGS Water Resources Division: National Academy Press, Washington, D.C., p. 16.

CONCLUDING REMARKS

Ground water is critical to many current and future needs of the Nation. Not only are the 130 million residents who drink ground water concerned about this precious resource, but everyone has a stake in ground water because of its role in the hydrologic cycle. Better understanding of ground-water systems on a regional and national basis is necessary for water managers to know what actions are needed to ensure the future sustainability of the Nation's aquifers and to help national water policy focus on the most pressing issues. Current activities of the Ground-Water Resources Program serve as prototypes for possible new directions of the program. Past, present, and potential future activities of the Ground-Water Resources Program are summarized in Table 1.

The USGS continues to provide unbiased, scientifically sound data and assessments to assist managers and policymakers to address the Nation's most critical ground-water issues. Through its expertise in hydrology, biology, geology, and mapping, the USGS is uniquely qualified to address ground-water resources in a fully integrated manner. The National Research Council (NRC) is currently examining USGS ground-water programs and has been asked to review the program plans that are briefly described here.

Table 1. *USGS Ground-Water Resources Program and general ground-water resource investigations—Past, present, and potential future activities*

[... indicates the same activities as the previous time period; GW, ground water; SW, surface water]

Past	Present	Future priorities
	Scientific assessment of critical issues	
Regional aquifer analysis	Integrated regional aquifer study of the Middle Rio Grande Basin	Further regional aquifer studies that integrate USGS expertise in hydrology, biology, geology, and mapping
Water-level declines measured for selected aquifers and some RASA systems	... + High Plains monitoring	... + Additional periodic multi-State water-level monitoring of major aquifer systems
Water-use data collected on a geographic basis	...	... + Enhanced water-use information based on aquifer units
Subsidence studies at local scale	...	... + Regional assessment of subsidence
Saltwater intrusion studied at local scale or one time assessment under RASA	... + Synthesis of known information on freshwater/saltwater relations along the Atlantic coast	Regional assessments of saltwater intrusion and freshwater discharges to coastal environments
GW/SW interaction focusing mainly on streamflow depletion	... + GW/SW interaction in the southwestern United States	... + Studies on a broad range of issues related to GW/SW interaction in major regions of the country
GW in complex geologic environments studied at local scale on an ad-hoc basis	...	... + Analysis of GW in karst, fractured rock, permafrost, and other complex environments
	Regional and national overviews	
National overview of the status of GW availability and use in 1923, 1952, 1963, and 1970's	None	Periodic overviews on a regional and national scale
	Access to ground-water data	
Localized computer data base	...	Internet access to GW site data
Local hydrologic maps	... + National Ground-Water Atlas	National Aquifer Data Base on Internet