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REPORT TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Ground Water: An Overview

The Nation's ground water should be managed and cared for like the precious commodity that it is--especially in arid States.

GAO is attempting to direct attention to ground water as an important natural resource, and it raises questions about ground water management, conservation, and use which warrant attention by the Congress and study by Federal and State agencies.

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COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

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To the President of the Senate and the
Speaker of the House of Representatives

Problems of using the ground water from an aquifer faster than the water in the aquifer is replenished and, to a lesser extent, land subsidence and saltwater intrusion into fresh ground water reservoirs, are occurring in many localities across the Nation. This report discusses the importance of ground water, problems involving ground water supplies, efforts to manage ground water, and data needs.

We made the review to direct attention to ground water as an important natural resource and to suggest a number of questions regarding its management, conservation, and use which warrant attention by the Congress and study by Federal and State agencies and others responsible for the planning and administration of water resources development.

The review was made pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

Copies of this report are being sent to the Director, Office of Management and Budget; the Secretaries of the Interior, Agriculture, and Defense; and the Administrator, Environmental Protection Agency.

Comptroller General
of the United States

D I G E S T

This report discusses the importance of ground water, problems involving ground water supplies, what is being done to manage ground water, and data needs--primarily in the arid and semi-arid States. Several questions regarding its management, conservation, and use warrant attention by the Congress and study by Federal and State agencies and others responsible for planning and administering water resources development.

Presently, ground water (water below the surface of the earth) supplies about 20 percent of all fresh water used in the United States. The estimated storage capacity of aquifers (underground reservoirs) is nearly 20 times the combined volume of all the Nation's rivers, ponds, and other water on the surface. Although the ground water supply in the 48 contiguous States is plentiful, little more than one quarter of it--equivalent to about 10 years annual precipitation--is available for use because it cannot be extracted using present techniques.

The dependence on ground water varies from locality to locality. Only 2 percent of the water Montana used came from ground water, while 62 percent in Arizona came from ground water. About 80 percent of municipal water systems are supplied by wells which serve about 30 percent of the Nation's population. Irrigation accounts for over half of ground water use. (See pp. 1 to 4.)

GROUND WATER PROBLEMS

Many places across the Nation are using the ground water from an aquifer faster than the water in the aquifer is replenished. To a lesser extent, soil subsidence (lowering of the land surface resulting from reduced ground water) and saltwater seepage into fresh ground water reservoirs, are also occurring. (See pp. 5, 15, and 16.)

In the High Plains region of western Texas-eastern New Mexico, the ground water problem is particularly acute. The fast-dwindling and increasingly expensive supply of ground water, with no other local water source identified, may soon cause profound economic and social consequences there. Similar problems are developing in the ground water aquifer which extends from this region to as far north as the Platte River in Nebraska. (See pp. 9 and 13.)

GROUND WATER MANAGEMENT

Local and State governments, with technical assistance from the Government, usually manage ground water resources. Major Federal activities include data gathering, research, technical assistance, and water resources development or supply augmentation. (See p. 19.)

Ground water management, when it exists, aims to regulate ground water withdrawals and use of the water. In the Western States, emphasis has been on administering and protecting surface and ground water rights. More intensive ground water management generally occurs only after a locality has been faced with problems, such as declining ground water levels, soil subsidence, or saltwater entering the fresh water. State water rights laws and lack of sufficient geological and hydrological data prevent more intensive management. Federal, State, and local officials said that optimal water management would include using and managing surface and ground water as a unit and planning the use of nontributary ground waters (those that do not connect with surface water). A management scheme for nontributary ground water must be concerned primarily with conserving the limited supply.

Surface and ground water often are interrelated, and actions on one can affect the other. In such situations, officials said a different system of water rights and a different water economy should not develop for each water source. Furthermore, they pointed out that using surface and ground water together can increase water availability in a hydrological area.

MORE DATA NEEDED

In ground water management, the aquifer or aquifer system must be described in detail and the quantity and quality of the water supply must be continuously monitored.

The United States Geological Survey, Department of the Interior, has provided much of this type of data to managers through its Federal-State cooperative program. However, more data is needed.

State and local officials said that because of tight State and local budgets, the Government will have to develop the needed data if it is to be provided. (See p. 30.)

QUESTIONS

--Should the Government take a more active role in ground water management? If so, what should its role be and what agency or agencies should be responsible?

--Should future construction of Federal water resource projects depend on whether the States show that their laws provide for integrating surface and ground water rights?

--How crucial is an inventory of water rights to proper management of ground water? Should the Government be responsible for inventorying these rights?

--Should the Government systematically identify areas with ground water problems to assign priorities for Federal assistance in obtaining ground water data?

--Should there be a national water policy requiring all Federal agencies involved in water planning or construction activities to require use and management of surface and ground waters as a unit? If so, how should such policy be implemented?

--Should water be transferred from one river basin to another to reduce ground water pumping or to recharge aquifers?

--Is enough being done to identify and prevent the intrusion of saltwater into ground water?

--Should (or can) Federal programs be devised which provide incentives to decrease dependency on irrigation in water-short areas? How important is irrigation to the national economy? Is it feasible to compensate for decreased farm production in such areas by increased farm production in areas not requiring irrigation?

These questions, involving basic policy, warrant consideration by the Congress. Some should be studied by the Federal and State agencies responsible for the planning and administration of water programs; others may be more suitable for private research associations or academic institutions. GAO will also be considering these questions in future reviews of water-related issues.

PRESIDENTIAL CONCERN

On April 18, 1977, President Carter reported the results of a review he had made of 32 Federal water resource projects and noted that some would bring water to areas with no State ground water management programs. In the case of one project (the Central Arizona Project), the President recommended that further Federal funding be contingent upon further study of ground water supplies and the institution of ground water regulation and management by Arizona.

The President indicated that he was recommending the development of major policy reforms in the area of water conservation, including wise ground water management. When developing major policy reform for better ground water management, questions asked in this report should be considered and studied.

AGENCY COMMENTS

AGC00620

AGC00215

Officials of the Water Resources Council, the U.S. Geological Survey, and the Bureau of Reclamation generally agreed with the report findings and matters for future study. Water Resources Council officials emphasized that

AGC00076

ground water problems are national in scope. Officials of the Geological Survey stated that although the report did not deal with ground water quality, this is as important as ground water supply.

Although the review was primarily concerned with the ground water supplies of the Western States, GAO believes that any study of the eight questions mentioned above should be national in scope and that, where applicable, ground water quality should be considered.

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ABBREVIATIONS

ARS	Agricultural Research Service
ASCE	American Society of Civil Engineers
GAO	General Accounting Office
OWRT	Office of Water Research and Technology
USGS	United States Geological Survey

CHAPTER 1

INTRODUCTION

Subsurface water in completely saturated spaces between soil particles or rocks is considered ground water. Layers of soil or rocks bearing ground water (underground reservoirs) are called aquifers. Aquifers have a storage capacity nearly 20 times the combined volume of the Nation's rivers, ponds, lakes, and all manmade water impoundments.

Ground water occurs under two conditions: artesian and water table. An artesian condition results when an aquifer is bounded on top by an impermeable formation causing increased water pressure. When a well is drilled, the water will either flow to the surface or rise in the well-bore, depending upon the extent of saturation. When an aquifer is not bound by an impermeable formation, water-table conditions occur and the ground water must be pumped to the surface.

The ground water supply in storage up to a depth of one-half mile within the 48 contiguous States has been estimated by the U.S. Geological Survey (USGS) to be 180 billion acre-feet. The amount usable with present technology is about 46 billion acre-feet or about 10 years of annual precipitation. Between one-third and one-half of the United States is underlain by aquifers capable of yielding 50 gallons per minute or more to wells. Ground water, however, is not equally distributed across the Nation.

Nationwide, ground water supplies about 20 percent of the water withdrawn for use. The dependence on ground water for water supply, however, varies from locality to locality. For instance, ground water as a percent of total water use was 62 percent in Arizona but only 2 percent in Montana. Some areas of large population, such as Long Island, New York, depend almost exclusively on ground water for water supply.

Because of its generally good quality, ground water is an important drinking water supply. About 80 percent of all U.S. municipal water systems are supplied by wells. These serve about 30 percent of the U.S. population. Another 10 million families have individual well systems. Ground water is the water source for nearly all of the rural population. Nationwide, the largest use of ground water is for irrigation, mostly in the Western States.

In 1950, ground water use in the United States totaled 30 to 35 billion gallons per day. It increased to about 46 billion gallons per day in 1960, and by 1980 may be about 80 to 100 billion gallons per day. Ground water use is expected to increase because of a growing population and larger water demands, the availability of ground water, its generally good quality, and the current trend away from new dam construction. In some areas, it will be necessary to develop all available water supplies in the near future.

Texas and California are the largest users of ground water. In 1970, the amount of ground water withdrawn in California was about 20.5 million acre-feet of which about 18.0 million acre-feet was for irrigation. In 1970, Texas withdrew about 10.3 million acre-feet of ground water of which 8.8 million acre-feet was for irrigation.

The following is a brief description of the role of ground water in each of the States we visited during our study. The description is based on information contained in Federal and State studies and reports.

TEXAS

Ground water, a significant resource throughout much of the State, especially the western portion, supplies about 75 percent of the total water used for municipal, industrial, and irrigation purposes. It is nearly the sole source in areas such as the southern High Plains, an area of 25,000 square miles.

CALIFORNIA

Ground water use is about 40 percent of total water use in the State, with irrigation accounting for about 88 percent of total ground water withdrawn for use.

