THE NATION'S WATER RESOURCES

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UNITED STATES

WATER RESOURCES COUNCIL

WASHINGTON, D.C. 1968

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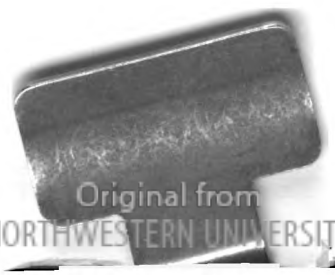

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THE NATION'S WATER RESOURCES

THE FIRST NATIONAL ASSESSMENT OF THE

WATER RESOURCES COUNCIL

WASHINGTON, D.C. 1968

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THE WHITE HOUSE

WASHINGTON

November 12, 1968

Dear Mr. President:
Dear Mr. Speaker:

I transmit the first assessment of the Nation's water resources under the Water Resources Planning Act of 1965.

A nation that fails to plan intelligently for the development and protection of its precious waters will be condemned to wither because of its shortsightedness. The hard lessons of history are clear, written on the deserted sands and ruins of once proud civilizations.

The report I submit today is part of a national effort to assure that America will not neglect the management of her water resources in the years ahead. It is a sobering report, challenging our technology and spurring our conscience.

A paralyzing drought holding 30 million Americans in its grip, when the water taps almost ran dry in major northeastern cities . . .

Pollution infesting and destroying our most productive and scenic waters . . .

The nightmare of ravaging floods still hovering over too many American communities . . .

These are some of the stark warnings that nature's abundance can not be taken for granted.

These are some of the forceful reminders that a plentiful and reliable water supply is the elixir of our national life and future growth.

Rapid population growth and economic expansion foretell even more complex problems for the future.

- Expanding economic activity is consuming available water supplies in some regions.
- Some natural resources lie untapped, and opportunities for employment and economic expansion go unrealized because of lack of water resources.
- The need for swimming, boating and other recreational facilities close to urban centers is growing rapidly.
- Floods still plague many watersheds and downstream areas.
- Erosion from rural and developing urban areas continues to wash away our lands and choke streams and lakes with sediment.
- Organic and chemical wastes and heat from our industrialized society threaten the purity of streams, lakes, and estuaries.
- Conflicts are widening between the needs to develop water resources and to preserve the scenic and natural quality of water-related environment.

These problems only illustrate the need to analyze and then to take positive action to assure water resources adequate to the demands of America's future.

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That positive action has already begun. The Water Resources Planning Act of 1965 created a cooperative framework between the Federal Government, States, local governments, and private enterprise. It established the Water Resources Council, a Cabinet-level agency, to develop unified plans and policies. Under that legislation:

— I have established four river basin commissions—the Pacific Northwest, the Great Lakes, the Souris-Red-Rainy, and the New England—to coordinate development of water and related land resources.

— 49 States are participating in comprehensive water-resources planning as a result of the matching grant program provided by this Act.

The recently authorized National Water Commission will review and advise the Nation on the entire range of its water-resource problems. The assessment prepared by the Water Resources Council will help the Commission in devising more effective water-resource policies.

The Water Quality Act of 1965, requiring standards and clean-up plans for all interstate and coastal waters, establishes a blueprint for future actions. All States have submitted water quality standards, and most have already been approved. These standards will allow us to carry out comprehensive, river-basin pollution control plans, coordinating all Federal, State, local, and private investments to achieve our goals for water quality.

These landmark legislative actions, together with others in recent years, have created the framework for action. But this is not enough.

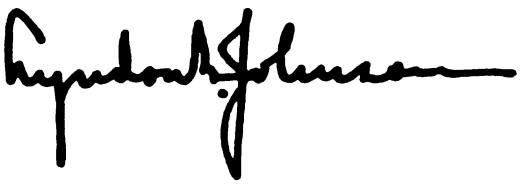
It is important that we have a composite, national view of water problems and needs if we are to attack them intelligently and comprehensively.

The national assessment I am transmitting is the first attempt at this most difficult problem. It represents the coordinated efforts of many Federal, State, and regional agencies and organizations, working with the Water Resources Council. This assessment identifies several problems requiring priority attention and should serve as a basis for further analysis.

Through such analysis as well as other activity under the Water Resources Planning Act we can continually assess, plan, and develop our water resources in an intelligent and thoughtful manner.

Responsible government can not overlook the importance of water management to the Nation's economy and health. This assessment merits your close attention.

Sincerely,



Honorable Hubert H. Humphrey
President of the Senate
Washington, D. C.

