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THE NATION'S WATER OUTLOOK TO THE YEAR 2000

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EXECUTIVE SUMMARY

The drought of 1976-1977 served as an amplifier of long-recognized, but frequently ignored, water problems. At issue is the allocation of scarce water resources for environmental enhancement, recreation, food and energy production, and municipal and industrial water supplies.

It has been estimated that 1980 demands on national water resources will nearly double those of 1954, and that by the year 2000 demands will triple those experienced in 1954.

During 1975, the Nation's freshwater withdrawals for all purposes averaged 420 billion gallons per day (bgd). This included a substantial reuse of flows. Of the total amount used, approximately 112 bgd were consumed through evaporation or incorporation into products. A maximum estimate is that by 1985, the total national withdrawal of fresh water will reach 600 bgd, including reuse. Depending upon the nature of the energy-water picture, between 116 and 154 bgd will be consumed.

According to the U.S. Geological Survey (USGS), thermal electric plant withdrawals exceeded irrigation withdrawals in 1965 to become the leading use of water. This shift resulted from rapid growth in electric demand and the widespread use of once-through cooling systems. While it is expected that thermal electric facilities will be expanded in the future, it is likely that closed evaporative systems will be used for cooling. This would reduce water withdrawals but result in increased consumption of the water used. In terms of overall consumptive use, irrigation stands as the frontrunner.

From a nationwide perspective, there is sufficient water to meet projected needs well beyond 1985. This optimism should be tempered, however, by a realization that national totals do not reflect geographic or temporal variations, and some severe local and regional problems can be expected. For the entire eastern third of the Nation, the water supply outlook is good to the year 2000. Exceptions are the Miama-Ft. Lauderdale and Chicago areas where year 2000 depletion levels are expected to be higher than the norm. In the remaining two-thirds of the Nation, 20 percent or more of the available water supply is already being consumed. The Souris-Red-Rainy Region, most of the Columbia North-Pacific Region, and the northern part of California are exceptions.

Significant water supply problems exist or are anticipated in southern California, the Great Basin, the Lower Colorado, the Rio Grande, the High Plains of Texas, and the south-central portion of the Missouri River Basin. Many of these areas are large consumers of water for irrigated agricultural production, and expected water use for development and processing of coal and oil-shale deposits in some of them will add to the difficulties. Unless there is a shifting of water allocations, water may already be limiting growth in some of the more critical areas.

The avenues of relief for tight water supplies are additional development and reduction in use. The former has been the traditional approach, while the latter has been a much talked about but poorly exercised alternative. This is unfortunate since large quantities of water are wasted and opportunities abound for meeting many projected needs without new development. In the long run, there are many alternatives for easing the severity of water problems. The difficult aspect is implementation. Impediments to optimal water development and efficient use which merit attention include:

-- the prevailing body of water law,

-- failure to recognize the interrelationship of surface and ground waters,

-- the ingrained idea that per capita use of water must continually increase to maintain our standard of living,

-- the artificial separation of water quality and water quantity management, and

-- the failure to establish a price for water which is commensurate with the value of its use.

Historic trends in American water resources development have been strongly influenced by provincial interests and an ardent belief in the sanctity of individual water rights. These traditions have fostered the generation of almost impregnable institutions which were adequate in their day, but now often constrain efficient allocation and management of the Nation's limited water supplies. Most authorities on water use believe that unless a philosophy of total water management begins to take hold, it will be difficult to cope with tough contemporary issues. Institutional rather than technical constraints are the barriers to timely solution of many regional water problems and they believe that the design of comprehensive water management policies is long overdue.

Finally, decisionmaking based on studies of alternative futures seems worth pursuing. The complexity of factors shaping the Nation's destiny makes the use of single projections, such as the Water Resources Council's

Modified Central Case, more hazardous than ever. Analyses of a feasible range of tomorrows would likely result in more rational and flexible decisions.

This review emphasizes the technical aspects of water resources problems. The many social and political considerations related to comprehensive water management policies are not intensely explored.

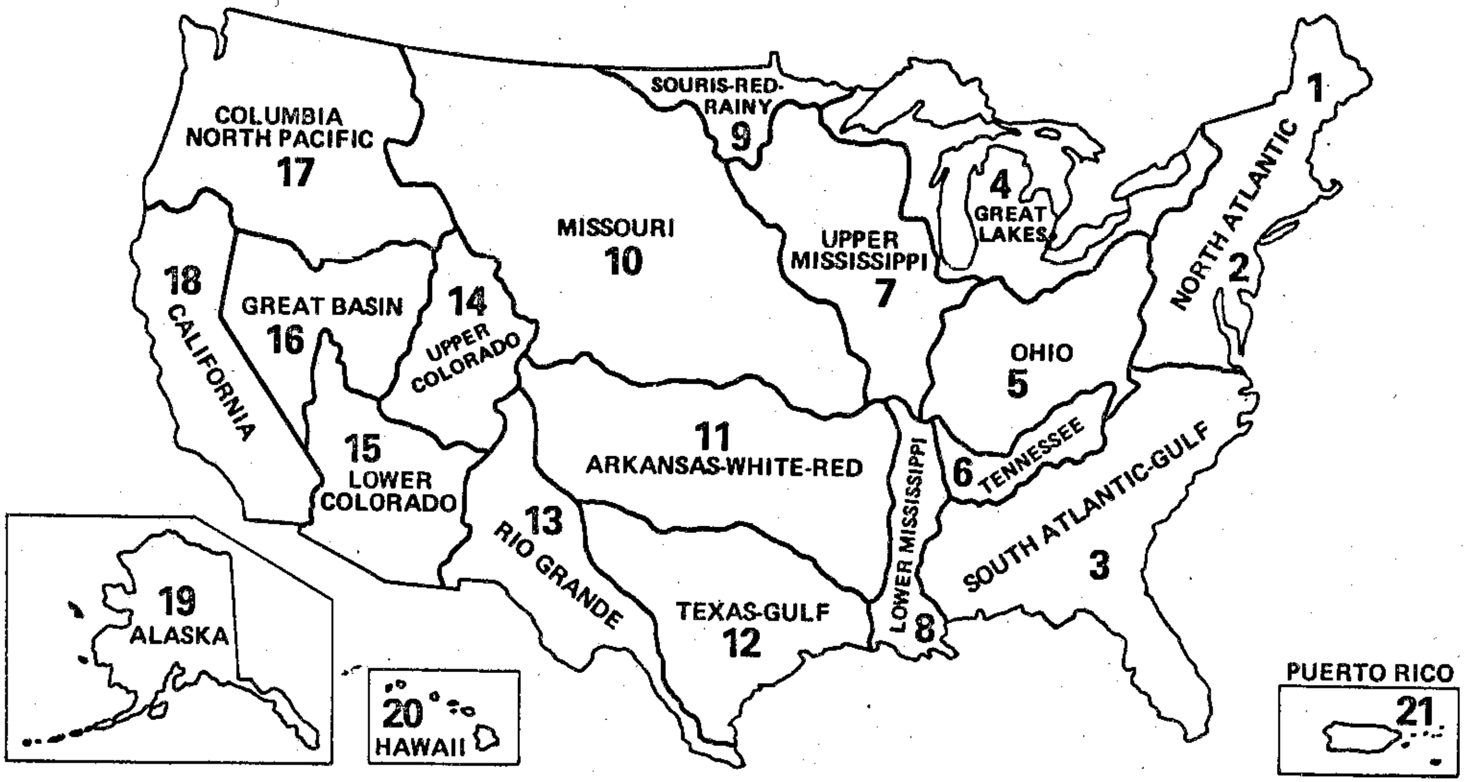
THE NATION'S WATER OUTLOOK TO THE YEAR 2000

I. INTRODUCTION

The importance of water to the Nation was underscored by President Carter in his May 23, 1977, Environmental Message to Congress which called for the development of a national water resources management policy. The 1976-1977 drought, accelerating rates of water consumption and steadily increasing environmental pressures were all motivating factors.

Decisions on new water resources developments should be based on an understanding of the present and on plausible forecasts of the future. The current situation is reviewed herein, projections to the year 2000 are given, and emerging problems and possible courses of action are identified. Regional issues are discussed in the context of the U.S. Water Resources Council's (WRC) 21 regions (Figure 1), while dollar flow analyses are reported for the U.S. census configurations. Some trends are reported on a State basis. A common areal subdivision for evaluating all data could not be found.

FIGURE 1 **WATER RESOURCES REGIONS (UNITED STATES WATER RESOURCES COUNCIL)**



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II. FACTORS IMPACTING ON THE ALLOCATION AND USE OF THE NATION'S WATER RESOURCES

Water resources are developed for purposes ranging from residential water supply to fish and wildlife enhancement. The amount of water used, the manner in which it is used, and the degree of treatment to which it must be subjected are dependent on numerous factors. These include: population; municipal, industrial and agricultural needs; energy resource development needs; recreation plans; water quality management programs; environmental enhancement and preservation considerations; and the nature of Federal, State and local institutions. The importance of these factors is discussed in this section and their possible impacts on future water development trends are analyzed.

Water Use

Water uses are not all compatible and resulting conflicts require that allocations be made on the basis of compromise. The nature of these trade-offs can best be understood by reviewing the constraining aspects of the principal water use sectors.

Irrigation.--Water requirements for irrigation are normally seasonal. The quantities of water needed vary with climate and type of crops raised. In humid areas, water withdrawals are often non-uniform and range from about 10 percent of the total demand in May to 30 percent in September. In arid and semiarid regions, the rate of withdrawal is more nearly uniform. In general, as much reserve water storage as possible should be provided to ensure against shortages during extended dry periods. Irrigation water use conflicts with many other uses. For example, irrigators like to store as much water as possible during winter months, minimizing releases from storage, while hydropower producers are anxious to have water flowing out of reservoirs through their turbines.

Hydroelectric Power.--Historically, requirements for hydroelectric power have been seasonal but with increasing air-conditioning loads, the situation has shifted. The use of hydroelectric facilities to provide peak power, as opposed to furnishing base load, is also becoming more prevalent. This type of operation increases conflicts with recreationists and others desiring minimal short-term fluctuations in reservoir levels. In general, conflicts between water use for power and other purposes stem from opposing seasonal requirements. For example, heavy summertime releases for navigation dictate maximization of storage during the winter, a situation which is incompatible with discharging from storage during the same period to produce electricity. On the positive side, hydropower production does not adversely affect all water uses. Water passed through turbines during the summer can be used downstream for irrigation, navigation, flow augmentation, or other purposes.

Navigation.--Water requirements for navigation are highly seasonal with the heaviest demands occurring during the driest months of the year. Reservoir releases for navigation are competitive with irrigation and hydropower storage requirements and with recreational uses at reservoir sites. They do, however, compliment instream flow needs.