NEBRASKA

Nebraska has a large total ground water supply of good quality. As of 1970, all of the States' municipal water systems, except for those of Omaha, Long Pine, and Crawford, were supplied by wells and 40 percent of Omaha's supply was ground water. In addition, wells supply water for three-fourths of the 4.1 million acres of irrigated land and much of the industrial and commercial water supply and water for livestock. Nearly all rural homes depend on ground water as their water source.

NORTH DAKOTA

Ground water represents 40 percent of total water used and satisfies 73 percent of domestic needs. Most of the larger cities, however, use surface water. Ground water meets 30 percent of current irrigation needs and is expected to meet about 50 percent in a few years. There are 40,000 wells in the State, of which 250 to 300 are high yield wells for irrigation and municipal supplies.

SOUTH DAKOTA

From 30 to 35 percent of all water used in South Dakota is ground water. Although wells supply 33 percent of irrigation water, ground water supplies less than 15 percent of irrigation needs in the western part of the State because of its poor quality. Only about five percent of municipal water supplies is ground water.

WYOMING

For 1965, an estimated 3 percent of all water consumed by man's activities in the State was ground water. By 1970, this figure had increased to about 8 percent, and may be about 15 percent by the year 2000. The increase from 1965 to 1970 was mainly due to irrigation. The year 2000 projection by the State Engineer's Office was based on potential industrial development, irrigation, and tourism.

Most water wells in Wyoming provide water for rural domestic and livestock use, and many communities depend entirely on ground water. However, irrigation uses the largest volume of ground water. Much of the anticipated growth of irrigation, according to the State Engineer's Office, will depend on ground water "because either the practical limit of surface water development will have been reached locally or development is (or will be) limited by legal constraints."

MONTANA

Only about 2 percent of the total water withdrawn for use was ground water. This was 250,000 acre-feet of ground water versus 13,000,000 acre-feet of surface water. Irrigation used nearly one-half of the ground water withdrawn. Ground water was used for all domestic, one-half livestock, and about one-third municipal and industrial needs.

COLORADO

Ground water accounts for 16 percent of total State water use and is virtually the only water supply in some eastern areas. Ground water resources are largely east of the Continental Divide. For instance, in the northern High Plains (9,500 square miles) of Colorado, the Ogallala Formation aquifer supplies water for municipal and domestic, most stock, and nearly all irrigation uses. The Colorado Geological Survey has stated that "Colorado's ground water resources are becoming increasingly important with their development continuing at a fast pace."

SCOPE OF REVIEW

We discussed ground water programs and problems with officials of those various Federal agencies in the Washington, D.C., area which are concerned with water resource development and officials of Federal and State agencies in the States of California, Colorado, Montana, Nebraska, North Dakota, South Dakota, Texas, and Wyoming. We also reviewed numerous reports and documents of these agencies and private organizations.

The data we obtained was not examined in detail nor was its validity evaluated because our purpose was to obtain a general overview of ground water problems and management. Most of our effort was directed toward obtaining information concerning ground water quantity rather than quality.

The Safe Drinking Water Act of December 16, 1974, (Public Law 93-523), provides, among other things, the means to prevent ground water pollution caused by injection of wastes into ground water aquifers. Extensive hearings on the pollution aspects were held by the Public Health and Environment Subcommittee of the House Interstate and Foreign Commerce Committee.

CHAPTER 2

GROUND WATER PROBLEMS

Problems of ground water overdrafting and, to a lesser extent, land subsidence and salt water intrusion, are occurring in many localities across the Nation. (See map p. 6.) The latter two problems generally occur as a result of overdrafting of aquifers under certain geological and hydrological conditions.

GROUND WATER OVERDRAFTING

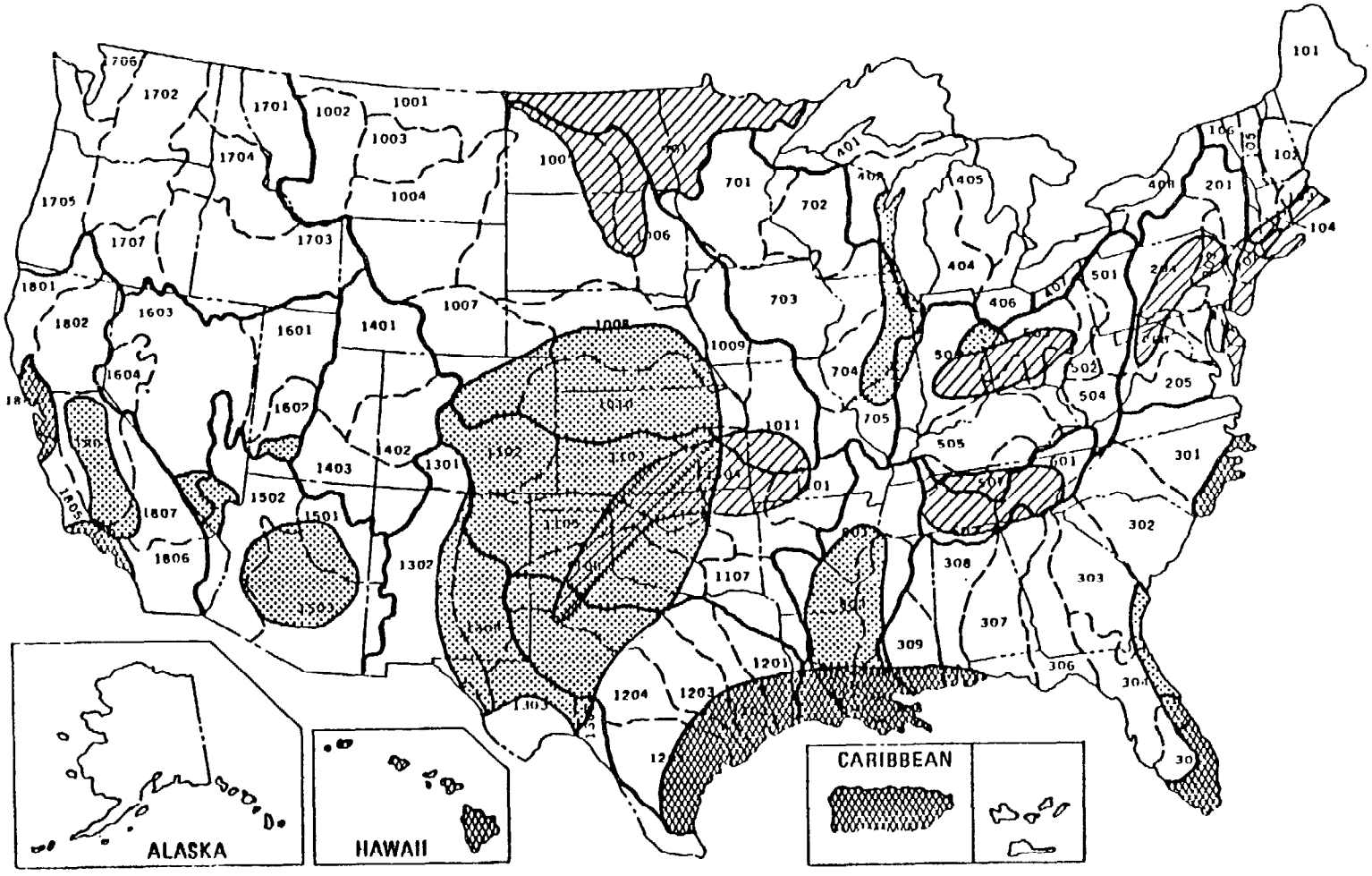
Overdrafting of ground water occurs when withdrawals from an aquifer exceed net recharge. Substantial overdrafting generally has one of two effects. Where the aquifers are interconnected with rivers, streams, lakes, etc., the overdrafting lowers the water levels or decreases the flow of the surface water. Substantial overdrafting of nontributary aquifers (those not interconnected with surface water bodies) results in taking water out of storage and is often referred to as ground water mining or storage depletion.

Overdrafting of stream-connected aquifers reduces surface water levels and flows and may eventually deplete the water supply in a hydrological area. Overdrafting of nontributary aquifers may be considered mining of a finite resource. In both cases, this results in the need to (1) limit or cease pumping, (2) deepen existing wells or drill new wells, or (3) seek alternative sources of water. Ground water users are faced with having no water supply or a reduced supply, or the cost of deepening or drilling wells. Also, lower well water levels increase energy costs to pump the ground water.

Serious economic and social problems may result when economies develop based on a limited ground water supply. When the water available to wells becomes too expensive to pump or is depleted, water must be imported at a great expense or the economy declines with adverse social and economic results, such as unemployment and dislocation. Sometimes water may not be available for importation.

In addition, overdrafting can result in large Federal expenditures for water resources development projects to provide water to replace or supplement ground water. Examples are the Central Arizona Project ($1.5 billion) and the Central Valley Project, California ($3.5 billion).

THE NATURE OF PRESENT GROUNDWATER PROBLEMS, 1975.



Source: Preliminary information from the Water Resources Council's 1975 National Assessment

The Federal Central Arizona Project will include the construction of canals to carry water from the Colorado River to Phoenix and to Tucson. The Governor of Arizona, in testifying on April 1, 1976, before a congressional committee 1/ concerning the need for the project stated that:

--Arizona has a water emergency.

--The water overdraft in the Phoenix area (population 1.2 million) is two and one-half times greater than the replenishment of that water.

--The water overdraft in Tucson, the largest city in the Nation that depends strictly on wells, is five times greater than the amount of recharge or replenishment of water.

--Land subsidence of 2-1/2 feet, affecting 1,000 square miles, has been experienced because of overdraft.