Honorable John W. McCormack
Speaker of the
House of Representatives
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WATER RESOURCES COUNCIL
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WASHINGTON, D.C. 20005

Secretary of the Interior
Chairman
Secretary of Agriculture
Secretary of the Army
Secretary of Health, Education, and Welfare
Secretary of Transportation
Chairman, Federal Power Commission

November 1, 1968

Dear Mr. President

I am pleased to forward to you the First National Assessment prepared by the Water Resources Council.

This report describes the Nation's water and related land resources and their use and management problems.

The report also contains the findings and recommendations of the Council. The recommendations were prepared after review of what now appear to be our most important national and regional water and related land resources problems.

The Council recognizes the limitations of this First National Assessment which was based on existing data, with limited analysis, and relying heavily upon the judgment of Federal and State water officials. The Council has recommended steps to improve future assessments in order more adequately to inform the Executive Branch, the Congress, the States, and the public of problems and actions needed to meet water and related land resources requirements. A Council analytical and information system, compatible with Member Agency data systems, will be developed to support the National Assessment.

In preparing this First National Assessment, the Council has received the cooperation of many Federal and State agencies. Without this willing cooperation the report would not have been possible. Special recognition should be given to the work of the various task groups, the Council's Planning Committee, and the Council staff.

The National Assessment and the Council's framework studies will provide information on water requirements and development potentials that should be of great value to the National Water Commission in its consideration of national policy issues. The Council will cooperate fully with that Commission

Sincerely yours,

Stewart L. Udall
Chairman

The President
The White House
Washington, D. C.

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Acknowledgments

Parts 2 through 6 of this report were a responsibility of the Planning Committee of the Water Resources Council. Membership and participation on the Planning Committee:

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Special acknowledgment is given to work of Bruce Blanchard in planning and carrying out the Assessment. Data on natural runoff and water used in 1965 were provided by the Department of the Interior. Economic projections were furnished by the Departments of Commerce and Agriculture. The preparation of each chapter in the report was assigned to a lead agency or field committee.

Detailed acknowledgments of participation are given in part 7.

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Foreword

THE WATER RESOURCES COUNCIL

The Water Resources Planning Act of 1965 (PL 89–80) established the Water Resources Council to carry out the policy of the United States as set forth in the Act to encourage the conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis by the Federal Government, States, localities, and private enterprise with the cooperation of all affected Federal agencies, States, local governments, individuals, corporations, business enterprises, and others concerned.

The Members of the Council are the Secretaries of Agriculture; the Army; Health, Education, and Welfare; the Interior; Transportation; and the Chairman of the Federal Power Commission. The Secretaries of Commerce and of Housing and Urban Development are Associate Members, and the Director of the Bureau of the Budget and the Attorney General are Observers. The President has designated the present Secretary of the Interior as Chairman. The Council Members meet at least quarterly, and have delegated certain responsibilities to their Representatives who meet together with the Council's Executive Director at least bi-weekly. Other departments and agencies are invited to Council meetings when matters pertaining to their responsibilities are under consideration. In addition, the Council organization includes a staff and administrative, technical, and consultative committees. The functions of the Council are:

To maintain a continuing study and prepare periodically an assessment of the adequacy of supplies of water necessary to meet the water requirements in each water resources region in the United States and of the national interest therein.

To maintain a continuing study of the relation of regional or river basin plans and programs to the requirements of larger regions of the Nation.

To appraise the adequacy of administrative and statutory means for coordination and implementation of the water and related land resources policies and programs of the several Federal agencies, and to make recommendations to the President with respect to Federal policies and programs.

To establish, after consultation with appropriate interested Federal and non-Federal entities and with the approval of the President, principles, standards, and procedures for Federal participation in the preparation of comprehensive regional or river basin plans, and for the formulation and evaluation of Federal water and related land resources projects.

To coordinate schedules, budgets, and programs of Federal agencies in comprehensive interagency regional or river basin planning.

To carry out its responsibilities with regard to the creation, operation, and termination of Federal-State river basins commissions.

To receive plans or revisions thereof submitted by river basins commissions and to review and transmit them, together with their recommendation, to the President.

To assist the States financially in developing and participating in the development of comprehensive water and related land resources plans.

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The responsibility for development and management of the Nation's water resources is divided among many Federal, State, local, and private interests. Water resources are used for many different major purposes by numerous competing interests. There is a recognized need for participation of many local, State, Federal, and regional jurisdictions and interests in comprehensive planning and multipurpose development.