Maintaining navigation depths by use of low dams generally has little effect on other water uses within a river basin. This is because these structures do not impound large volumes of water, but serve only to provide greater uniformity of flows. Many advantages result from this type of operation. Benefits to fish and wildlife, recreation, pollution control, and aesthetic enhancement may directly result.

Large multipurpose reservoirs, such as those on the main stem of the Missouri River, often provide storage to meet periodic navigational flows. The operating policies for these reservoirs must therefore be designed to accomodate the opposing requirements of other water uses for which storage is provided.

Recreation.--About one-fourth of the Nation's outdoor recreation activity is water dependent. In 1975, swimming, fishing, boating, water skiing, and ice skating accounted for 2.8 billion activity days and this is projected to increase to 7.7 billion by 2000.[1/]

1/ U.S. Water Resources Council. Nationwide and regional analyses. For 1975 assessment. Unpublished. 1977. (referred to hereafter as WRC-1975).

Although the demand for water-based recreation is increasing, the opportunities for taking advantage of it have been diminished due to shifts in population centers, increasing transportation costs and degraded water quality. Some recreational needs may be met by providing better access to existing water resources, improving water quality, reducing competition for use of available waters, and imaginative use of urban storm-water flows and other waters ordinarily wasted.

Concurrent with the increased emphasis on water-based recreation has been a growing concern for environmental enhancement and preservation. The result is constraint on the furtherance of traditional water resources development and a heightened competition among the water use sectors. The recreation-environment ethic portends sweeping changes in the nature of future water resources developments and adds a new dimension to the relevant decisionmaking processes.

Water requirements for recreation are usually greatest in the summer. The sportsman and vacationer desire substantial stream flows and maximum, unvarying reservoir levels during this period. Such conditions are optimal for fishing, boating, and other water sports but are in conflict with many other water users.

Flood Control.--The utilization of storage works for flood control requires that ample volume be available to impound floodwaters and that this volume be released quickly to prepare for the next flood. Of all water storages, flood control is the least compatible.

Problems associated with flood flows are mostly the result of man's persistence in occupying floodplains. Although these areas may be dry for years, they are in reality a part of a river's channel during periods of peak flow. An economic toll is exacted for man's occupancy of floodplains and it ranges from simple time delays to the loss of human life. The annual charge for the Nation has reached one billion dollars and few regions escape some form of payment.[2/] Damages can be reduced by restricting use of flood-prone areas, constructing protective works, floodproofing buildings and use of early-warning systems.

Urban Water Supply.--Urban water requirements vary with locality but the national average is about 170 gallons per capita per day. Normally, the maximum daily municipal use is about 180 percent of the yearly average, with summer averages higher and winter averages lower. Storage is often needed to carry a community through long periods of dry weather and this may conflict with other water development objectives.

Water Quality Control.--The increasing emphasis on a quality environment has produced new and significant conflicts in the water management field. Most stem from the desire of environmentalists or water quality officials to maintain prescribed levels of flow to enhance conditions for fish and wildlife or improve overall water quality. The problem is that

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2/ Information provided by Mr. Eugene Stallings, U.S. Army Corps of Engineers, Office of the Chief of Engineers, Engineering Division, Hydraulic Engineering Section.

maintenance of specific instream flows forecloses or limits many withdrawal uses. Summer months are the most critical.

Energy Production and Energy Resource Development.--Water is used to produce energy directly (hydropower), to process other energy-producing resources, and for restoring lands despoiled during mining operations. Water requirements for extraction of coal, oil shale, uranium, and oil gas are not large, although secondary recovery operations for oil are heavy water users. Significant quantities of water may be used in coal slurry pipelines and are needed in the retorting and disposal of spent oil shale. Conversion of coal to synthetic gas or oil to electric power and electric power generation all require large quantities of water.

In the energy industry, withdrawals for cooling of thermal electric plants is the largest category of water use, totaling approximately 170 billion gallons per day (bgd) in 1970.[3/]

Availability of water will influence the location and design of energy-conversion facilities. This is a particularly important consideration in many water-deficient areas of the West which are rich in coal and oil shale. The competition for water between the energy industry and other water use sectors, notably irrigated agriculture, is expected to intensify.

3/ U.S. Geological Survey. Davis, G.H. and L.A. Wood. Water demands for expanding energy development. Circular No. 703. Washington, D.C. 1974.

Population

Population changes affect a locality's water needs and its capability of providing the water required to meet them. Water quality and the nature of water and waste treatment facilities are also influenced.

According to the Water Resources Council, the population of the United States is projected to reach a total of about 268 million by the year 2000 (OBERS).4/ The Gross National Product is projected to increase from $900 billion (1975) to $2,100 billion (2000).

The greatest percentage growth in population and income is expected in the "Sunbelt" States where most Federal dollars for water resources projects have been going. If the present trend continues, these States will have about 45 percent of the Nation's population by the year 2000. This growth is expected to occur primarily in existing metroplitan areas, intensifying the pressures on their water and land resources. Since World War II, for example, Houston, Texas, has increased its population from 385,000 to 1,400,000; Tucson, Arizona, from 45,000 to 332,000; and San Jose, California, from 68,000 to 446,000. The rapid growth rate of western cities, many of which are located in arid regions, forebodes increasing problems of competition for water in those areas. The water supplies of

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4/ U.S. Water Resources Council. Nationwide and Regional Analyses for 1975 Assessment. Unpublished. 1977. Population projections by the Bureau of Economic Analysis (Dept. of Commerce) formerly the Office of Business Economics, and the Economic Research Service (Dept. of Agri.) OBERS (only one "E" for economy).

Phoenix and Tucson are rapidly being depleted and the expectation that water from the Central Arizona Project will solve their problem might be overly optimistic.

Environmental Protection

The focus on environmental preservation and enhancement has impacted significantly on water development processes. Conflicts between users such as irrigators and manufacturers have been sharpened and new conflicts between traditional water users and conservationists have emerged.

The issue of instream flow reservations is a case in point. Instream flow maintenance is intended to protect or enhance the aquatic and esthetic values of a stream and preserve existing fisheries. The problem is that reservation of instream flows conflicts with other legal claims on water which are already greater than natural flows for many localities.

Although current (1978) estimates of instream flow needs are crude, the quantities of water involved are large, especially during low-flow periods. If attempts are made to maintain such levels of flow, many river basins will experience severe water allocation problems. This could become one of the most critical water resources issues of the future. Montana has given legal standing to instream nonconsumptive uses [5/] and other States are considering or have enacted similar statutes.

5/ Nonconsumptive use means that the water supply is not depleted in quantity.

Water Law and Institutions

The drought of 1976-1977 focused attention on the Nation's water supply problems but their roots go much deeper. Historically, water resources development has been influenced by provincial desires and the sanctification of individual water rights. This has fostered many institutions which were adequate in their day, but which now often constrain efficient water allocation and management.

Changes in institutions such as water rights, organizational structures, and long-standing social customs appear needed to effect systematic changes of the scale required, but incremental improvements could be made with little disruption of current policies and practices. For example, Federal loans for financing private irrigation development could carry a restriction requiring these facilities to be designed and operated for maximum conservation of water resources.

State Laws.--State water rights laws and regulations often constrain efficient water use. This is especially true with respect to irrigated agriculture in States west of the Mississippi River.

Western water law generally follows the appropriation doctrine which states in principle that an earlier acquired water right shall have priority over later acquired water rights. This doctrine may encourage wasteful use of water and at best provides little incentive for conservation.

Nearly all States east of the Mississippi River follow the riparian law of water rights. The riparian landowner has the right to use water at any time, with restriction on place of use and subject to sharing water in times of shortage. Adjacent landowners are protected from uses that unreasonably diminish water quantity or quality. Although permit systems are little used in the eastern States, such systems will likely become more common as conflicts over water use increase.

Appropriation States do not recognize any part of a water right which is in excess of the amount of water reasonably needed or actually used. In most western States, administrators have the power to prevent wasteful means of diversion and conveyance and excessive application of water. More vigorous exercise of this power, combined with a more explicit definition of beneficial use would help resolve this problem.

The States could review their water law doctrines and remove legal impediments to water-saving practices. If a district or a user makes reductions in water use that require a significant investment, there could be some form of reward such as the privilege to use or sell the saved water. States could also consider making changes in their laws to facilitate transfers of water rights. The Federal Government, working through the River Basin Commissions or other regional authorities, could assist States in developing laws that recognize the interrelationship between surface water and groundwater and that provide for coordinated management. This would promote more efficient use of the total water supply.

Indian Water Rights.--Historically, State law has accommodated establishment of water rights related to diversion of a watercourse for beneficial use. The central feature of this appropriative right is the right to obtain water in periods of reduced supply before others having rights established later in time are served. First in time, first in right, describes the process. Presently, permits are issued by States as evidence of rights and on the basis that unappropriated waters are available.

Indian water rights are independent of the State law system. They arise in Federal law and generally are established at the time a reservation is created. When the reservation is on lands aboriginally owned by the Indian tribe, the water rights may be considered to exist from time immemorial.[6/] Ordinary appropriated waters have a priority dating to the time of first use or from the date of a permit while Indian rights have a priority in time dating at least to the date the reservation was established. Indian reservations considered to have aboriginal water rights would have first priority on the body of water serving their supply.

The legal basis for reserved Indian water rights was established by the U.S. Supreme Court in the case of Winters v. United States.[7/] The finding was that the government, in creating a reservation, intended to reserve water for Indian lands so these could be put to use. In Arizona v. California, 373 U.S. 546 (1963), the court approved a quantification of Indian water rights based on the amount of water sufficient to irrigate all practicably irrigable acreage on a reservation. Although this measure serves those areas engaged in farming and ranching, it is possible that

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6/ National Water Commission. Water Policies for the Future. Washington, D.C. U.S. Govt. Print. Off., 1973.

7/ Winters v. United States, 207 U.S. 564 (1908).

Indian reservations created for other types of occupations may have water rights measured in different terms. This relates to the statement in Winters which implies that interpretation of agreements with Indian Nations should support the purpose of the agreement.

The competition between Indian and non-Indian water rights poses some extraordinary problems. Most Indian reservations pre-date extensive water development projects in the western U.S. although the use of water in significant quantities by the Indians has generally developed only in recent years.

For example, resource potentials of Indian reservations in the Upper Missouri River Basin are enormous.[8/] There are 23 reservations wholly or partly in the basin encompassing over 12 million acres or about 3.6 percent of the region's area. Most Indian lands are underlain with large reserves of coal and other valuable minerals and many have outstanding recreation features and contain large areas suitable for agricultural development. Preliminary surveys indicate that Indian water requirements may constitute a significant portion of the annual flows in the Missouri River and its tributaries. For example, the United States Department of Interior Water for Energy Management Plan has estimated that in the States of Montana and Wyoming, Indian water requirements in the Yellowstone sub-basin and the

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8/ U.S. Congress. Senate. Committee on Interior and Insular Affairs. Water Resources of the Missouri River Basin. 94th Congress 2d session. Washington, U.S. Govt. Print. Off., Nov. 1976.