--The act authorizing the project specifies that, except on Indian reservations in the project service area, no project water may be delivered to develop new agricultural lands.

The Commissioner of Reclamation described the Central Arizona Project as "primarily a rescue type of operation."

The Federal Central Valley Project is a large multipurpose project in California consisting of 19 dams and related water conveyance systems and hydroelectric generating plants. The project's primary purpose is to provide irrigation water to the Sacramento and San Joaquin Valleys. The project was needed because, among other things, the existing ground water supply was not adequate to support the level of irrigation farming taking place. For instance, in requesting authorization for the project's San Luis Unit (serving the Westlands Water District) the Department of the Interior stated that the ground water level average rate of decline was about 10 feet per year and, in some places, 20 feet per year. According to advocates of the San Luis Unit, without the project, the area served by the Westlands Water District (about 572,000 acres) would be fit for growing only sagebrush.

1/Hearing Before the Senate Committee on Appropriations, Public Works for Water and Power Development and Energy Research--Part 7.

In both the situations cited above, it appears that the population and economies of the areas developed at higher rates than could be supported by the existing water supply. Once such developments had taken place, crisis-oriented solutions had to be considered which involved large expenditures and required Federal assistance.

Local overdrafts of aquifers were being experienced to some extent across the Nation. The Water Resources Council's first national assessment of the Nation's water resources situation, published in 1968, stated that ground water storage depletion is a severe problem in some areas, or a major problem in many areas, of the Arkansas-White-Red, the Texas-Gulf, Rio Grande, and Lower Colorado Water resources regions. The report said also that such depletion is a major problem in some areas, or a moderate problem in many areas of the Missouri and California regions. An earlier U.S. Geological Survey paper noted about 40 overdrawn ground water reservoirs in the Western States. Nearly all of these were in California, Arizona, New Mexico, and Texas.

Problems of significant water level declines have also occurred in the humid Eastern States and the Pacific Northwest. For instance, Long Island, New York, an area of sizable population dependent upon ground water as its major water source, is experiencing significant water table declines.

The Federal Government has provided assistance to the States and localities in increasing available water supplies. This assistance has been in the form of water resources development projects and in such activities as conjunctive use of urban water; total water management studies; and research in artificial recharge, weather modification, and saline water conversion.

The Bureau of Reclamation and the Corps of Engineers are the primary constructing agencies for water resources development projects. These agencies, along with USGS, Agricultural Research Service, and Office of Water Research and Technology (OWRT) are also carrying out research in artificial recharge, total water management (which the Bureau of Reclamation said it plans to give high priority), and weather modification. The Bureau of Reclamation spent over $4 million in fiscal year 1976 for research projects under contract for weather modification on the High Plains

and in the Colorado River Basin and the Sierra Nevada Mountains.

Generally, ground water overdrafting is of a localized nature because of varying geological and hydrological conditions. The ground water problems in areas we visited during this study are discussed in the following sections of this chapter.

High Plains region of western Texas-eastern New Mexico

The High Plains region of Texas and New Mexico is probably the best known and most unique area of ground water overdrafting in the United States because of its geographical size, its large dependence on ground water, and the lack of a feasible water supply for import. Thus, proper management to insure conservation and planned use of the ground water resources in this region are more important than in areas where alternative supplies of water may be available and economically feasible to import.

The High Plains of western Texas extending into eastern New Mexico is the southernmost extension of the Great Plains Physiographic Province of North America, which stretches from southern South Dakota into Nebraska, Kansas, Oklahoma, and to the northern edge of the Pecos River Valley in Texas. The High Plains in Texas covers about 35,000 square miles, including the Canadian River Basin and the upper parts of the Red, Brazos, and Colorado River basins within the State. It averages about 300 miles from north to south and about 120 miles from east to west, including parts or all of 42 of the State's counties.

The Ogallala Formation, an interstate aquifer system, underlies virtually all of the northern High Plains in Texas and about 22,000 of the 25,000 square miles of Texas' southern High Plains. It extends into New Mexico, Colorado, Oklahoma, Kansas, and Nebraska.

The sole source of recharge to the Ogallala is precipitation, which is negligible. Withdrawals are especially large in the major irrigation areas in the northern part of the southern High Plains and in areas to the south where municipal and industrial water supplies are pumped. A June 1975 USGS document reports that ground water withdrawals in the southern High Plains of Texas in recent years have been 7 to 8 million acre-feet per year and the recharge was perhaps 140,000 to 150,000 acre-feet per year. Extensive

efforts have been underway to slow the withdrawal rate by increasing efficiency of water use through water conservation practices.

The Texas Water Plan of November 1968 predicted, however, that if by 1985

> "a supplemental surface supply of water has not reached the High Plains, this vast area will have begun an area-wide retrogression to dryland farming which will have profound economic consequences throughout the State."

Studies by Texas A & M University predict a potential economic demand of 6.7 million irrigated acres in the southern High Plains alone if water could be made available at costs which would give irrigators an economic incentive to irrigate rather than dry farm. Unless water is imported from outside the area, however, the studies predicted that irrigation would begin a severe decline by 1985, to 2.2 million irrigated acres which would be supportable by ground water available in 2020.

The Department of the Interior issued a report, "Critical Water Problems Facing the Eleven Western States" (April 1975), which states that the thriving economy of the western Texas-eastern New Mexico area, which is presently based on irrigated agriculture, is threatened by a rapidly declining ground water supply. The report stated that irrigation activity will start to decline about 1980 and that, nationally, "* * * significant social and economic dislocations will occur with this decline in irrigation activity."

According to the study, the estimated 1970 population of the western Texas-eastern New Mexico area was about 1.2 million. For the area as a whole, per capita income was less than the national average and, generally, was projected to decline over time. A return to dryland farming could substantially reduce the income of the farmers in the area.

Considerable study has been made by Federal, State, and private organizations of the possibilities for importing water from the Mississippi River, the Missouri River, Alaska, Canada, and the Gulf of Mexico. The Mississippi River source had been considered the most feasible. The Bureau of Reclamation and Corps of Engineers made a joint State-Federal reconnaissance grade study which was completed in 1973. 1/

1/The study report is entitled "West Texas and Eastern New Mexico Import Project."

the study concluded that the economic and environmental costs are so large that a plan to import water from the Mississippi River is not justified in the near future and, more specifically, not in time to rescue the irrigation economy of the area. The Texas Water Plan of 1968 anticipated that, with Federal assistance, water would be imported from the Mississippi River. It was believed that other areas within Texas are unable to provide the High Plains area with water. The Plan also foresaw other areas in Texas as facing the prospect of returning to dryland farming as available water supplies are exhausted.

The report "Critical Water Problems Facing the Eleven Western States" recognized, as an alternative to water import, a management plan for the area which anticipates the depletion of the ground water aquifer. The plan would need to set out the management procedures and institutional arrangements that should be adopted to minimize the effect of ground water depletion on the agricultural economy, total economy, and the environment of the area. The plan, according to the report, should be developed in such a manner that the aquifer will be managed for long-term use. The report recommended that:

"1. A State-Federal organization should be formed to investigate and define the ground-water resource and make recommendations regarding its future use. The organization would be responsible for considering the potential of weather modification procedures, groundwater recharge projects, and other augmentation opportunities. Such an on going organization would have need for both State and Federal financing but the primary emphasis would be on State control and regulation with technical studies and analysis as required from Federal organizations.

"2. A State-Federal interagency study be initiated to develop alternative agricultural enterprises geared to the long-term use of ground water in the High Plains. Such enterprises could involve: more efficient use of water, adaptation of crops requiring less supplemental water, new methods of water application such as drip irrigation, a more balanced irrigation and dry farm arrangement, use of irrigation only as drought insurance, and advanced agronomic practices.

"3. A Federal study be made of the national social and economic impacts of the loss of the irrigation economy of the High Plains area and of the possibilities of development of alternative non-agricultural enterprises as a replacement for the declining agricultural activity."

For fiscal year 1977, the Bureau of Reclamation received $150,000 to begin a total water management study of the High Plains region of western Texas-eastern New Mexico. The estimated total cost is $1 million.

The principal objectives of the study will be to (1) determine the quality and quantity of the region's water resources, (2) investigate the water resources available to supplement the existing Canadian River Project supply for municipal and industrial use in the area, (3) evaluate present irrigation systems and practices and make recommendations for more efficient use of the present water supply, (4) develop alternative plans for the most economical and beneficial use of playas 1/ water, (5) evaluate the potential for increasing water supplies by atmospheric weather modification, and (6) develop plans for reducing evaporation loss of surface water supplies. A report on the study is scheduled for completion in fiscal year 1981.

The Economic Development Administration, Department of Commerce, was authorized by Section 193 of Public Law 94-587 (dated October 22, 1976) to study the depletion of the national resources of those regions of the States of Colorado, Kansas, New Mexico, Oklahoma, Texas, and Nebraska presently using the Oqallala aquifer. This study, with the cooperation of the Corps of Engineers, State and local agencies, and the private sector, is to develop plans to increase water supplies to assure an adequate national food supply and to promote the economic vitality of the High Plains region. In formulating these plans, the act directed that consideration be given to all past and ongoing studies, plans, and work on depleted water resources in the region, and that an examination be made of the feasibility of various alternatives to provide adequate water supplies in the area including, but not limited to, the transfer of water

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1/The sandy, salty, or mud-caked floor of a desert basin with interior drainage, usually occupied by a shallow lake during the rainy season or after prolonged, heavy rains.

from adjacent areas. The act also required a final report, with recommendations, to be transmitted to the Congress not later than July 1, 1980, on the costs of reasonably available options, the benefits of various options, and the costs of inaction. If water transfer was found to be part of a reasonable solution, a recommended plan to allocate and distribute water in an equitable fashion was also to be included.