Upper Missouri Basin above the confluence of the Yellowstone River could reach an annual level of 2.6 million acre-feet of consumptive use by the year 2020.

Rational water planning is dependent upon quantification of all existing and proposed water uses. Studies of future water uses in the western United States have addressed the issue of Indian water rights to greater or lesser degrees but the fact remains that the quantities of water involved are generally unknown or in dispute. Until this matter is resolved, estimates of future streamflow depletions will be biased accordingly, and decisions on tradeoffs with other users will be clouded.

Federal Reserved Water Rights.--Another legal issue of importance is the Federal reserved water doctrine. This doctrine provides that where lands were reserved from the public domain, the United States implictly reserved water sufficient for use in accordance with the purposes for which they were reserved.

The issue of Federal reserved water rights is especially significant in the public land States because considerable water originates or flows through national forests and national parks. The uncertainty created in attempting to strike a water budget where there is no quantification of Federal reserved rights makes planning difficult at best. To date, adjudication of Federal reserved rights has not been extensive.

It is generally believed that Federal reserved water rights questions are tied mainly to conflicts with the water law doctrine of prior appropriation but similar problems could arise in States following the riparian doctrine and this should be recognized.

Special consideration could be given to integrating Federal reserved rights into existing State water rights systems. Thereafter, these rights could be subject to court decrees, interstate compacts, or other institutional developments affecting the source of water involved. Establishing a forum outside the judicial system to resolve Federal reserved water rights questions deserves further consideration, and might be worth investigating on a trial basis.

III. NATIONAL TRENDS AND PROBLEMS (1955-2000)

Water Supply

From a national perspective, there are abundant fresh water resources. Average annual percipitation is 30 inches for the conterminous United States, and average natural runoff is about 1,200 bgd. Large reserves of groundwater also exist. The difficulty is that the geographical and temporal distribution of water are highly variable. Regions exhibiting high levels of consumptive use through irrigated agriculture, such as the southwest and west central States, have the most varied annual runoff. While little can be done to control the climate, development of water storage capacity can ease sporadic stream flows.

According to WRC, existing storage facilities can convert about 30 percent of nature's annual water supply to man's use. By developing additional storage capacity, a higher percentage conversion can be realized. The problem is that the potential for new storage is concentrated in water-rich regions east of the Mississippi River.

Augmenting the Nation's surface water resources are about 50 billion acre-feet of economically accessible groundwater. Unfortunately, only about 2 percent of this is available on a continuing basis and most of it is located in humid regions. Much of the non-renewable groundwater in the arid West is being exhausted at a rate which will cause significant reductions in total groundwater availability by the year 2000.

Water Use

In 1975, the Nation's total freshwater withdrawals from all sources were about 420 bgd (USGS-1977). Of this amount, 112 bgd were consumed through evaporation or incorporation into products and the remaining 308 bgd were returned to surface water sources for reuse. By the year 2000, WRC estimates that total withdrawals will be 311 bgd and that 135 bgd will be consumed. This constitutes a reduction of 14 percent in withdrawal and an increase of 20 percent in the amount of water consumed based on their estimated water use in 1975 of 361 bgd (Figures 2 and 3, WRC-1975).

WRC predicts that tough water quality laws will stimulate increases in recycling of waters by manufacturing and electric generating sectors. The result of this would be a decline in water withdrawals by the year 2000. The amount of water withdrawn for manufacturing use is projected to decrease by 47 percent, accompanied by an increase of 137 percent in consumption. Withdrawals for electric power generation are anticipated to decrease by about 24 percent due to conversion from once-through cooling to cooling towers. This decline is expected to be accompanied by a substantial increase (600 percent) in the amount of water consumed.

In a study of national water supply problems, the Government Accounting Office questioned WRC's assumptions on water withdrawals. They stated: [9/]

9/ Government Accounting Office. Comptroller General of the United States, Water resources planning, management and development: What are the Nation's water supply problems and issues? Publication CED-77-100. Washington, D.C. July, 1977.

FIGURE 2 **HISTORIC AND PROJECTED FRESHWATER WITHDRAWALS, 1955-2000 (UNITED STATES WATER RESOURCES COUNCIL)**

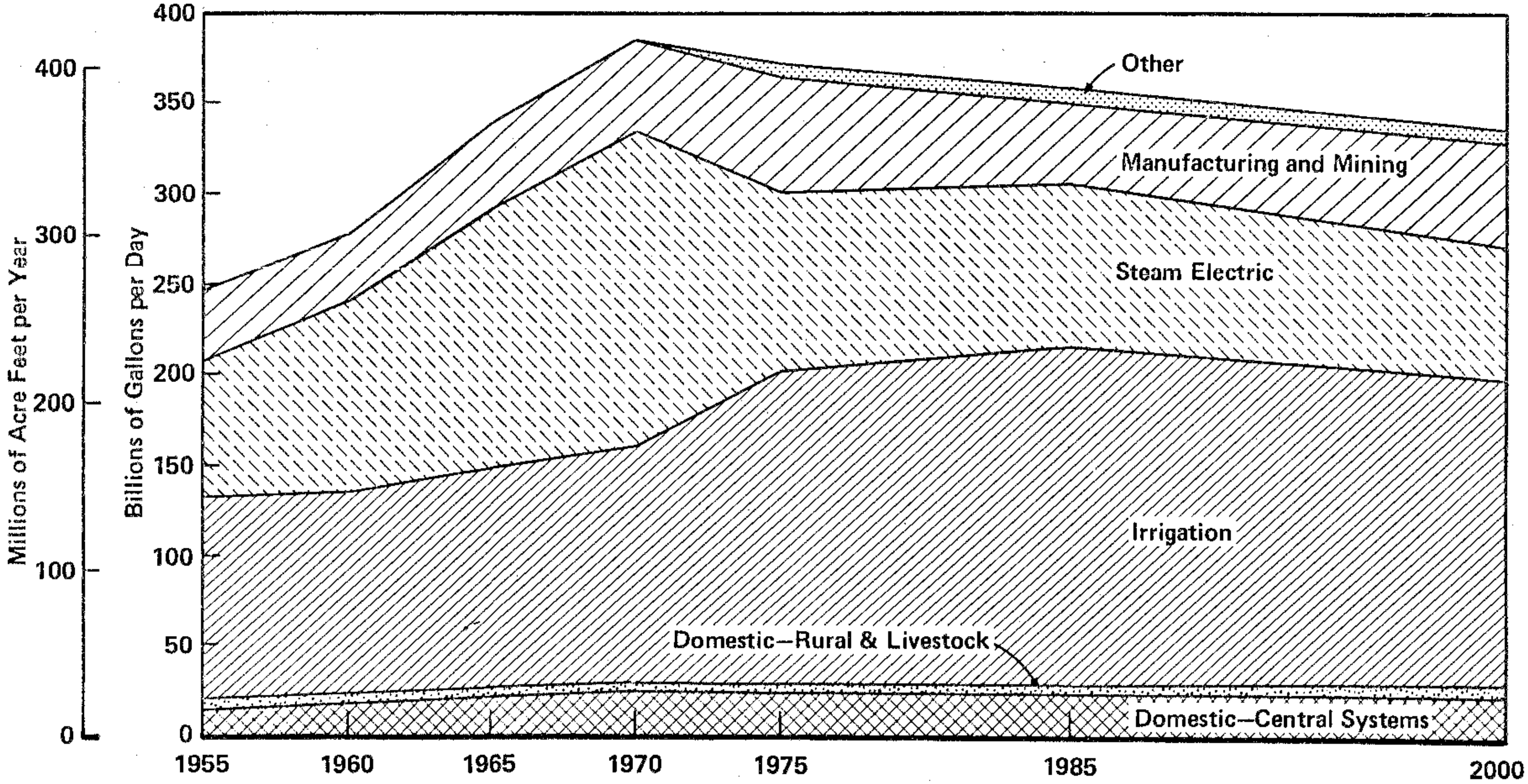
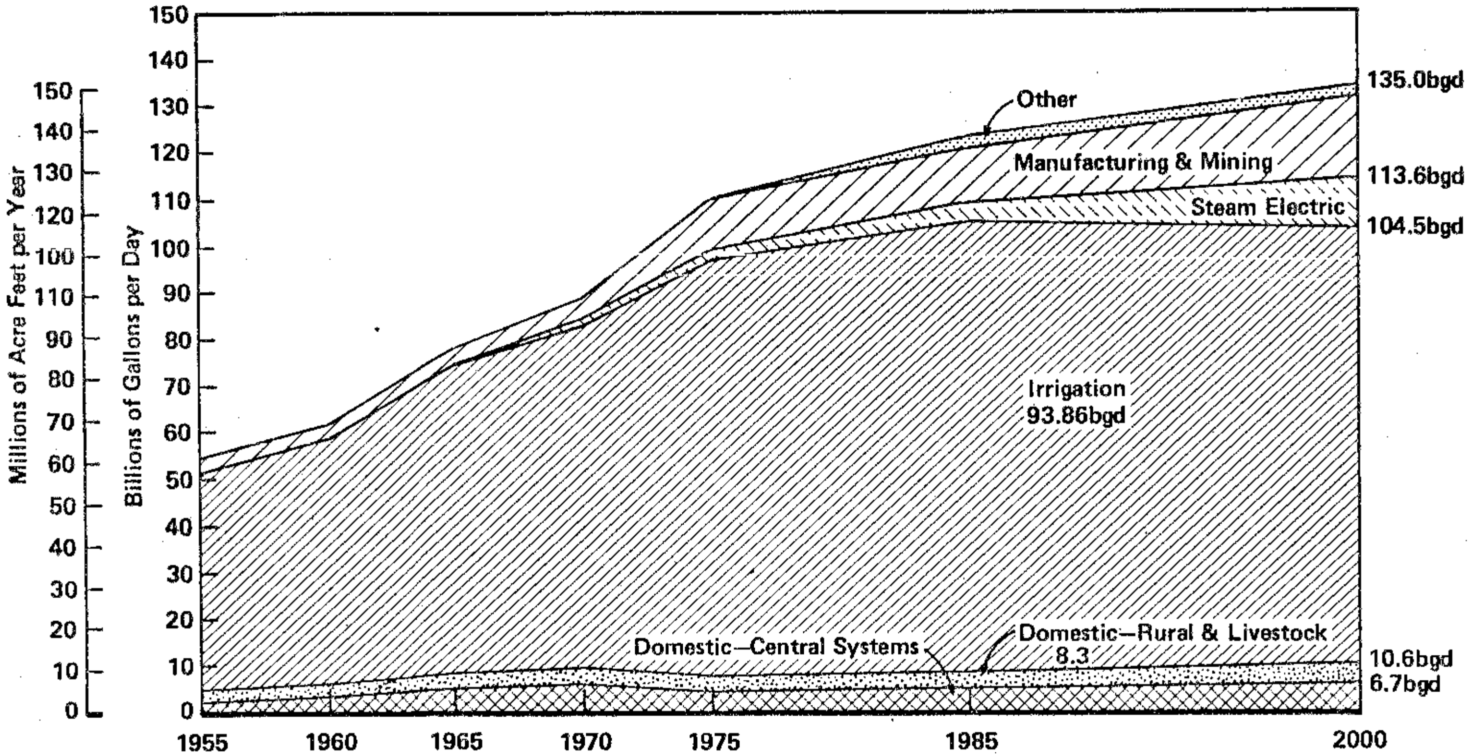


FIGURE 3 **HISTORIC AND PROJECTED FRESHWATER CONSUMPTION, 1955-20000 (UNITED STATES WATER RESOURCES COUNCIL)**



> This assumption seems questionable because the stringent requirements of Public Law 92-500 may be modified, and industry may find it cheaper, particularly for existing facilities, to continue using water on a once-through basis with wastewater treatment before returning it to the stream rather than construct more costly recycling facilities.

According to WRC, irrigation water withdrawals are expected to decline about 8 percent by the year 2000 because of increasing depletions of deep groundwater in southwestern regions. Consumptive use in that sector is expected to increase less than 2 percent due to water use conflicts and the likelihood that no new large-scale irrigation projects will be publicly funded. This premise has also been challenged by GAO. They note that: 10/

> ...irrigation will show substantial increases in some parts of the country, for example, Souris-Red/ Missouri River areas, where agricultural conditions are suitable and water supplies are available. Here again we think the Assessment's assumption that there will be a slower growth in food and fiber requirements and that no new large-scale irrigation projects will be funded seems questionable.

A 1977 report by Oak Ridge National Laboratory stated "...there will be a considerable increase in water use for energy between 1975 and 1985 and water availability may constrain development in several basins in the western United States." 11/ It was noted that localized problems could also be expected on small tributaries in the eastern part of the Nation.

10/ Ibid.

11/ Oak Ridge National Laboratory. A nationwide assessment of water quality impacts of the national energy plan. ORNL/TM-6098. Oak Ridge, Tennessee. December, 1977.

Water requirements of other sectors could be affected by a national energy plan. Redistribution of population and industrial activity could result from a shift to coal and electricity, and boom towns in coal mining regions might use more water than the mining processes. Secondary industrial growth and related urban growth could also require considerable amounts of water. A study of these impacts to the year 2000 seems warranted.

Alternative Futures Planning

WRC's 1975 Assessment is based on a "modified central case"--a future considered most likely to occur by its designers. By analyzing this scenario, useful insights to policy matters can be gained, but a more informative approach might be to construct several feasible futures. Varied assumptions could be compared in terms of trends they would create and the importance of differences in opinion by investigators such as WRC and GAO could be more directly analyzed. Better decisions could be the outcome since they would be guided by a feasible range of futures rather than a single projection.

Problems and Conflicts

According to estimates being developed for the Water Resources Council's 1975 Assessment, the entire eastern third of the Nation has a relatively good water supply outlook to the year 2000. Exceptions are the Miami-Ft. Lauderdale and Chicago areas where year 2000 depletion 12/ levels

12/ Depletion means that the available water supply is reduced through consumptive use (mostly evaporation) so that that fraction is no longer available for other uses.

are expected to be higher than the norm. In the remaining two-thirds of the Nation, most current or projected depeletion ratios exceed 20 percent with the exception of the Souris-Red-Rainy Region, most of the Columbia North-Pacific Region, and the northern part of California.

Significant water supply problems exist or are expected to occur in southern California, the Great Basin, the Lower Colorado, the Rio Grande, the High Plains of Texas, and the south central portion of the Missouri Basin. Many of these areas, while dedicated to irrigated agricultural production, will be subject to future water demands for development and processing of coal and oil-shale deposits. Domestic water use is also expected to increase as more people find these areas attractive places to live.

The trends indicated on Figures 2 and 3 should be accepted with caution. GAO's questioning of these has already been mentioned and other assumptions could be challenged as well. By exploring a wider range of futures, the sensitivity of decisions based on them can be compared and the importance of differences explicitly defined.

Conflicts among water use sectors are on the increase in all regions and the severity of many of these supports the assertion that the design of encompassing total water management policies is long overdue.

IV. REGIONAL TRENDS AND PROBLEMS

Water Use

The period from 1950 to 1975 witnessed significant increases in regional water use, especially for the West and Southwest where irrigated acreage expanded significantly. Water used in manufacturing and mining increased about 52 percent and water utilized in steam electric facilities (largely for cooling) increased about 65 percent (WRC-1975). Table 1 lists quantities of water withdrawn by State in 1955 and 1970 with the percentage change. Nationally, water withdrawal[13/] use increased about 54 percent and State increases ranged from about 4 percent to over 400 percent. In general, increases in water withdrawals in the western States can be attributed to the rapid growth of irrigated agriculture while increases elsewhere are mostly related to industrial growth and expansion of steam electric facilities.

Summary of Regional Water Issues

While water use has steadily grown, supplies have remained fixed (importation, exportation and groundwater mining excepted). The result has been expansion of local and regional water problems. The nature and extent of these is summarized in Table 2. A more detailed discussion is given in the section on "Water Supply and Water Quality Problems of the Twenty-One Regions".

13/ Water withdrawn may be returned to the source and reused.

TABLE 1

Trends in Water Withdrawal, Exclusive of Hydroelectric Power, By States 1955-1970 (Million Gallons Per Day)*

State	Water Withdrawal 1955	1970	Percent Change
Alabama	3,000	6,700	+120
Alaska	--	250	--
Arizona	7,200	6,800	- 5
Arkansas	1,500	3,000	+100
California	30,700	48,000	+ 56
Colorado	7,100	13,000	+ 83
Connecticut	2,000	3,500	+ 75
Delaware	370	1,200	+225
Florida	2,800	15,000	+435
Georgia	2,200	5,300	+140
Hawaii	--	2,700	--
Idaho	15,400	16,000	+ 4
Illinois	9,900	16,000	+ 62
Indiana	7,000	8,600	+ 23
Iowa	1,800	2,100	+ 17
Kansas	2,200	3,800	+ 73
Kentucky	3,500	4,500	+ 29
Louisiana	5,200	9,100	+ 75
Maine	550	760	+ 38
Maryland	1,900	5,200	+174
Massachusetts	2,500	4,200	+ 68
Michigan	7,000	13,000	+ 86
Minnesota	1,800	3,400	+ 89
Mississippi	1,500	2,100	+ 40
Missouri	2,300	3,500	+ 52
Montana	10,100	8,000	- 21
Nebraska	3,300	6,000	+ 82
Nevada	2,000	3,300	+ 65
New Hampshire	250	700	+180
New Jersey	4,300	6,300	+ 47
New Mexico	2,700	3,200	+ 18
New York	8,900	18,000	+103
North Carolina	2,200	5,900	+168
North Dakota	410	650	+ 59
Ohio	10,800	18,000	+ 67
Oklahoma	1,000	1,500	+ 50
Oregon	7,500	5,900	- 21
Pennsylvania	11,000	20,000	+ 82
Rhode Island	450	460	+ 15
South Carolina	950	3,400	+258
South Dakota	250	600	+140
Tennessee	4,300	6,400	+ 49
Texas	17,200	27,000	+ 57
Utah	4,600	4,200	- 8
Vermont	100	110	+ 10
Virginia	2,000	5,500	+175
Washington	6,400	7,200	+ 12
West Virginia	4,100	5,800	+ 41
Wisconsin	5,100	6,300	+ 23
Wyoming	11,100	5,800	- 42
District of Columbia	380	1,300	+242

* Based on data from Estimated Use of Water in the United States, 1955, 1970, U.S. Geological Survey Circulars No. 398 and 676.

TABLE 2

Major Water Use Issues (U.S. Water Resources Council, 1977)

Region	Water Quantity	Water Quality	Institutional
(01) NEW ENGLAND	Heavy withdrawal demand; surface and groundwater.	Pollution from municipal and industrial sources.	
(02) MIDDLE ATLANTIC		Potable water supplies degraded by pollution; increased salt concentration in estuaries.	
(03) SOUTH ATLANTIC-GULF	Shortage of fresh surface water in parts of Florida; also locally in urban areas of region.		
(04) GREAT LAKES		Industrial, muncipal and agricultural pollution.	Lake level regulation--many interest groups on both sides of issues.
(05) OHIO	Pollution from industrial wastes and acid mine drainage.		
(06) TENNESSEE	Pollution from point source discharges; low dissolved oxygen in hydroelectric discharge.		
(07) UPPER MISSISSIPPI		Heavy chemical and biological loading of surface waters.	Lack of comprehensive management strategy.
(08) LOWER MISSISSIPPI		Industrial pollution and increasing salt content of water; lower region.	
(09) SOURIS-RED-RAINY	Water table lowered because of agricultural and urban consumption.	Deterioration due to intense recreational use, poor sewage treatment, and cropland runoff.	
(10) MISSOURI	Conflict between instream uses and offstream uses.		Water rights Indian vs. State vs. Federal.
(11) ARKANSAS-WHITE-RED	Groundwater depletion--heavy use in irrigation, domestic and industry.	High salinity of surface water--not potable.	
(12) TEXAS GULF	Groundwater overdraft; declining water tables.	Altered salinity gradients in estuaries; high salinity of inland surface water-upland; pollution from poor effluent treatment downstream.	
(13) RIO GRANDE	Conflict between instream uses and offstream uses; surface and groundwater over-appropriated; high phreatophyte consumption.	High salinity of surface waters, hypersaline inflow to Rio Grande "estuary."	
(14) UPPER COLORADO	Conflict between instream and offstream uses; developing water storage and delivery systems.	High salinity of surface water and groundwater; heavy metal pollution from mining.	Water rights Indian vs. State vs. Federal.
(15) LOWER COLORADO	Conflict between instream and offstream uses; declining water table.	High salinity of surface water and groundwater; heavy metal pollution from mining.	Water rights Indian vs. State vs. Federal..
(16) GREAT BASIN	Water shortage during critical flow period; high diversion requirements.	High salinity of surface waters--from irrigation runoff.	Water rights.
(17) PACIFIC NORTH-WEST	Conflict between instream uses and offstream and (irrigation).		
(18) CALIFORNIA	Distribution problem; excessive groundwater uses; drainage associated with high water table and salt balance.		
(19) ALASKA	There are no major water problems as yet.		
(20) HAWAII			Water rights.
(21) CARIBBEAN	Periodic water shortages, distribution problems, groundwater use limited, storage sites limited.		