Although the Congress authorized $6 million for this study, as of April 1977, no funds have been specifically appropriated. However, the Economic Development Administrator has agreed to provide up to $1.2 million of fiscal year 1977 funds that are available for this type of study.

Potential problem areas in other parts of the High Plains

Situations similar to that of western Texas-eastern New Mexico are developing in other parts of the High Plains. USGS reported that the southern High Plains in Texas and New Mexico is typical of the High Plains region as a whole, except that this area is heavily developed. USGS further stated that

> "current and projected effects of development in the Southern High Plains demonstrate the effects that might be anticipated in other areas of ground-water mining (extraction at rates so in excess of replenishment that water levels decline persistently)."

Other areas will show similar development trends, particularly if not regulated by law.

A USGS paper entitled "The Role of Ground Water in the National Water Situation" (1963) stated that the situation in western Kansas (about three-fifths of the State) was similar to that in the southern High Plains of Texas in the 1930s and 1940s. The paper stated also that all of the High Plains region, except perhaps the Sand Hills of Nebraska, ultimately faced the same decisions as the southern High Plains of Texas faced.

USGS recently reported that withdrawals of ground water for irrigation exceed natural recharge in large parts of western Kansas. Continued withdrawals at the rate would deplete the supply and seriously affect the economy of the area. State officials of Colorado told us that areas in the eastern part of the State, mostly the High Plains, are having large ground water level declines. For

example, in the Burlington area, declines of over 16 feet were reported for the period 1964-71. Withdrawal of ground water for irrigation quadrupled between 1960 and 1968 in the northern High Plains of Colorado.

Other ground water overdraft areas in States we visited

Texas, California, and Colorado reported significant overdrafts of ground water in areas additional to those discussed above. For instance, San Antonio, Texas--which had a population of about 800,000--depends on the Edwards aquifer for its entire water supply. The Edwards provides water for public supply, industrial use, and irrigation in an extensive area of south-central Texas. USGS has predicted that if demands for water from the Edwards continue to increase, as they are likely to do in this rapidly growing area, the predictive results will be severe declines in water levels during periods of drought, large reductions in the amount of water available to all users, reduction in flow, or even periods of no flow from the springs.

According to USGS, projected ground water requirements will exceed the available ground water supply in two areas of Texas: (1) the High Plains and (2) the San Antonio area. The 1968 Texas Water Plan projected that supplemental water supplies must be made available in the following areas no later than the dates shown: San Antonio area (1985), (2) Corpus Christi area (1987), (3) El Paso area (2000), (4) High Plains (1985), (5) Trans-Pecos area (1990), and (6) the Lower Rio Grand Valley (1980).

In 1970, water levels declined in areas of 75 of the 93 counties of Nebraska. Water levels were being significantly lowered in areas of Box Butte, Polk, Hamilton, York, Clay, and Filmore counties. Areas in the counties of Adams, Clay, Chase, Holt, Dawson, Buffalo, and Hall were also experiencing declines.

The State of California, in its November 1974 water plan, reported, in addition to the San Joaquin Valley, significant overdrafts in the Tulare Basin and overdraft in parts of the Central Coastal area, the Sacramento Valley, Ventura County, the Upper Santa Ana River Basin, and Coastal Orange County. Imported water has enabled the water levels in Santa Clara and Livermore Valleys to recover. It was anticipated that water would be imported in the future to supplement other areas of overdraft.

Ground water levels were declining in Colorado mostly in the High Plains region. Montana reported one area (Great

Falls) of decline while North Dakota, South Dakota, and Wyoming noted no areas of overdraft.

LAND SUBSIDENCE

In many areas of the United States, overdrafting of ground water has reduced water levels from 100 to 600 feet. Where these declines have occurred in unconsolidated aquifers containing many fine-grained compressible interbeds, the increased effective stress as a result of ground water withdrawals has caused compacting of sediments and reduction in pore space and the resultant sinking of the land surface. The aquifers that have been mostly affected are chiefly confined aquifer systems. Subsidence may also result from withdrawal of other liquids, such as petroleum.

According to USGS, significant subsidence due to water level decline has occurred in five States: Louisiana, Texas, Arizona, Nevada, and California. Subsidence has been the greatest and most extensive in the San Joaquin Valley of California. Maximum subsidence as of 1972 in the western part of the Valley was 29 feet in some areas. About 5,200 square miles had subsided with about 4,200 square miles subsiding more than 1 foot. The subsiding areas are underlain by a confined aquifer system in which the artesian head had been drawn down by 200 to 600 feet. Water wells were as much as 3,500 feet deep in some areas.

Other examples of appreciable land subsidence are Santa Clara Valley (13 feet by 1969), the Houston-Galveston area of Texas (a maximum of 7.8 feet from 1943 to 1973), and central Arizona (a maximum of about 7 feet). Subsidence in other areas has generally been much less.

Adverse effects

Land subsidence has caused large amounts of damage in some areas totaling millions of dollars. In the Houston-Galveston area, it has resulted in structural damage, such as cracked buildings and disrupted pavements, damage to well casings, and submergence of coastal lowlands. The Corps of Engineers reported that at high tides, seawater from Galveston Bay flows through a residential area near Houston because the area has sunk about 8 feet since 1945. Some homes have already been abandoned in one of the area's subdivisions. Based on a recommendation by the U.S. Corps of Engineers, the Congress authorized by Public Law 94-587, dated October 22, 1976, the expenditure of $15,680,000 to buy out homeowners and convert the area to a park.

An example of subsidence damage in the San Joaquin Valley is the necessity for the Bureau of Reclamation to restore the design capacity of the Delta-Mendota Canal. Between June 1975 and September 1976, the Bureau awarded six contracts totaling about $3.7 million for rehabilitation projects. For example, the largest contract was awarded on October 24, 1975, for about $2 million to rehabilitate 17 miles of the canal. Another contract for about $1.5 million was awarded on November 4, 1975, to rehabilitate 8 additional miles. Tilting of the land surface had appreciably reduced the canal water flow.

A report issued by USGS stated that enormously expensive damage to harbor facilities, drainage structure, and the like from land subsidence may be more expensive to repair than the expenses related to importing ample good quality water supplies. Large surface water imports to several subsidence areas, such as San Joaquin Valley in California, have greatly reduced ground water pumping, resulting in recovery of the artesian head that has slowed or nearly stopped land subsidence.

SALTWATER INTRUSION

Saltwater intrusion into fresh ground water aquifers can result from the movement of seawater into coastal aquifers or saline ground water into inland fresh water aquifers. Most intrusion is caused by (1) the reversal or reduction of fresh water discharge which allows the heavier saline water to move into an area where only fresh water previously existed, (2) the destruction of natural barriers that formerly separated bodies of fresh and saline waters, or (3) the results of disposal of waste saline water. The U.S. Environmental Protection Agency has reported that there have been significant saltwater intrusion problems.

Seawater intrusion of coastal aquifers

Under natural conditions, fresh ground water in coastal aquifers is discharged into the ocean at or seaward of the coastline and a balance exists between the fresh ground water and saltwater pressing in from the sea. When ground water levels are lowered by overdrafting, natural drainage, or impediment of natural recharge by construction or other activities, the fresh water flow to the ocean is reduced. The saltwater tends to underride the less dense fresh water and, thus, moves into areas where only fresh water previously existed.

Because of the high salt content of seawater, as little as two percent of it mixed with fresh ground water can make that portion of the aquifer unusable based on drinking water standards for total dissolved solids. Only a small amount of intrusion can have serious implications regarding the future use of an aquifer as a water supply source.

Coastal aquifers can also be contaminated by landward migration of seawater into rivers and streams. Reduction of stream flow or deepening of channels may allow the seawater to move inland.

Saline water intrusion of inland aquifers

Large quantities of saline water exist under many different geological and hydrological environments in the United States. According to the Environmental Protection Agency, most of the Nation's largest sources of fresh ground water are in close proximity to natural bodies of saline ground water. Intrusion may occur when saline water migrates upward into fresh water aquifers due to man-induced changes in the hydrologic pressure or the direct transfer of saline waters vertically through wells or other penetrations.

Severity of the problem

The Environmental Protection Agency reported in 1973 that 42 of the 50 States have reported significant saltwater intrusion problems. Saltwater intrusion appears to be a problem in all of the coastal areas and is widespread in inland areas. On the Atlantic Coast between Massachusetts and Florida, each of the States had reported problems with seawater intrusion. The seriousness of the problem is usually dependent on the intensity of urban and industrial development, with resulting increased withdrawal of ground water. California has had many problems with seawater intrusion and has tried hard to solve or reduce the problem. Florida was the most seriously affected State, followed by California, Texas, New York, and Hawaii.

About two-thirds of the contiguous United States is underlain by saline waters containing high concentrations of dissolved solids. The problem of saltwater intrusion in inland areas can be the same as in coastal areas.

Because of the relatively slow movement of ground water, saltwater intrusion may detrimentally affect its

quality for years under the most favorable circumstances, or many decades in other cases. The movement of poor quality water into fresh water supplies is generally considered a more serious problem than ground water depletion. Wells may have to be abandoned while ample supplies of water are in the aquifer. Declining water tables may stabilize or rise if pumping is reduced, but dissolved contaminants may be difficult or impossible to remove. Saltwater intrusion reduces the amount of fresh water available for use.