Trends in Water Project Expenditures (1950 to 1975)

Federal water resource expenditures from FY 1950 to FY 1975 are reported for the northeastern, southern, north central and western regions of the U.S.[14/] Data were obtained from the U.S. Army Corps of Engineers (CE), Interior's Bureau of Reclamation (BR), Agriculture's Soil Conservation Service (SCS), and the Tennessee Valley Authority (TVA). A major portion of the expenditures reported by these agencies went to the South ($14.8 billion) and the West ($14.0 billion). The north central region received $7.8 billion while the Northeast's allotment was the least, $2.3 billion. The highest expenditures, on a per capita basis, were in the West at $377, and the lowest were in the Northeast at $47. Per capita expenditures were $220 in the South, and $136 in the north central States.

The cited figures for CE cover construction and maintenance for navigation, flood control, and multipurpose projects from FY 1950 to FY 1975. The BR data cover total construction, operation and maintenance appropriations under the 1939 Reclamation Project Act (53 Stat. 1187) from FY 1950

14/ The northeast region circumscribes: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Pennsylvania. The north central region consists of Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas. The southern region includes: Delaware, Maryland, the District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas. The western region encompasses: Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, and Hawaii.

through FY 1975. The SCS data include construction obligations for small watershed programs (P.L. 83-566) and for flood prevention operations and emergency measures programs (P.L. 534) from July 1, 1949 to September 30, 1976.

Table 3 shows a breakdown of expenditures by the four agencies according to region. As the table indicates, of the total $26.5 billion of CE expenditures allocated during this period, most were for projects in the South (42.9 percent), and least for those in the Northeast (8.2 percent). The North Central and West each received approximately 25 percent of the CE expenditures. Only three regions were recipients of BR projects: the South, North Central, and West. Of the $8.5 billion appropriated during the period, 87.2 percent was allocated to the West, 9.6 percent to the North Central and 3.2 percent to the South. For SCS, most of its $1.9 billion expenditures were in the South (53.3 percent), followed by 21.0 percent in the north central region, 17.3 percent in the West, and 8.2 percent in the Northeast. All of the $2.1 billion TVA appropriations have been in the South. Combining the expenditures of all four agencies--$39 billion from FY 1950 to FY 1975--the South and West received the largest percentages, 37.9 and 36.1 percent, respectively. The north central region received 20.0 percent, while the Northeast received 6.0 percent.

Table 3 also presents expenditures on a per capita basis, using 1974 census data. Cumulative per capita expenditures over the period averaged $184. On a regional basis, however, the West shows the highest per capita

TABLE 3

Expenditures, FY 1950 to FY 1975, of the Corps, BR, SCS, and TVA for Water Resources Projects

Regions	Corps 1/	BR 2/	SCS 3/	TVA 4/	Total	1974 Pop. 5/ (1000)	Cumulative Per Capita Expenditures ($)
	(in $1000 and percentage)						
Northeast	$ 2,167,387 (8.2)		$ 156,106 (8.2)		$ 2,323,493 (6.0)	49,412	$ 47
South	$11,357,813 (42.9)	$ 274,980 (3.2)	$1,023,712 (53.5)	$2,124,538 (100.0)	$14,781,043 (37.9)	67,149	$220
North Central	$ 6,591,902 (24.9)	$ 810,024 (9.6)	$ 401,508 (21.0)		$ 7,803,434 (20.0)	57,559	$136
West	$ 6,338,929 (24.0)	$7,380,747 (87.2)	$ 330,546 (17.3)		$14,050,222 (36.1)	37,261	$377
Total	$26,456,031	$8,456,751	$1,911,872	$2,124,538		211,381	$184 (avg)

1/ U.S. Army Corps of Engineers, "Civil Works Expenditures by States" (1975).
2/ U.S. Dept. of Interior, Bureau of Reclamation, "Water and Land Resources Accomplishments: Federal Reclamation Projects (1975). Appendices II and III.
3/ U.S. Dept. of Agriculture, Soil Conservation Service, "Total Obligations by Fiscal Years" (1975).
4/ Tennessee Valley Authority, memorandum from A.C. DeCosta, May, 1977.
5/ U.S. Bureau of the Census, "Current Population Reports," series p-25.

expenditure of $377, and the South next with $220. The north central and northeast regions showed per capita expenditures of $136 and $47, respectively.

Table 4 shows the agency per capita expenditures by region. CE per capita appropriations were highest in the West and South, each with approximately $170. The north central and northeast regional agency cumulative per capita expenditures were $115 and $44, respectively. BR's cumulative per capita expenditures were by far the largest for the West at $198, followed by $14 for the north central area, $4 for the South, and zero for the Northeast. The SCS spent $15 per capita in the South, $9 in the West, $7 in the north central region, and $3 in the Northeast. TVA spent $32 per capita in the South.

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TABLE 4

Agency Cumulative Per Capita* Expenditures
(In Dollars) FY 1950 to FY 1975

	Corps	BR	SCS	TVA	Total
Northeast	44	--	3	--	47
South	169	4	15	32	220
North Central	115	14	7	--	136
West	170	198	9	--	377

* Source: See references in Table 3.

The South and West have been the prime recipients of Federal water resources funds from FY 1950 to FY 1975, with the north central region receiving an intermediate amount and the Northeast receiving the least. On a per capita basis, the West has received by far the largest amount, followed by the South, north central region and the Northeast.

There are several reasons for the uneven distribution of water project expenditures by the Federal agencies. For example, the West has received most of BR's funds due to the nature of reclamation laws. Extensive flood control and waterways developments in the South are reflected in the large expenditures of the CE in that region. The Northeast has received fewer Federal dollars because many of its municipal and industrial water supply projects are ineligible for Federal funding. The north central region is characterized by traits of both the East and West and the nature of water projects is influenced accordingly.

Historic trends in expenditures for water resources projects have been shaped largely by Federal statutes and local political pressures. In the future, increased emphasis on the environment and water pollution control and a tendency toward non-structural solutions to water resources problems can be expected to shift the regional distributions which have prevailed for the last 25 years.

V. WATER SUPPLY AND WATER QUALITY PROBLEMS OF THE TWENTY-ONE REGIONS

An account is given here of water problems identified in the twenty-one water resources regions. The data were taken from WRC's preliminary nationwide analyses (WRC-1975). Although underlying assumptions for some projections are subject to question there is consensus among water authorities about the general nature of most regional water problems.

Region 1--New England

Water Supply--Fresh surface waters in the New England region are estimated to be sufficient to meet withdrawal and instream flow requirements through the year 2000. Local problems in high-density areas such as Boston, are anticipated, however. Freshwater withdrawal is projected to decline by half due to increased industrial water recycling and expanded use of salt water for steam-electric power generation. Total consumptive use is expected to double due to expanded use of recycling cooling systems.

Water Quality--Industrial and municipal wastes have degraded much of the water quality of this region and have destroyed or adversely affected freshwater and anadromous fisheries. About 13% of the region's stream miles do not meet water quality standards for Best Practicable Technology (BPT). The water quality problem is especially severe in the southeastern part of the region. Current and projected streamflow depletions threaten instream fisheries, estuarine ecosystems, and outdoor recreation. Salt water intrusions pose a threat to the usability of groundwater aquifers.

Region 2--Middle Atlantic

Water Supply--Public water supply is a major problem in the Middle Atlantic region. Metropolitan New York City must import most of its water because available freshwater supplies are limited or expensive to treat. Regional consumption is currently 1,827 million gallons per day (mgd), and is expected to double by the year 2000. Domestic water consumption is expected to increase about 1.3 times, manufacturing consumption about 2.5 times and steam-electric power generation about 6.5 times. This latter increase is related to the fact that more water evaporates in recycling systems than in once-through cooling systems.

Water Quality--About 23 percent of the region's streams do not meet current water quality standards. Acid mine drainage from the west contaminates downstream waters and exportation of large amounts of water to the New York metropolitan area has caused serious water quality problems in exporting areas. Raw and inadequately-treated waste loads are a major cause of water quality degradation. Further increases in municipal and industrial discharges, nutrient enrichment and thermal pollution will endanger the delicate ecosystems of the bays and estuaries.

The major river in the region--the Hudson--is already saline or brackish for much of its length and increased freshwater withdrawals will amplify this problem. In addition, Long Island is facing serious problems due to extensive groundwater use and resultant salt water intrusions. The region does not have adequate treatment facilities or solid waste disposal sites.

Another water quality problem is salinity of the estuaries. Changes in water use will affect the rather delicate balance between fresh and salt water in the estuaries and bays. Doubling freshwater consumption, as is projected over the next 25 years, will decrease the quantity of freshwater inflow to the ocean and bays and the fresh/salt water interface will extend farther inland.

Limited recreation sites along the coast are threatened by continued offshore sludge disposal and shoreline erosion, yet there is a great need for these recreational areas. Increased flood damage is another problem related to stress on the resource base, as urban development increases runoff and the incidence and severity of floods.

Region 3--South Atlantic-Gulf

Water Supply--Ground and surface water resources are generally adequate in this region although some future water supply problems are anticipated. It appears that additional storage will be required throughout the region to meet future water needs. The most critical areas are the Everglades and Florida's bays and estuaries. Low flows into these areas could be reduced by 40 percent or more by 2000 if projected levels of demand are realized, and during critical months flows might even be eliminated.

Water Quality--Although many of the areas's streams are of good quality, about 32 percent will not meet water quality standards, even if BPT is applied. Depletion of surface water by crop irrigation is increasing the potential for salt water intrusion, especially near the coastal cities of Tampa, Miami, and Jacksonville, Florida; Charleston, South Carolina; and Savannah, Georgia. Groundwater withdrawals are also causing salt water intrusion, especially in North Carolina. Heavy metals such as mercury, pesticides, bacterial contamination and siltation from navigation dredging are also problems in the region.

Threats to water-based recreation result from alteration of existing channels, beach erosion and encroachment, and the development of flood plains and wetlands. To provide for the projected increase in recreational activities, it would appear that water surface areas would have to be increased about 1.7 times.

Region 4--Great Lakes

Water Supply--This region has the highest per capita use of water in the Nation. Its ample water resources (64 million acres of lake surface and about 12,000 miles of streams) can satisfy all present and projected water needs. By the year 2000, manufacturing withdrawals of water are projected to decrease about one-fifth while electrical power production requirements are expected to increase fourfold. A shift from once-through water use to closed-system operations for steam-electric and manufacturing processes is underway in response to effluent limitation guidelines.