CHAPTER 3

STATE AND FEDERAL ROLES IN GROUND WATER MANAGEMENT

Management of ground water resources has been primarily a local and State responsibility with assistance from the Federal Government. Major Federal ground water activities have been data gathering, research, technical assistance, and water resources development.

Ground water management in the Western States has basically involved a degree of regulation of ground water withdrawals and use under the State water rights systems. More intensive regulation has taken place in some areas of severe ground water problems. However, substantial damage had already occurred in some of these areas and other problem areas have not received needed attention. Federal and State agencies recognize the need for improved ground water management. However, officials in many of these agencies said that ground water management must improve to provide orderly development, proper use, and conservation of the resource. One constraint to such improvement--the lack of more geological and hydrological data--is discussed in chapter 4.

STATE AND LOCAL MANAGEMENT EFFORTS

All the States studied somewhat restricted or regulated ground water withdrawals, basically to protect existing water rights, mainly by administering water rights, well permit systems, and well-spacing requirements, and by designating critical or controlled ground water basins. Generally, the States had water programs that included ground water data gathering, research, and special studies, such as ground water modeling. Some also performed other activities, such as weather modification, artificial recharge, and importing surface water. The amount of these efforts varied from State to State. Some of the States depended on the Federal Government for much of these activities while others used the Federal effort to supplement their efforts.

The type and degree of management varied from State to State; however, the management in some States was similar to that in others. For instance, both North and South Dakota used a well permit system, had the authority to require meters, had a safe-yield policy with regard to withdrawals from all aquifers, and limited the application of both surface and ground water for irrigation.

Montana, Wyoming, Colorado, and Nebraska designated critical or controlled ground water basins for more intensive management.

California and Texas authorized the establishment of public management agencies to manage the ground water resources in a basin or other geographical designation. Designation of controlled basins or creation of local management agencies were usually at the initiation of local water users after problems developed. A brief description of ground water management in four of the eight States we visited is shown in appendix I.

Because of varying geological and hydrological conditions, the Federal and State officials generally agreed that management at the State and local levels rather than at the Federal level is preferred. Widely recommended approaches were (1) implementation of conjunctive use and management of surface and ground water resources and (2) operation of nontributary ground water basins on a safe-yield or planned depletion basis. The officials told us that constraints to implementing these recommendations were State water rights and lack of sufficient detailed geological and hydrological information.

FEDERAL EFFORTS

The Federal Government does not have a direct role in the management of ground water resources except on public lands. It does provide assistance to State and local agencies with management responsibilities. The major contributions are providing data and technical assistance and assisting in increasing available water supplies.

Data and technical assistance

U.S. Geological Survey

USGS provides data and technical assistance for ground water management through its Federal/ State Cooperative Program. Under this program, the Federal Government and over 500 State and local agencies share cooperatively in the cost of USGS performing investigations and research programed in collaboration with State and local agencies. These cooperative projects are designed to provide the continuing appraisal of water quantity and quality and to improve hydrological information and understanding and make the results available to Federal, State, and local agencies for use in developing, utilizing, conserving, and managing water and land resources. More than half of the water

resources data gathered in the United States, precluding most stream gaging, is provided by the cooperative program. For fiscal year 1976, the Federal contribution to the cooperative program was $26,954.00.

Data collection, analysis, and dissemination is a continuous process. Included in these activities are 7,400 continuous record and 5,400 partial record streamflow stations; 1,200 lakes or reservoir stations; 3,000 water quality stations; 14,000 ground water observations wells; and 12,000 project-type short-term wells. Area resource appraisals and problem-related studies include aquifer modeling, saline waters, waste disposal, and others totaling 576 projects which are usually completed in 1 to 3 years and result in a published report. Studies related to critical problems include 15 projects on deep waste emplacement and 19 on artificial recharge.

USGS also performs water-data collection, resources investigations, and research activities under the National Water Data System with regard to the public domain, interstate river basins and aquifers, or other areas of interstate or international concern. The USGS purpose is to acquire, process, store, and disseminate data on the quantity, quality, location, movement, and changes in water supply, including analytical studies and appraisals of local, regional, or national conditions, with focus on critical or urgent national water solutions to water problems and to extend the knowledge of hydrology. USGS is nearing completion of regional ground water appraisals of quantity and quality. Full coverage of the Nation is targeted for fiscal year 1978. Under Office of Management and Budget (OMB) Circular A-67, USGS is also responsible for coordinating water data activities of all Federal agencies.

In the critical national water problems program, USGS activities included monitoring changes in ground water due to coal and oil shale mining, subsurface waste storage, the availability of deep ground water supplies from the Madison aquifer of the Northern Great Plains, and an evaluation of the geological physical, chemical, and biological controls on artificial recharge to provide (1) methods for predicting the relative success of proposed artificial recharge facilities in different environments and (2) guidelines for determining treatment and operating procedures at recharge facilities to enhance recharge. USGS officials told us that about one-third of their projects directly relate to ground water.

Office of Water Research and Technology

OWRT programs are directed toward water and water-related problems through research and technology development. OWRT is also responsible for coordinating Department of the Interior water research.

OWRT performs its water research and development activities through contracts and grants. Under Title I of the Water Resources Research Act of 1964 (Public Law 88-379) as amended, OWRT provided noncompetitive annual funds allotment to support one State university water resources research and training institute in each State and in Puerto Rico, the District of Columbia, the Virgin Islands, and Guam. In fiscal year 1976, $110,000 was allotted to each of the institutes in the 50 States and Puerto Rico, and $40,000 was allotted for the District of Columbia, the Virgin Islands, and Guam. The act provides for up to $250,000 in allotments to each State institute. These State institutes play a major role in providing data to ground water managers within their respective States. Title I also authorizes an appropriation of $5 million for matching grants to the State institutes on a dollar-for-dollar matching basis. In fiscal year 1976, about $3 million was provided to the institutes for such research as ground water depletion, pollution, land subsidence, ground water quality, and water use efficiency.

Title II of the act authorizes up to $10 million for grants, matching grants, contracts, or other arrangements made with academic, private, public or other institutions, organizations, and individuals to do needed water research work related to the mission of the Department of the Interior. About $4.8 million was appropriated under title II in fiscal year 1976. OWRT also operates a Water Resources Scientific Information Center for disseminating research information. Overall, only about 5 percent of OWRT's program is directly related to ground water.

Agricultural Research Service

ARS performs water resources research at research centers across the Nation. ARS also had seven experimental watersheds where ARS examines the complete water cycle, including ground water. In fiscal year 1975, ARS had four ground water projects. Three of these dealt with artificial recharge and one with natural recharge. The artificial recharge research was being done for Fresno, California (a ground water dependent city), the southern High Plains of Texas, and Phoenix. The other project was a study of how ground water quality in

Fresno is affected by recharge from overirrigation. Two other projects were related to ground water as a source of discharge to streams. ARS is also doing some cooperative work with the Bureau of Land Management on recharging ground water on certain public lands. The costs for the four ground water projects in fiscal year 1975 were about $350,000, not including overhead.

LEGAL PROBLEMS AFFECTING GROUND WATER MANAGEMENT

Although there are several areas of effective ground water management which present legal problems, the most obvious is claims of water rights to a supply of water. It is not practical to discuss in detail the rules of water law in the 50 States. In many States such rules have not been clearly established. However, in some highly developed areas with semiarid climate and limited local supplies of water (such as southern California), the rules applicable to the use of water have been developed in great detail.

Traditionally, water rights have been established in lawsuits between parties seeking to control the use of a water supply inadequate to both parties' needs.

According to a document published by the American Society of Civil Engineers (ASCE), 1/ the following are principal terms which may be encountered in discussion of water rights:

> "1. Riparian Right.--Land adjacent to a stream, river, or lake is riparian to that body of water. Under the common law, the waters of the stream are available on a correlative basis for the use of all riparian owners. The right depended on location of the land and not on prior use of the water. Accordingly, the riparian doctrine has a 'dog in the manger' potential in the event of shortages; that is, by sole reason of location of the land, an owner may be able to assert a right to his share of a limited supply, to the exclusion of earlier development from the stream. As a result, in most jurisdictions where water litigation has resulted from problems of shortage, the rules with regard to severance (which terminates the

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1/ASCE--Manuals And Reports On Engineering Practice - No. 40 entitled "Ground Water Management" (1972)

riparian claim) and other restrictions upon the riparian right have become extremely technical, generally to the end of restricting application of the classic common law rules.

"2. Overlying Right.--In those jurisdictions where ground water rules are developed, the overlying land owner either possesses rights which are analogous to riparian rights on a stream, or asserts absolute title to water under his land. In either event, more recent decisions of the courts have found theories making it possible to restrict the arbitrary exercise of dormant rights of this nature.

"3. Appropriative Right.--In the semiarid western states, where there was obviously insufficient local water to develop all of the lands, the law of appropriation was adopted by custom, court decision, and statutory rule. Basically, the appropriative right is a right based upon priority of diversion and application of the water to beneficial use. It is a 'first come, first served' approach, whereby a limited supply is utilized to its capacity as the ingenuity of the pioneer puts it to beneficial use. It depends on demonstrated application of water to a beneficial use, rather than on location of lands with relation to the point of diversion or use."

Any attempt to effectively manage ground water must take into account existing water rights unless such rights are to be acquired under the police or taking power of the State. As pointed out in the ASCE document referred to above, the problem for a ground water manager becomes one of inventorying existing rights, and either accommodating the management plan to the existing framework of rights, or revising the framework through court or legislative action if it is too severe a constraint. Other means of modifying legal constraints include purchase of rights and water exchange agreements.

The ACSE document further commented on the legal problems involving ground water management as follows:

"In most jurisdictions, the only sure method of defining the extent and nature of a water right is through litigation. Yet most of the 'historic adjudicated rights' the manager will encounter arose from limited lawsuits involving two, or a

very few, water users in some limited area. The judgments involved are seldom binding upon the broad range of water-right claimants who may be included within the hydrologic unit to be managed. Plenary adjudications of all rights in a basin are rare.

"Yet, in the absence of general adjudication, the inventory of rights is often a chancy endeavor. There have been instances where implementation of a management plan has necessarily been preceded by a general adjudication of all rights in the hydrologic unit. There have been other instances where the development of management plans has been frustrated by latter-day assertions of water rights which were not fully accommodated in the plan.

* * * * *

"So long as the supply remains inadequate to meet the demand, however, the essential function of water rights remains a critical factor in ground water management. The manager must recognize those rights and adapt his plan for utilization of the resource accordingly, unless means can be found which are politically, physically, and financially feasible to eliminate the shortage. If the latter alternative can be taken, the need to accomodate the plan to an existing shortage can be minimized. A resource in surplus supply has little need of the legal tools for its allocation.

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"It is almost instinctive to assume that lawyers, water rights, and litigation are troublesome constraints to be overcome in the formulation of a rational water management plan. This initial response may well obscure the potential utility and flexibility of litigation as a tool for water management. The major water adjudication within a hydrologic unit can, if properly handled, offer a solution to many organizational and financing problems which are otherwise extremely troublesome."

* * * * *

"Under circumstances where a water shortage has been eliminated by importation of supplemental supplies or where the law of water rights has been slow to develop because of ample local supplies--the opportunity for political (as distinct from litigated) solutions to the management problem exists. In this situation, the commodity being allocated is the money available to pay for more expensive imported water, or to improve the quality of local water, or avoid construction of surface storage and distribution facilities.

* * * * *

"The political or utility approach has the great attraction of simplicity. It avoids water rights problems by ignoring them. But it has two essential prerequisites: (1) There must be a surplus of water physically available to meet all current requirements; and (2) the water users must be willing to forego definition and defense of their water rights. The latter requirement is what has most often made the political approach unavailable to the basin manager. To implement such an approach requires substantial salesmanship--which may indeed be a prime requisite for any successful basin manager."

OPPORTUNITIES FOR IMPROVEMENTS IN GROUND WATER MANAGEMENT

Good ground water management involves use of the resource with knowledge of the probable effects of its use and with proper planning to prevent or minimize adverse effects. The Western States generally are recognizing the need for better ground water management and have taken some steps in that direction. Nebraska's recently enacted Ground Water Management Act (see app. 1) is an example. Management of the ground water resources of the Western States, however, generally has been limited as evidenced by the numerous problems described in chapter 2. More intensive regulation of ground water basins usually has been crisis-oriented, occurring when faced with a severe problem, such as saltwater intrusion or declining water levels. Much damage had already occurred in some of these areas, and some problems had not received needed attention.

As water demands increase, ground water is expected to supply a greater portion of water withdrawn for use. Thus, good ground water management may be even more important in the future than it is today. Many areas are beginning to experience ground water level declines and the number may increase with greater water demands.

Problems, such as saltwater intrusion, land subsidence, and other social and economic problems of ground water overdrafting generally have resulted because ground water has not been properly managed and its use planned so as to prevent or minimize these problems. Ground water overdrafting may not necessarily be undesirable since the water in storage otherwise would not be used. However, when it is not planned and the adverse effects are not considered and dealt with, severe problems may result.

Ground water management can be improved by development and implementation of a management system to provide for the orderly development, proper use, and conservation of ground water of all major aquifers. Because of the varying geological and hydrological conditions of ground water, Federal and State officials with whom we discussed ground water management believed that the resource can most effectively and efficiently be managed at the State and local governmental levels. In this regard, the National Water Commission recommended that ground water be managed through public management agencies.

The Commission expressed no strong preference for management by a State agency or a public management district embracing each critical aquifer. The form of organization, according to the Commission, should depend on the problems encountered--hydrological, institutional, and legal. However, according to the Commission, the more comprehensive the management needs to be, the more appropriate is the district form of organization with oversight by the State Engineer or a State agency.

The Commission further recommended that the States adopt legislation authorizing the establishment of water management agencies with powers to manage ground water aquifers. As shown in appendix 1, several Western States have implemented such legislation and management agencies have been created for several areas experiencing substantial problems. At the time of our review, not all major aquifers were under the management of such agencies and some of these were experiencing problems. Insufficient

data as a major constraint limiting ground water management is discussed in chapter 4.

The most widely recommended improvement in ground water management mentioned during our study was conjunctive use and management, where possible, of surface and ground waters. Ground water is often naturally interrelated with surface water, and actions concerning one source ordinarily affects the other. These surface and ground waters should be viewed as one water source. According to the National Water Commission, ground water basins cannot be managed as effectively as isolated units, but must be integrated with management of surface water supplies.

Conjunctive use can also increase available water supplies in a hydrological area. A ground water basin in which the aquifer has been drawn down has value as a storage reservoir. The aquifer can be recharged from surface water supplies to utilize the unused capacity. A basic objective of conjunctive management would be that during times of heavy precipitation or high surface water flows, water in excess of surface water rights or needs would be used to recharge the aquifer, rather than leaving the area. During this time of surplus surface water, ground water pumping would stop to the extent that needs can be met by such surplus. In times of low surface runoff and short supplies of surface water, ground water could be used to satisfy water demands of those who normally pump ground water and those who normally withdraw surface water but whose requirements cannot be satisfied from surface water supplies.

A Commission report entitled "A Summary-Digest of State Water Laws" stated:

> "While the law has been slow in requiring, or even permitting, State administrators to manage ground water basins conjunctively with surface watercourse, no one seriously disputes the need for such conjunctive management."

Legal, administrative, and economic problems may also arise when different laws and economies are established on the basis of each source. For example, in States, such as Colorado, surface water rights generally have a higher priority than ground water rights because they were established at an earlier date. The State could prohibit the use of ground water from certain surface-water-connected aquifers when all surface water rights cannot be met. This can cause economic difficulty for those dependent upon ground water.

The Commission, in its comprehensive study of the Nation's water resources problems and needs, made several recommendations designed to improve ground water management. With regard to conjunctive use, the Commission recommended that State laws should be amended to provide for integrating the rights in both surface and ground waters and that uses of both should be administered and managed conjunctively. These laws and regulations, stated the Commission, should provide for maximum use of the combined resource, where possible, by authorizing or requiring users to substitute one source of supply for the other.

CHAPTER 4

GROUND WATER DATA--A CONSTRAINT TO IMPROVING GROUND WATER MANAGEMENT

Although much ground water data has been collected by Federal and State agencies and others, we were told during our study that substantially more geological and hydrological data--primarily of a more specific and detailed nature--will be needed to provide for the orderly development, proper use, and conservation of ground water resources. According to Federal and State officials, the lack of such specific and detailed data is a major constraint to improving ground water management.

TYPE OF DATA NEEDED

Proper management of an aquifer requires a detailed geological and hydrological description of the aquifer. This would include the aquifer boundaries, thickness, saturation, quality, and storage capacity; quantities available to wells under existing technology; amounts and points of natural recharge and discharge; and interrelationships with surface waters. Ground water managers also need to know the feasibility of (1) importing water, (2) artificial recharge, and (3) other means of increasing available water supplies in the area.

Once a management system has been implemented, monitoring of the quantity and quality of the ground water is necessary. For instance, the safe-yield of an aquifer is usually not a single, fixed rate of withdrawal but is a variable rate depending upon many complex and interrelated factors. A system based on a safe-yield use of an aquifer requires monitoring because one or more of the interrelated factors may change.

WHY MORE DATA IS NEEDED

The type of information indicated above is needed to serve, along with economic, social, and political considerations, as the basis for management of an aquifer, aquifer system, or ground water basin. With these data, decisionmakers can determine the most effective and efficient means to provide for the orderly development, proper use, and conservation of ground water to prevent or minimize ground water problems. The California Water Plan--Outlook in 1974 (November 1974) states:

"In developing ways in which ground water can be used to help meet water demands, the collection, analysis and verification of a large amount of geologic, hydrologic, and water quality information is necessary***Local agencies have benefited mainly by being able to make decisions on ground water management based on fact instead of speculation."

An example of the need for geological and hydrological information is illustrated by the following. USGS identified five methods for controlling seawater intrusion, a major problem in many areas. These methods were (1) reducing ground water pumping in the coastal area, (2) artificially recharging the aquifers, (3) modifying the pumping pattern, (4) maintaining a pressure ridge of fresh ground water above sea level in the intruded aquifers along the coast, and (5) establishing a pumping trough adjacent to the coastline. The first four methods control intrusion by maintaining ground water levels above sea level. The last method uses a ground water trough near the coastline to block the landward migration of seawater.

Geological and hydrological data are necessary to determine, among other things, the ground water level necessary to keep out the seawater, the quantity of ground water that can be pumped and still maintain the proper water level, the means and desirability for artificial recharge, and the best location for the pumping trough. This information should be available before the seawater intrusion occurs so that action can be taken to prevent such intrusion before it damages fresh water supplies.