Water Quality--Water quality problems stem from industrial, municipal, and agricultural wastes. Pollution is a serious threat to Lake Erie and Lake Ontario, but is less of a problem in the upper three Great Lakes. The Detroit River, which connects Lake Erie to the upper three Lakes, is stressed by discharge from urban centers, notably Detroit. In 1971, adverse conditions were evident along 38 percent of the region's major streams and Great Lakes shorelines.

Outdoor recreation opportunities are generally adequate in the Great Lakes region, although sites near major population centers are in need of development.

Region 5--Ohio

Water Supply--The average annual streamflow in this region is sufficient to satisfy most water supply needs. There are, however, some local needs which may require additional water source development. Water used for steam-electric plant cooling, manufacturing, and domestic purposes accounted for about 85 percent of total consumptive use in 1975.

Water Quality--Surface water quality is the most pressing problem. Even with BPT, 10 percent of the stream miles in the northeastern part of the region and 70 percent of the stream miles in the southwestern sections would not meet water quality standards.

Much of the pollution occurs in the Ohio River. Acid mine wastes, steel and chemical industry pollutants, and municipal effluents are the dominant sources. Upper reaches of the river are most affected and cannot support commercial fishing. The middle portion of the river has alternating zones of recovery and degradation, but is generally an improving transition zone. The lower portion of the mainstem has relatively few sources of pollution and exhibits relatively good water quality. Scheduled improvements should expand recreational usage of the river and reinstate a viable commercial fishing industry although the timetable for these is somewhat uncertain.

Region 6--Tennessee Region

Water Supply--Water supply in the Tennessee Region is not a problem in the foreseeable future. Primary water users are the manufacturing, domestic, and steam-electric sectors.

Water Quality--Surface water quality is generally good, although some stream reaches suffer adverse effects from heavy point source discharges. These occur mainly in the Chattanooga and Knoxville areas in Tennessee, and in the Decatur-Huntsville area in Alabama. Some non-point pollution problems are also noted, principally in the headwater streams in coal mining areas, and these may be difficult to control.

A 42 percent increase in water-based and water-related land-based recreational activities is projected for the year 2000. These requirements are expected to be met primarily by an increase in recreation-developed land.

Region 7--Upper Mississippi

Water Supply--Projected water needs for instream uses are expected to be met 80 percent or more of the time, although in the southern part of the region, groundwater in limited. The 1977 average outflow of the region was 121 bgd of which about 10 percent was consumptively used (not returned to the stream). By the year 2000, another 4 percent is projected to be consumed. Manufacturing and steam-electric power generation account for about 85 percent of current withdrawals.

Water for recreational use is in short supply in the southern portion of the region and local shortages are expected in the northern section around 1990.

Water Quality--Water quality problems are related to heavy chemical and biological loadings of surface waters. Each year, about 2.4 billion pounds of Biochemical Oxygen Demand (BOD) are generated in the region, two-thirds of which are discharged to water courses. Even with use of Best Available Technology (BAT), reduction of BOD by the year 2000 will be slight. Suspended solids stemming from sediment and industrial wastes are also major pollutants and WRC estimates that even with implementation of BAT, only a slight reduction is likely.

Region 8--Lower Mississippi

Water Supply--Surface water resources are adequate for most needs, although the quality of these presents a problem in some localities. About 75% of freshwater withdrawals are from surface sources, the remainder being pumped from wells. Many municipalities and industries use groundwater because of the poor quality of surface waters.

Total consumption of water by offstream uses is projected at 5,581 mgd by the year 2000. Of this amount, irrigation accounts for about 64%, minerals extraction industries about 9%, and manufacturing industries about 12%.

Water Quality--The most serious water quality problems in the Lower Mississippi region are industrial pollution and the increasing salt content of the Mississippi River.

The quality of surface waters is generally good for agricultural and industrial use, except in the western part of the region, where the streamflows in the Arkansas and Red Rivers are frequently saline. Groundwater supplies are of good quality and are used to meet about 24% of the freshwater withdrawal demand.

Domestic water systems for the major urban areas, particularly downstream from Baton Rouge, Louisiana, encounter difficulties in providing safe drinking water when the mainstream flow of the Mississippi is the source of supply. This problem may intensify as the river flow is gradually reduced by upstream consumption, thus allowing salt water from the Gulf of Mexico to encroach upstream. There is also uncertainty about effective removal of toxic materials discharged by upstream industries. Untreated BOD from point and non-point sources, suspended solids and heat discharges from electric power generation constitute other significant pollution problems. Even with use of BAT, little reduction in BOD load can be expected if sources are not controlled.

Region 9--Souris-Red-Rainy

Water Supply--The primary water supply problem in this region is the depletion of groundwater from agricultural and urban consumption. In the western part, groundwater is being withdrawn more rapidly than it is being recharged. Otherwise, water supplies appear to be adequate to meet projected needs through the year 2000.

Water Quality--Water quality problems stem from intense recreational use, inadequate waste treatment and cropland runoff. Groundwater quality in the eastern Rainy River Basin is generally better than in the Souris and Red River basins. Most groundwater in the north-central part of the Red River Basin contains high levels of dissolved solids making it undesirable for many purposes. In the Souris River Basin, water is in short supply and the quality of groundwater is very poor. The quality of water in the Souris River varies with volume of streamflow but the concentration of dissolved solids is generally excessive for use as drinking water and in many places, the water is unfit for irrigation.

Region 10--Missouri Basin

Water Supply--In many parts of the Missouri region, streamflows appear to be insufficient to meet projected water needs. This is largely the result of growing conflicts between offstream uses of water (principally irrigation), and instream uses of water (fisheries, wildlife, outdoor recreation, navigation, and hydroelectric power generation).

About 41 percent of the water consumed comes from groundwater sources. In some cases where these are being mined, locally severe problems exist. By the year 2000, groundwater supply problems will likely expand unless shifts in water management practices occur.

At the 1975 level of development, the major depleting use of water in the Missouri River Basin was irrigated agriculture (about 78 percent), followed by evaporation from man-made reserviors (about 15 percent). All other depletions totaled about 7%, with those from domestic use and manufacturing and minerals production each representing about 1.5%. Projections to the year 2000 do not indicate any significant change in this distribution.

Conflicts between offstream uses and instream requirements to maintain fish and wildlife habitats are expected to be severe throughout the region by the year 2000. In many sub-basins, flows are already depleted (1977) to less than 60% of average flows during critical summer months. Based on WRC estimates of instream flow requirements, some aquatic life might be endangered if projected consumptive uses are realized. Recreation would be similarly affected.

Water Quality--Surface water quality is generally poor while groundwater quality is good. About two billion pounds of suspended solids are discharged into the Missouri River each day. This discharge is much higher than in any other region due to intense mining. More than half of it occurs in the upper reaches of the Missouri River in North and South Dakota. High concentrations of BOD have also been found, mainly below urban centers and tributaries. Organic loadings of streams are influenced by heavy animal feedlot runoff in Kansas, Nebraska, and Iowa.

Region 11--Arkansas-White-Red

Water Supply--The major water problem is groundwater depletion from irrigation withdrawals. In 1975, these amounted to about 10,375 mgd, over 60% obtained from groundwater sources. Irrigation of crops accounts for about 90% of the total regional water consumption. With continued pumping at current rates, the economic life of many aquifers will terminate by the year 2000.

Water Quality--The principal water quality problem in the region is high salinity and sediment loads of surface waters. In the headwaters of the Arkansas, Canadian, and Red Rivers, water quality is good, but quality deteriorates rapidly when streams flow through highly erodible and frequently alkaline soils of the western plains. Sediment loads are excessive in all the rivers and high salinity in the Arkansas, Cimarron, Canadian, and Red Rivers, and in many of their tributaries, precludes their use as potable water. Although regional groundwater is generally of satisfactory quality for municipal water supplies, it is difficult and costly to develop. Most larger cities are reluctant to depend on groundwater as a source because of the threat of depletion.

Region 12--Texas Gulf

Water Supply--The principal water problem of the Texas Gulf region is groundwater overdraft. In 1975, freshwater withdrawals to supply the needs of domestic water systems, manufacturing, minerals extraction, irrigated agriculture, steam-electric power generation, and other users were about 17,000 mgd. Approximately 70% of which was used in irrigated agriculture.

Surface water flows and quality are inadequate in much of the region and groundwater is heavily used to compensate. The major aquifers of good quality water (Ogallala formation in the High Plains) are being pumped far in excess of natural recharge. Changes in cropping patterns, improvements in irrigation practices and revisions in land-use management can prolong the useful life of these aquifers, but shifts in economic base will eventually result unless large-scale imports of water occur.

It is projected that in the year 2000, water consumption will be decreased to about 85 percent of the current rate if expected reductions in irrigated acres occur.

Water Quality--Water quality problems are altered salinity gradients in estuaries, high salinity of inland surface water, and pollution from poor effluent treatment downstream. About 18 percent of the total miles of free-flowing streams in the region are sub-standard in water quality, many of these deficiencies occurring in the Trinity River Basin.

In 1973, it was estimated that 834 million pounds per year of BOD were discharged to the surface waters of the region. It is projected that with employment of BAT at point sources, this could be reduced by about 85 percent.

The discharge of suspended solids to surface waters was estimated to have been 28,279 million pounds per year in 1973, 85 percent contributed by non-point sources. BAT, applied only to point sources, would do little to relieve this problem.

Region 13--Rio Grande

Water Supply--The limited quantity of water in the Rio Grande region is inhibiting the area's economic productivity and adversely affecting the quality of life. One-third of the water withdrawn is from underground sources and water table declines of 2 to 5 feet per year are common. Groundwater overdrafts are also affecting the base flow of some streams.

The average annual runoff of the region ranges from 10 inches in the Colorado high country to 1 inch in the East. Consumptive uses deplete 80 percent to 95 percent of the mean annual flow, and in dry years the consumptive requirements often exceed the flow. Projected population increases, although modest, indicate additional increments of municipal and industrial water. Agricultural water rights will be transferred to meet at least some of these needs. Eighty thousand acres of irrigated land are expected to be retired through transfers of water rights and because of salinity problems. Most of the region shows a shortage of water for recreation, notably in the Albuquerque area where three-fifths of the region's population resides.

Water Quality--While water quality is good in the upper mountain reaches of the river, its quality diminishes rapidly as the flow picks up dissolved solids in the saline soils of the lower reaches. Both surface and groundwater are of poor quality. The high salinity of this water aggravates the problem of salt buildup on irrigated lands, and several thousand acres of cropland have been abandoned as a result. An added problem is the hypersaline inflow to the Rio Grande estuary.

Region 14--Upper Colorado

Water Supply--The water supply problems in the Upper Colorado region are associated with the need to provide sufficient quantities of water for agricultural production, instream flows and downstream obligations. Current streamflows appear adequate to meet the estimated instream flow needs in an average year but in the northern and central parts these cannot be met in dry years. By the year 2000, WRC predicts there will be insufficient water for instream flow requirements even during normal years. About 95 percent of the water withdrawn is used for irrigation and a 9 percent increase is expected by the year 2000.

Indian water rights have not been fully quantified, creating uncertainty as to the availability of water supplies for agricultural development, community development, oil shale conversion, and coal production. It appears that several water rights issues will have to be resolved in the central and southern parts of the region before development of oil shale deposits and coal fields can proceed. There are several pending court suits by Indian tribes, the outcome of which could have far reaching effects on the nature of future water use.

Water Quality--River water salinity is a basinwide problem with far-reaching consequences for adjacent regions and Mexico. It affects nearly 17 million people and about a million acres of irrigated land. The flows of the Colorado River have developed salt loadings which adversely affect irrigated crop production and municipal and industrial water uses in Arizona, California, and Mexico. The problem is especially severe at the Mexican border where salt concentrations average about 1,160 parts per million. A companion problem is pollution from heavy metals mining.

Region 15--Lower Colorado

Water Supply--The area's water resources are stressed by competing demands for irrigated agriculture, municipal water supplies, stream fisheries and wetlands, transfers to California, and downstream commitments to Mexico. The Lower Colorado region is currently using all of its available water supplies and some reordering of priorities appears needed for the future.

Present water use requirements have been met by mining groundwater supplies, but a declining water table precludes continuation of this practice. Consumptive use by agriculture is the main reason for the high streamflow and groundwater depletions. Substantial reductions in the level of irrigated agriculture must be contemplated if anticipated water shortages are to be resolved.

Water Quality--Water quality problems include high salinity of surface and ground waters and pollution from agricultural, mining, domestic, and manufacturing effluents.

High salinity concentrations, mainly from irrigation, are beginning to impact on agriculture itself and salts leached into groundwaters and naturally occurring salts have combined to degrade the primary source of drinking water for about half the region. In some areas, groundwater has become too saline to pump.

Effluents from mining activity have resulted in unacceptable concentrations of lead and other heavy metals in many water supplies including those in the Flagstaff and Kingman, Arizona areas. Furthermore, there are indications of radioactive contamination of groundwater aquifers near Gallup, New Mexico, due to leachates from uranium ore processing.

Region 16--Great Basin

Water Supply--The supply of surface and groundwater is presently insufficient to meet the demands placed upon it. If left unchecked this situation will become even more unmanageable by the turn of the century. Annual consumptive uses of water are projected to increase from 4,319 mgd in 1975 to 5,542 mgd in the year 2000. Irrigated agriculture is expected to consume about 83 percent.

Water-based and related land-based recreation activities are each projected to increase by about 15 percent within the next 25 years. To meet this additional demand, WRC estimates that an additional 4 million acres of water surface area will be required. Diversion of additional water from the Upper Colorado River under the Central Utah Project is expected, but this will not provide all of the water required. Unless other sources of water are tapped to meet year 2000 projections, decisions may have to be made limiting some or all expected uses.

Water Quality--The high dissolved solids content of both surface and groundwaters is the primary water quality problem of the region. Dissolved solids originate from: leaching during irrigation; salts leached by surface and groundwater; and natural leaching from geological bedrock formations. The problem is further complicated by runoff from increased fertilizer applications to the soil.

Region 17--Pacific Northwest

Water Supply--The foremost water problem in the Pacific Northwest is the conflict between instream flows requirements (hydroelectric generation, fish and wildlife) and offstream irrigation requirements. If projected instream flow requirements are met, irrigation consumption will have to be reduced about 40 percent by the year 2000. A reduction of over 32 percent in irrigated lands and a decrease of 18 percent in the value of agricultural production would also occur.

About three-quarters of the region's water-based recreational demand comes from Portland and Seattle. To meet anticipated growth, WRC estimates that a two-fold expansion of recreational water surface area will be needed by 2000.

Water Quality--Water quality in the region is good. In the Columbia River and Puget Sound it is generally excellent.

Region 18--California

Water Supply--The principal problems are curtailed surface water supplies during protracted droughts and excessive groundwater pumping. A water distribution problem also exists because most of the State's water is located in the north while the major consumptive use is in the Central Valley.

In 1975, the surface water flow of 48,788 mgd was adequate to supply withdrawal requirements of 41,490 mgd and consumptive use of 28,334 mgd. In 1977, the drought mandated that demand reduction measures be implemented. In the year 2000, water withdrawals and consumption are expected to be

83 percent and 88 percent of 1975 levels, rspectively. Water consumed by crop irrigation is expected to decline by 16 percent during the next 25 years due to projected decreases in irrigated farmland while domestic water use is expected to expand by a factor of 1.4. Manufacturing accounted for 1.9 percent of 1975 water consumption. This is expected to more than double, reaching 551 mgd by the turn of the century. Annual steam-electric power generation consumption is expected to increase over six times, from 32 mgd in 1975 to 205 mgd by the year 2000.

The shortage of groundwater is critical in the San Francisco and Los Angeles areas. Some groundwater problems also exist in areas between these population centers. Groundwater depletion is estimated to be 2.2 million acre-feet but WRC predicts a 12 percent decrease in this deficiency by the year 2000.

Water Quality--The quality of most of the region's waters is superior to the national average. Only 5 percent of 12,639 miles of stream do not meet BPT water quality standards. The Sacramento and Central Coast waters are among the cleanest; San Fransisco Bay is of average quality; and the Southern Coastal areas are above average.

The principal water quality problem is high salinity resulting from wastewater and irrigation return flows. This is pronounced in the San Joaquin River and Delta. Similar problems are encountered in the Colorado River, of which California is one of the largest users, and the Salton Sea, which receives irrigation return flows from the Imperial and Conchella Valleys.

Region 19--Alaska

Water Supply and Water Quality--The Alaskan region has no major water supply or water quality problems, but population increases and expansion of industrial operations will require that care be exercised to guard against water scarcity and water quality deterioration.

Region 20--Hawaii

Water Supply and Water Quality--The Hawaii region has no major water supply or water quality problems but impending issues relate to the control of municipal and industrial wastes, deterioration of groundwater quality, and salt water intrusion.

Region 21--Caribbean

Water Supply and Water Quality--Water supply problems in the Caribbean stem from the limited availability of freshwater and the lack of good storage sites. In Puerto Rico, water distribution is also a problem because most water is found on the north coast, while the southern part of the island is water deficient. Some industries in that area have developed seawater conversion facilities as a result. An added difficulty is salt water intrusion of groundwater supplies along the coast.

In the Virgin Islands the topography is not conducive to large water storage facilities. Desalinated seawater, rain collected in cisterns and public catchments, wells, wastewater recycling, and water imported from Puerto Rico are thus relied upon to meet the Island's needs. Groundwater depletion is also a problem in this area.

VI. APPROACHES TO SOLVING THE NATION'S WATER PROBLEMS

Approaches to alleviate or resolve water supply problems are discussed herein. The objective is to indicate the general feasibility level of the method and to point out regions in which it has the most potential.

Surface Water Development

Surface storage serves to provide a higher level of dependable streamflow than would be available under natural conditions. Most regions have some additional storage capacity but this is limited in the western States where most good sites have already been developed. Although there is much opposition to dam building, it should be recognized that these structures are often the most dependable devices for increasing local water supplies. As such, they should be given due consideration along with other alternatives.

Groundwater Development

The Nation's groundwater reserves are enormous but non-uniformly distributed across the continent. According to a 1977 GAO study, the groundwater problem is most severe in the High Plains region of western Texas and eastern New Mexico.[15/]

15/ Comptroller General of the United States, "Ground Water: An Overview". Government Accounting Office Publication CED-77-69. Washington, D.C., June, 1977.

> The fast-dwindling and increasingly expensive supply of groundwater, with no other local water source identified, may soon cause profound economic and social consequences there. Similar problems are developing in the groundwater aquifer which extends from this region to as far north as the Platte River in Nebraska.

In other regions, opportunities exist for supplementing water supplies by additional development of groundwater sources. For example, a July 6, 1977 news release by the U.S. Geological Survey stated the following:

> The use of groundwater could be doubled in the dry and drought-plagued Great Basin region of Nevada and Utah.
>
> Overall, an additional 1.5 million acre-feet (490 billion gallons or 1.8 billion cubic meters) of groundwater could be pumped annually in the region, but only if a number of problems, such as legal conflicts with surface-water rights and coordinated spacing of pumping wells, are resolved.

The USGS also noted that the development of an additional 1 million acre-feet of groundwater yearly could support the municipal and industrial water needs of more than 2 million people or the irrigation needs of another 250,000 acres of farmland.

In the long run, unless groundwater recharge balances groundwater withdrawal, the supplying aquifer will be mined out. The enduring nature of solutions to regional water supply problems through expansion of groundwater use will thus depend on how aquifers are managed and on local climatic conditions.

Conjunctive Use of Surface and Ground Waters

Surface water and groundwater are often interrelated, and actions on one can affect the other. In such situations, using surface and groundwater conjunctively can increase water availability.

Conjunctive use requires coordinated operations of surface and ground water storages. Annual water requirements are generally met by surface storage while groundwater storage is used to meet cyclic requirements covering dry years. The operational procedure involves a lowering of groundwater levels during periods of below-average precipitation and a subsequent raising of levels during wet years. Transfer rates of surface waters to underground storage must be large enough to assure that surface-water reservoirs will be drawn down sufficiently to permit impounding significant volumes during periods of high runoff. To provide the required transfer capacity, methods of artificial recharge such as spreading, ponding, injecting, returning flows from irrigation, or other techniques can be used.

The coordinated use of groundwater and surface-water sources will result in provision of larger quantities of water at lower costs. In California, it has been found that the conjunctive operation of the Folsom Reservoir and groundwater basin yields a conservation and utilization efficiency of approximately 82 percent compared with about 51 percent efficiency for the operation of the surface reservoir alone.[16/]

16/ Clark, J.W., W. Viessman, Jr., and M.J. Hammer. Water Supply and Pollution Control, 3rd edition, Harper and Row, Inc., New York. 1977.

Opportunities for conjunctive use of water supplies are extensive in the Mid-West and western United States but widespread implementation of these systems is constrained by State water laws and related institutions. Appropriate reforms will be required if this efficient approach to water management is to become commonplace.