This type of information, if properly presented, can be instrumental in obtaining public understanding of and support for needed measures to solve, prevent, or minimize ground water problems. Voluntary improvements in ground water management (such as conjunctive management and use of surface and ground waters and the establishment of management agencies for major aquifers or ground water basins) often may require the willingness of water users to accept a change in the water rights system and to provide the funds needed for such actions as artificial recharge and water import. The public must see the need for and the benefits of improving ground water management.

Water is an important asset, especially in the semiarid Western States. Those with established water rights can be expected to be reluctant to agree to any change in the water rights system for fear of losing all or part of their right or its priority standing. Owners of water rights may

not approve giving a management agency regulation authority over their rights. Therefore, action at the State level may be needed to obtain improved ground water management and good data will be needed to support such action.

Although large amounts of ground water data is available, many Federal and State officials have expressed a need for more data. Much of this need is for data more specific and detailed than that already obtained.

For instance, a North Dakota official told us that the State will require modeling of aquifers in the future in order to carry out its policy of operating aquifers on a safe-yield level.

USGS said that information on the continually changing quantity and quality of water resources is needed for effective planning, design, development, management, and use of ground water resources. Available information, according to USGS, is still inadequate for both applying hydrologic principles and understanding area occurrence of water, and a major effort in ground water research and investigation will have to be undertaken if ground water reservoirs are to fulfill their potential as elements of comprehensive, multipurpose water development.

In its 1973 budget justification, USGS reported that the average percent of current ground water data and information being met on a nationwide basis was as follows: resource appraisal, 40 percent; subsurface waste storage, 5 percent; and system studies, 20 percent.

WHO WILL PROVIDE THE DATA?

USGS has been providing ground water data to managers for many years through its Federal/State cooperative program. According to USGS, this program provides over half of the Nation's water resources information base and is a continuing program which responds directly to changing and increasing demands of Federal, State, and local agencies for information essential to water resources decisionmaking. Cooperative projects are jointly planned by State and Federal representatives and are designed to fulfill specific needs.

The Commission, in its June 1973 report, recommended that Federal appropriations for the Federal/State cooperative program be increased to meet the amount of matching funds offered by the States. States had been offering funds for Federal matching in excess of Federal appropriations.

As shown by the table below, funding offered by the States for the cooperative program exceeded available Federal funds.

Fiscal year	Federal matching funds (actual obligations)	State funding offered
	(millions)	
1974	$24.9	$25.9
1975	25.9	28.5
1976	26.9	29.7
1977 (bud. est.)	27.8	30.8

The Federal funds listed above are for both surface and ground water activities funded under the cooperative program. In fiscal year 1975 USGS funded about 290 ground water and ground water related projects under the cooperative program. These projects amounted to about $9 million and were with 48 States, Guam, and Puerto Rico--an average of about $180,000 per State. Many of these projects were continuous or multiyear.

Many of the States have agencies that perform duties similar to USGS under the Federal/State cooperative program. Some of these States have large staffs while other States work through universities, contract out for such services, or depend largely on USGS. Generally, most officials we interviewed said that the Federal/State cooperative program has been an important program to the States.

Ground water data are relatively difficult to obtain and more costly than comparable surface water data. USGS officials told us that the average ground water study takes about 3 years to complete. Several State officials pointed out the lack of available State funding for obtaining needed data and indicated that providing the data is the proper role of the Federal Government in ground water management. USGS and the Commission have pointed to a lack of ground water hydrologists as an additional constraining factor to obtaining sufficient geological and hydrological data, along with Federal and State budgetary constraints and the time required.

It is recognized by Federal, State, and local officials that improvements are needed in ground water management and that this will require substantially more geological and hydrological data. However, the extent of these needs, the resources involved, and priorities for data collection and analysis have not been determined.

During this study, we observed that Federal and State Government agencies do not appear to systematically identify areas experiencing ground water problems, or areas receptive to improved ground water management practices, for assigning priorities for Federal assistance in obtaining the type of ground water data needed for improved ground water management.

CHAPTER 5

MATTERS FOR FUTURE STUDY

The information developed in connection with this review indicates that there are a number of significant questions which warrant attention and study in future planning and administration of water resource development.

1. Should the Federal Government take a more active role in ground water management? If so, what should its role be and what agency or agencies should be responsible?

2. Should future construction of Federal water resource projects depend on whether the State(s) show that their laws provide for integrating surface and ground water rights?

3. How crucial is an inventory of water rights to proper management of ground water? Should the Government be responsible for inventorying these rights?

4. Should the Federal Government systematically identify areas with ground water problems to assign priorities for Federal assistance in obtaining ground water data?

5. Should there be a national water policy requiring all Federal agencies involved in water planning or construction activities to require use and management of surface and ground waters as a unit? If so, how should such policy be implemented?

6. Should water be transfered from one river basin to another to reduce ground water pumping or to recharge aquifers?

7. Is enough being done to identify and prevent the intrusion of saltwater into ground water supplies?

8. Should (or can) Federal programs be devised which provide incentives to decrease dependency on irrigation farming in water-short areas? How important is irrigation to the national economy? Is it feasible to compensate for decreased farm production in such areas by increased farm production in areas not requiring irrigation?

These questions, involving basic policy, warrant consideration by the Congress. Some, we believe, are most appropriate for consideration by the Federal and State agencies responsible for planning and administering water programs. Others may be more suitable for undertaking by private research associations or academic institutions. The questions are presented in order to assist in focusing attention on matters requiring further study and analysis. We will be considering these questions in future reveiws of water-related issues.

On April 18, 1977, the President of the United States reported the results of a review he had made of 32 Federal water resource projects and noted that some of the projects would bring water to areas where there are no State ground water management programs. In the case of one of the projects reviewed (the Central Arizonia Project), one of the President's recommendations was to make further Federal funding contingent upon further study of ground water supplies and institution of ground water regulations and management by the State of Arizona.

The President indicated that he was recommending the development of major policy reforms in the area of water conservation including wise ground water management. We believe that in development of the major policy reforms, recommended by the President for better ground water management, consideration and study should be given to the eight questions set forth in this chapter.

AGENCY COMMENTS

Officials of the Water Resources Council, USGS, and the Bureau of Reclamation concurred generally with this report. Water Resources Council officials stated that our report offered a valuable overview to the ground water situation in the Western States. They emphasized that ground water problems are not just limited to the Western States but also occur in the East (the map on page 6 was provided by the Council to highlight this point). Officials of USGS stated that the report provided a comprehensive discussion of ground water and that USGS should have prepared this type of report some time ago. USGS officials said that although the report did not deal with ground water quality, this subject was equally as important as ground water supply.

Although our review was primarily concerned with the ground water supplies of the Western States, we do recognize that ground water problems occur in the Eastern States and

that the problem of ground water quality is equally important as that of supply. We further believe that any study of the eight questions set forth in this chapter should be national in scope and, where applicable, ground water quality should be considered.

A BRIEF DESCRIPTION OF GROUND WATER MANAGEMENT IN FOUR OF THE EIGHT STATES WE VISITED

NEBRASKA

In Nebraska, surface and ground waters are public property that may be appropriated for beneficial use. Registration of wells with the State and well spacing of at least 600 feet apart is required of all wells. (Requirements in critical areas may be more stringent.) Nebraska water laws recognize to some extent the relationship of surface and ground waters by placing wells within 50 feet of a stream bank under the jurisdiction of the stream appropriation doctrine.

Under Nebraska's Ground Water Management Act of 1975, a Natural Resources District (of which there are 24 covering the State) may initiate action to have an area within the District designated as a critical area because it believes ground water supplies are inadequate. The State Director, after a public hearing, may make such a designation because ground water levels are declining or have declined excessively, conflicts between users are occurring or may occur, water is being wasted, or conditions exist or may arise that require regulation for the protection of the public interest. Within 60 days after designating an area as critical, the District must hold hearings on the type of controls needed.

The District may, with the State Director's approval, determine the permissible total withdrawals of ground water in the critical area, apportion withdrawals among the appropriators holding valid rights, require and specify a system of rotation of use of ground water, institute well-spacing requirements more restrictive than the 600 feet allowed by a 1957 State law, or any other regulation deemed necessary. If considered necessary, the District may ban well drilling for 1 year after public hearing and upon approval of the State Director. This ban may be extended for 1-year periods or removed whenever conditions warrant it.

If the District does not adopt controls within a year after designation of a critical area, the State Director may specify the controls for the District to enforce. In any event, the District must consult appropriate Ground

Water Conservation Districts and, if possible, use studies conducted and data collected by the conservation districts before adopting controls.

The act also requires a drilling permit for any well in the critical area having a capacity of over 100 gallons a minute. The State Director may deny a well application if it would conflict with adopted regulations or if the proposed use is not considered beneficial. The act further gives the District taxing powers within a critical area to cover administrative costs.

According to USGS, Nebraska has not designated any area as critical; however, one petition has been denied and another is currently being considered.

TEXAS

Under the common-law doctrine of riparian rights, ground water in Texas is private property and is subject to capture and use by owners of the overlying surface, their agents, or assignees. However, to cope with excessive competition for limited supplies of ground water in the semi-arid parts of Texas or to resolve other ground water problems, the State was resorting to limited management in some areas. The State authorized groups of water users to form underground water conservation districts to regulate well spacing and production and to preserve, protect, recharge, and prevent ground water waste.

The Underground Water Conservation Districts Act of 1949 was enacted by the Texas Legislature to provide for the creation of underground water conservation districts as a means of local regulation and administration of ground water. (In 1973 the act was amended primarily to allow for control of land surface subsidence caused by withdrawals of ground water.) The Texas Legislature, the Texas Water Rights Commission, and county commissioners' courts have the authority to create districts. Initiation of such action usually results from a petition by the users of the water. In all cases, the Water Rights Commission must first delineate the underground water reservoir or subdivision of it. The aquifer proposed for regulation must have ascertainable boundaries and must be capable of yielding at least 150,000 gallons a day to a well.

Only the Texas Legislature or the Water Rights Commission may create underground water conservation districts that emcompass all or parts of two or more counties. The

respective county commissioners' courts are responsible for creation of such districts whenever the aquifer (or subdivision), as delineated by the Water Rights Commission, lies wholly within one county.

Each underground water district may make and enforce rules to provide for conserving preserving, protecting, recharging, and preventing waste of ground water. It may enforce its rules by injunction, mandatory injunction, or other appropriate remedy in a court of competent jurisdiction. In carrying out their responsibilities, districts may acquire land; construct dams; drain lakes, depressions, draws, and creeks; and install pumps and other equipment necessary to recharge the aquifers. Districts may also hire professional engineers to make needed surveys of the aquifers and facilties in order to determine water quantities available for use and to determine the improvements, development, and recharging needed by the aquifer.

Comprehensive plans for most efficiently using ground water and for controlling and preventing its waste may be developed by the districts. They may also carry out research projects, develop information, and determine limitations on ground water withdrawals. The plans and information developed may be published and brought to the attention of ground water users in the districts and urged for adoption and use.

Other management tools available to the districts are requirements for a well permit, logs of well production and ground water use, and the authority to levy and collect taxes on property in the district and to issue bonds. Well permits may be used to regulate spacing or production of wells. Wells producing less than 100,000 gallons a day are exempt from such requirements. Any person, firm, corporation, or association of persons affected by or dissatisfied with a provision of the act or a rule made by a district is entitled to file a suit against the district or its directors.

As of April 1975, six underground water districts had been created in the High Plains area of Texas. Another had been established to regulate development of the Edwards aquifer in the San Antonio area. However, only three of the six in the High Plains are considered operational or active. In 1975 the Texas legislature established the Harris-Galveston Coastal Subsidence District, whose board is to control the amount of ground water drain from the aquifers in the Houston area. Houston is also constructing

a system of canals and aqueducts to import water from the Trinity River.

The High Plains Underground Water Conservation District No. 1, estabished in 1951, covers all or part of 15 southern High Plains counties in Texas, and contains 5,215,600 acres (8,149 square miles). The District is primarily concerned with the orderly development and conservation of ground water pumped from the Ogallala aquifer. During its early years, the District's primary efforts were educating water users as to the nature and severity of the overdraft problem and the need to conserve water.

All landowners in the District are required to pay a $10 deposit and secure a permit before drilling a well capable of producing more than 100,000 gallons of water a day. The permitted well must be spaced from all existing wells in accordance with its permitted capacity. The deposit is returned to the applicant after a driller's log and well-completion report are received by the District.

In carrying out its responsibilities, the District performs such duties as maintaining an 800 unit water-level observation program; conducting numerous specialized studies involving well completion, ground water availability, contamination, and other geologic, geochemical, and hydrologic studies; and carrying out water abatement and artificial recharge programs. In 1954, the District initiated efforts to secure an income tax allowance for the taxpayer's cost in the amount of the aquifer beneath his property that was dewatered annually as a result of water pumped to create income. A recent survey by the District showed that the annual income tax allowance and rebate to taxpayers in several of the counties within the District approach $800,000 a county.

NORTH DAKOTA

Ground water was considered to be privately owned for many years. However, both underground streams and percolating waters are now subject to appropriation for beneficial use under the same procedures applicable to surface waters.

The State operates a water permit system under the appropriation doctrine. Permits are processed by the State Engineer who recommends rejection or acceptance to the State Water Commission, which consists of the Governor and five appointed commissioners. The State Engineer, an appointee of the Governor, may also stipulate various conditions to

be met before the permit becomes a perfected permit after 4 years of probational use. A permit can be issued by the State Engineer over the rejection of the Commission.

In making or denying awards of permits, consideration is given to water availability and crop and precipitation patterns. A 4-year use pattern is monitored by the State before declaring the right perfected or a permanent property right. A portion of the right may not be challenged, if not used, although total abandonment will cause the right to revert back to the State. Water (both surface and ground water) applied for irrigation is generally limited to 1 cubic foot a second for each 80 acres of land irrigated not to exceed 3 acre feet per year, for a specific time in each year.

Although the State operates under the appropriation doctrine, there has never been a call placed on the State water rights system. In other words, the water resources have not been developed to the extent that all rights cannot be satisfied.

There are 59 local water management districts which manage drainage projects and surface reservoirs. Ground water problems, however, are the responsibility of the State Engineer. The lack of ground water problems is attributed to the past low development rate in the State and the fact that the current administrative framework existed before accelerated development. State officials expect that the State will require modeling of critical aquifers in the future and that the administrative system will evolve into a ground water management process. Management, according to the State officials, will actively focus on water users and optimal applications of the resource in addition to operating the aquifer at a sustained yield level. They said that a sustained safe-yield level will be determined by the political process with technical input by the State Engineer.

Water meters were required on all high-yield wells after June 1, 1975. This could allow close monitoring on pumpage which could be correlated with effects on the aquifer.

CALIFORNIA

California operates under the principle of correlative rights, a variant of the common-law doctrine. The rights of all owners of land over a common basin, saturated strata,

or underground reservoir are coequal. One landowner cannot extract more than his share (even for use on his lands) where the rights of others are injured nor can he claim more than his share on the basis of peculiar benefit to him from its use. In a time of shortage, all the landowners would share the shortage proportionally.

The State's primary method for regulating or managing ground water is approval of local public management agencies with the authority to manage a particular basin, county, or other pertinent geographical area through such practices as water conservation measures, buying and selling water, importing water, recharging ground water, and constructing facilities.

The Orange County Water District, one of these public management agencies, was formed in 1933 by an act of the California Legislature to provide management and conservation of the ground water basin, including both quality and quantity of water and the protection of Orange County's water rights in the natural flows of the Santa Ana River. The District is governed by a 10-member Board of Directors representing areas within the District.

Some of the major activities of the District were purchasing water from outside the basin for artificial recharge, recharging with Santa Ana River water, constructing seawater intrusion barriers, constructing a wastewater reclamation and seawater desalting facility, operating several multipurpose recreational use projects, and planning in advance. These activities were financed by two methods.

Under its legislative act, the District can levy and collect a replenishment assessment on water extracted from the ground water basin. These funds must be used to purchase supplemental water to recharge the basin, or to construct, operate, and maintain water production facilities and acquire water rights and facilities used to replenish and protect the ground water supply. The District also levied ad valorem (property) taxes to pay for management costs, capital investment of projects required in basin protection programs, and water rights acquisition. The District is empowered to issue bonds but has never used this authority.

With regard to ground water management, the California Water Plan of 1974 states that:

> "Efficient management of surface and ground water resources will require comprehensive investigation of the

institutional, legal, economic, and financial effects of management proposals***Although ground water management at the lowest possible governmental level is frequently advantageous, regional management may be necessary in many areas if maximum use of ground water resources is to be achieved. Regional authority might be established by (a) legislation, (b) stipulation by a coalition of adjacent water service agencies, or (3) the legislative processes associated with water rights permits administered by the State."

PRINCIPAL OFFICIALS RESPONSIBLE FOR THE ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
DEPARTMENT OF THE INTERIOR		
SECRETARY OF THE INTERIOR:		
Cecil D. Andrus	Jan. 1977	Present
Thomas S. Kleppe	Oct. 1975	Jan. 1977
Stanley K. Hathaway	June 1975	Oct. 1975
Kent Frizzell (acting)	May 1975	June 1975
Rogers C. B. Morton	Jan. 1971	May 1975
Fred J. Russell (acting)	Dec. 1970	Jan. 1971
Walter J. Hickel	Jan. 1969	Nov. 1970
COMMISSIONER, BUREAU OF RECLAMATION:		
R. Keith Higginson	Apr. 1977	Present
Donald Anderson (acting)	Feb. 1977	Apr. 1977
Gilbert Stamm (note a)	Apr. 1973	Feb. 1977
Ellis L. Armstrong	Nov. 1969	Apr. 1973
DIRECTOR, UNITED STATES GEOLOGICAL SURVEY:		
Vincent E. McKelvey	Dec. 1971	Present
William A. Radlinski (acting)	May 1971	Dec. 1971
William Pecora	Sept. 1965	May 1971
DEPARTMENT OF AGRICULTURE		
SECRETARY OF AGRICULTURE:		
Bob Bergland	Jan. 1977	Present
John Knebel (acting)	Oct. 1976	Jan. 1977
Earl L. Butz	Dec. 1971	Oct. 1976
Clifford M. Hardin	Jan. 1969	Nov. 1971
Orville L. Freeman	Jan. 1961	Jan. 1969
DEPARTMENT OF THE ARMY		
SECRETARY OF THE ARMY:		
Clifford L. Alexander, Jr.	Feb. 1977	Present
Martin R. Hoffman	Aug. 1975	Feb. 1977
Howard H. Calloway	May 1973	July 1975
Robert F. Froehlke	July 1971	May 1973
Stanley R. Resor	July 1965	June 1971

a/Served as Acting Commissioner from April to May 1973.

APPENDIX II

	Tenure of office	
	From	To
CHIEF OF ENGINEERS:		
Lt. Gen. John W. Morris	July 1976	Present
Lt. Gen. William C. Gribble, Jr.	Aug. 1973	June 1976
Lt. Gen. Frederick J. Clarke	Aug. 1969	July 1973

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