Weather Modification

Precipitation management technology has been developing rapidly and it is now proven that some forms of precipitation augmentation are feasible for increasing water supplies. Studies sponsored by the Bureau of Reclamation in 1973 of the potential increase in water supply from operational weather modification in the Upper Missouri River Basin indicate that seeding winter orographic storms in headwater areas can provide as much as 1.8 million acre feet (maf) of new water annually to the Missouri River Basin.[17/] The cost of providing this water is estimated to be $2.50 per acre-foot, which is inexpensive relative to the development of other sources. The energy requirements per acre-foot are probably considerably less, but this is not documented.

Weather modification has been the subject of many field tests. Private firms have been active for over 20 years in seeding clouds to increase snowpacks for hydro-electric power companies and other water users. Snowpack

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17/ U.S. Department of Interior, Water for Energy Management Team. "Report on Water for Energy in the Northern Great Plains Area with Emphasis on the Yellowstone River Basin," Washington, D.C., January, 1975.

augmentation through seeding "orographic" clouds has been shown to increase snowpacks locally by 15 to 20 percent. This form of weather modification can only be carried out in winter and depends on the existence of the right types of clouds to seed.

Seeding of convective clouds to increase rainfall is also possible but the evidence is not conclusive that this method increases total rainfall. Despite the lack of proof of success, this form of cloud seeding has been used extensively in several areas, notably the Dakotas, Texas and Oklahoma.

Within the present state-of-the-art, the question of whether or not cloud seeding reduces precipitation downwind, is not settled. In southern California, following the seeding of winter convective cloud systems, apparent increases of rainfall have been noted 80 to 150 miles downwind. Until this question is settled, legal disputes are certain to arise over whether cloud seeding intercepts rainfall that might have fallen elsewhere to the benefit of others.

The status of operational weather modification programs is such that meaningful economic and technical evaluation is limited to special, localized cases. There is a need for substantially greater knowledge of: (1) the processes to be altered; (2) the methods by which alteration can be achieved; and (3) the extent to which resulting effects can be predicted in time, space and degree.

Conservation Measures

Conservation as a means of stretching the water budget or protecting water quality has long been recognized. The difficulty has been in getting people to accept and employ the technology available.[18/]

Large quantities of water are known to be wasted and opportunities abound for meeting many projected needs through conservation rather than new development. The most promising water conservation candidate is irrigated agriculture.

Irrigation is the largest single depletor of water in the United States. Current irrigated land exceeds 50 million acres or about one-sixth of all land farmed. In the Missouri River Basin, for example, year 2000 estimates of depletions by irrigated agriculture range up to 23 maf per year. In contrast, even the highest estimates of annual depletions from energy resource development in that region are less than 3 maf.

Estimates of water saving obtainable through improved efficiencies in irrigation water management generally range between 20 and 50 percent. A very conservative reduction of 10 percent in agricultural water use in the Missouri River Basin could yield savings of about 1.5 maf annually without

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18/ Viessman, Jr., W. "Water and Energy Conservation in Irrigated Agriculture." Congressional Research Service. Issue Brief No. IB 77072. Washington, D.C. 1977.

adverse impact on crop yields.[19/] A reduction of even 1 maf in that basin would free enough water for most projected energy development needs.

On the national scene, the prospects for water savings are even more optimistic. In 1976, total withdrawals of water in the contiguous United States for all uses were about 400 maf with approximately 50 percent attributed to irrigation; during that same year, total depletions amounted to about 125 maf with irrigated agriculture accounting for almost 80 percent. Small percentage reductions in such large quantities of water can be substantial; it follows that if extensive gains are to be made through conservation, irrigation water use is the logical point to begin. Again, conservatively estimating a 10 percent reduction, savings of about 20 maf in water withdrawn annually and 10 maf in water depleted might be expected. In contrast, a White House Drought Study Group (1977) estimated potential savings in water withdrawals by irrigated agriculture of 40 to 50 maf per year and about 8 maf per year in depletions through a comprehensive conservation program. The importance of these figures is illustrated by considering that the average annual flow of the water-short Upper Colorado River Basin is less than 15 maf per year and that of the Missouri River Basin (the Nation's largest) is about 52 maf annually.

19/ U.S. Congress. Senate. Committee on Interior and Insular Affairs. Water Resources of the Missouri River Basin. 94th Congress, 2d session. Washington, U.S. Govt. Print. Off., Nov., 1976.

On the municipal and industrial scene, large reductions in water use through application of conservation measures are also possible. Savings of 20 percent or more are feasible by changing patterns of water use and developing plumbing codes which require installation of water saving devices in new construction.

Reductions in water use through conservation will be limited, unless existing systems (especially those used in irrigation) are modified. New systems can be designed according to revised procedures but the treatment of old systems will require great care since the cost of their revision may far exceed the owner's ability to pay. Costs associated with converting existing facilities to more water-use-efficient ones could be substantial and, in some cases, might foreclose the conservation option.

While conservaton can produce substantial water savings, it is not the final answer to the Nation's water problems. If maximum conservation were implemented today, the water released could soon be assimilated in new growth, and, like the capacity in a reservoir, once fully allocated, could no longer support additional needs.

Inter-Basin Transfers

Inter-basin transfers of water are not new (examples: California, New York, Colorado). The fact that such projects offer technical solutions to regional water problems makes them attractive though they are really "robbing Peter to pay Paul". Attitudes toward such undertakings range from approval to strong condemnation, especially on environmental grounds. The northwestern

United States has been very cautious about plans for exporting water to the Southwest. Canada has also raised questions and clearly stated the basic principles that will guide that Nation in managing its water resources. These attitudes are worth considering since they are generated in areas considered prime candidates for exporting "excess" waters.

Many large-scale inter-basin transfer schemes have been proposed.[20/] Several of the most well known are the Pacific Southwest Water Plan, the North American Water and Power Alliance and the Texas Water Plan. These projects would transport up to 110 maf of water annually. Many existing and/or anticipated water shortages could be resolved in this manner but the tradeoffs which would have to be made deserve careful attention.

Demand Reduction

Demand reduction can be used to limit present and future water use rates. Viable approaches include:

-- establishment of pricing policies,

-- installation of water saving fixtures,

-- water use restrictions, and

-- rationing.

Pricing is an effective mechanism for discouraging inefficient water usage. Special rate schedules can be developed to reward conservation and

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20/ Howe, C.W. and K.W. Easter. "Interbasin Transfers of Water", Johns Hopkins Press, Baltimore, Maryland. 1971.

can be tailored for residential, commercial, agricultural and industrial applications.

Installation of water saving devices such as dual-cycle toilets, flow-limiting shower heads, toilet inserts, and pressure reducing valves can effect significant water savings. A 1972 study conducted by the Washington Suburban Sanitary Commission in the Cabin John Drainage Basin indicated that the use of such devices, exclusive of the dual-cycle toilet, reduced consumption in apartment units by 12 percent, and in single family units by 18-20 percent.

Demand reduction techniques are applicable in all regions of the Nation. Such measures were implemented in California during the 1976-1977 drought. In San Francisco, residents were ordered to reduce water consumption by 25 percent. Los Angeles mandated a water use cut of 10 percent for residents, prohibited the hosing of paved areas, serving water in restaurants unless requested, operating non-recycling fountains, irrigating lawns or landscaping between 10 a.m. and 4 p.m. and ordered the repair of leaky plumbing. The island community of Santa Catalina ordered a temporary moratorium on new building construction, and Morro Bay voted to limit growth to 3 percent per year until supplemental water supplies could be found.

Wastewater Reuse

Wastewater reuse is gaining recognition as an option for augmenting local water supplies. This popularity stems from several factors. First, the Clean Water Act of 1977 requires application of BPT by April 1, 1979, and BAT by July 1, 1984. If pursued, these regulatory goals will result in cleaner wastewaters, more amenable to additional uses. Second, pressures of population concentration, limited availability of water supplies, and political-financial factors associated with water importation from other regions make use of reclaimed wastewater more attractive.

Wastewater reuse may be indirect or direct. Some communities indirectly reuse municipal wastewater by drawing water supplies from water courses containing municipal and industrial waste flows and irrigation return flows from upstream activities. Other communities such as Whittier Narrows, California have been practicing indirect reuse through groundwater recharge using municipal wastewater. The subsequent withdrawal of water from recharged aquifers can accommodate a variety of uses.

Direct reuse of treated effluents is becoming increasingly popular for many purposes, drinking water supplies excepted. However, the barriers to this form of reuse are likely to fall as matters of public health are resolved.

Municipal wastewater reuse has been most pronounced in the semi-arid Southwest where water is in short supply. In 1971, irrigators used most of the 133 billion gallons of wastewater available to that region. Next in line were industry, recreation and non-potable domestic water users.

Industries have used waste flows extensively in their processing water and cooling water stages of production. In 1965, each gallon of industrial water averaged recirculation two and one-quarter times before being discharged or consumed. In agriculture, the reuse of irrigation return flows has been practiced for centuries. Of the water diverted for irrigation in the U.S., approximately 30 percent returns to streams and is then available for reuse by others. Though the accumulation of dissolved salts in the soil and their subsequent transmission into drainage waters present problems, technological solutions are being devised. A total wastewater recycling system exists in St. Petersburg, Florida, 21/ and grants are becoming available for recycling projects.

The future for wastewater reuse seems bright, especially if treatment costs can be reduced.

Desalination

Desalination is technically feasible but the economics of conversion from salt to fresh water limit its practical application. In 1952, desalted water cost upwards of $7.00 per 1,000 gallons. By 1971, this cost had been reduced to $1.00 per 1,000 gallons, but to be competitive, it would have to be reduced to about $0.25 per 1,000 gallons. Efforts to reduce desalination costs are continuing but rapidly increasing energy costs have adversely affected these efforts.

Environmental problems involving the disposal of saline water conversion wastes are also significant. For example, for each million gallons of fresh water produced, about 2,000 tons of brine waste are discharged. For

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21/ Dove, L.A. From wastewater to resource in St. Petersburg, Florida. Resource recovery and conservation, 2 (1976/1977). Elsevier Scientific Publishing Company. Amsterdam, Netherlands.

sea water conversion plants ocean discharge of wastes is sometimes acceptable, but the waste disposal problems of inland plants are more complex. Possible inland disposal methods include evaporation ponds, transport by pipeline, deep well injection, and central stockpiling of dry salts. Each method has associated costs and environmental problems.

Today's price for desalted water ($80 to $180 per acre-foot) rules out its use for irrigation but there are opportunties for municipal water supply applications. At the Foss Reservoir in western Oklahoma, for example, a reverse osmosis desalination plant converts high chloride and sulphate water to potable water for municipal use.

Phasing Out Marginal Uses

Phasing out marginally efficient water uses could make additional water supplies available, but local hardships resulting from such action would have to be considered. Methods to effect such a phase-out include water pricing, taxation and regulation.

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