The existing development and use of the Nation's water resources have evolved over long periods in a setting of abundant natural resources. This has been without benefit of broad planning frameworks to relate individual problems and their solutions to available resources and the regional needs. With regional water consumption and withdrawal estimated to increase two- to six-fold in the next 50 years, the present developments and problems are likely to be dwarfed by those of the future.

A first step in water resources management is the development of cooperative Federal-State regional framework plans for water and related land resources development. The plans must set forth a program to meet the long-range requirements for water and related land resource development needed to meet each region's share of the national demands for goods and services and to provide balanced regional growth. At present, the Water Resources Council has framework studies under way in 11 of the 20 water resources regions of the Nation. The Council has scheduled the completion of framework planning studies for all regions which serve as guides to detailed comprehensive planning for water resource development and management.

The Water Resources Planning Act provides for the establishment of Federal-State river basins commissions. Their functions are:

To serve as the principal coordinating agency for plans for water and related land development.

To prepare and keep up to date a comprehensive plan for water and related land resources development within the basin.

To recommend priorities for data collection, for investigations, planning, and construction of projects.

To foster and undertake such studies as are necessary in preparing the comprehensive plan.

To submit to the Water Resources Council, with its comprehensive plan, recommendations for implementing the plan.

Commissions have been established for the Pacific Northwest, the Great Lakes, the Souris-Red-Rainy, and the New England river basins. These Commissions are demonstrating the value of cooperative Federal-State effort in comprehensive planning for development and use of water and related land resources. The Council urges the States which have not done so to consider the formation of Federal-State river basin commissions under Title II of the Water Resources Planning Act.

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TECHNICAL SUPPORT FOR WATER RESOURCES PLANNING AND MANAGEMENT

Technical support necessary for water resources planning and management includes data, analytical methods, research, and manpower. Hydrologic data are collected continuously or periodically at thousands of surface-water, water-quality, precipitation, groundwater observation, and snow measurement stations. In addition, extensive data are collected as a part of project-type water resources investigations by Federal, State, and local agencies. Plans for future water data collection are emphasizing coordinated programs, balanced to meet the needs of water resources planners and managers.

Data on the use of water resources are quite inadequate and place a severe limitation on comprehensive planning, the National Assessment, and other planning and policy activities that require reliable inventories of present uses and projections of future uses.

The Council is undertaking a study of Federal activities in collection and analyses of data on use of water resources, looking toward the establishment of an adequate system to meet the needs of the National Assessment, comprehensive planning, and other purposes.

Intensive and comprehensive water resources management requires a vigorous and coordinated water resources research program. To advance such a program, the Federal Council for Science and Technology maintains a Committee on Water Resources Research to identify needs and priorities in various categories, to recommend programs to meet those needs, and to facilitate coordination and communication in the water resources research field.

This First Assessment highlights the changing nature of future water problems and the constant need to reorient research programs. Greatly increased recycling and reuse of water will be accompanied by the need for new technology and processes in water treatment and conditioning, and in waste treatment and pollution control. Research to improve the efficiency of water use for industry, agriculture, and domestic purposes will be of increasing importance. Research is needed on alternatives for augmenting regional and local water supplies, including weather modification, desalting, vegetative cover manipulation and snowpack management, waste water treatment and reuse, and other methods. Much more knowledge is needed to develop optimum institutional arrangements for planning, managing, and financing regional water supplies and for coping with water problems arising from urbanization.

Water supply and water quality problems, or the exposure of an area to floods or drought, are important factors in the intensity and location of economic activity. Analytical systems have not yet been developed to fully measure the community and regional advantages that result from the alleviation of water problems. An accelerated Federal research program is needed to improve methodology for water planning and management from a nationwide, regionwide, and community view.

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In connection with its national assessment reports and otherwise as necessary, the Council is bringing high priority research needs to the attention of the research community.

The explosion of scientific and technical information is being felt in the water resources field. Knowledge of such information is vital to competent water resource management and development. A water resources scientific information system is being developed by the Department of the Interior for Government-wide dissemination of scientific information. The Council urges the use of this system to provide up-to-date information to planners, developers, and managers in the water resource field.

Many thousands of people are employed in activities related to research, planning, construction, and operation of water resources developments. There is presently a significant need for additional technically and professionally qualified personnel. Better training is required as water resources planning, development, and management become more complex. Future requirements for qualified personnel are expected to increase substantially.

The Council is encouraging and assisting the development of training programs needed to support the manpower requirements of State and Federal agencies for comprehensive planning and management of water and related land resources. Improved technical support, generally, for water resources planning and management is essential to meeting the Nation's future needs for water and related land resources.

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PART 1

The Nation's Water and Related Land Resources

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The Nation's Water and Related Land Resources

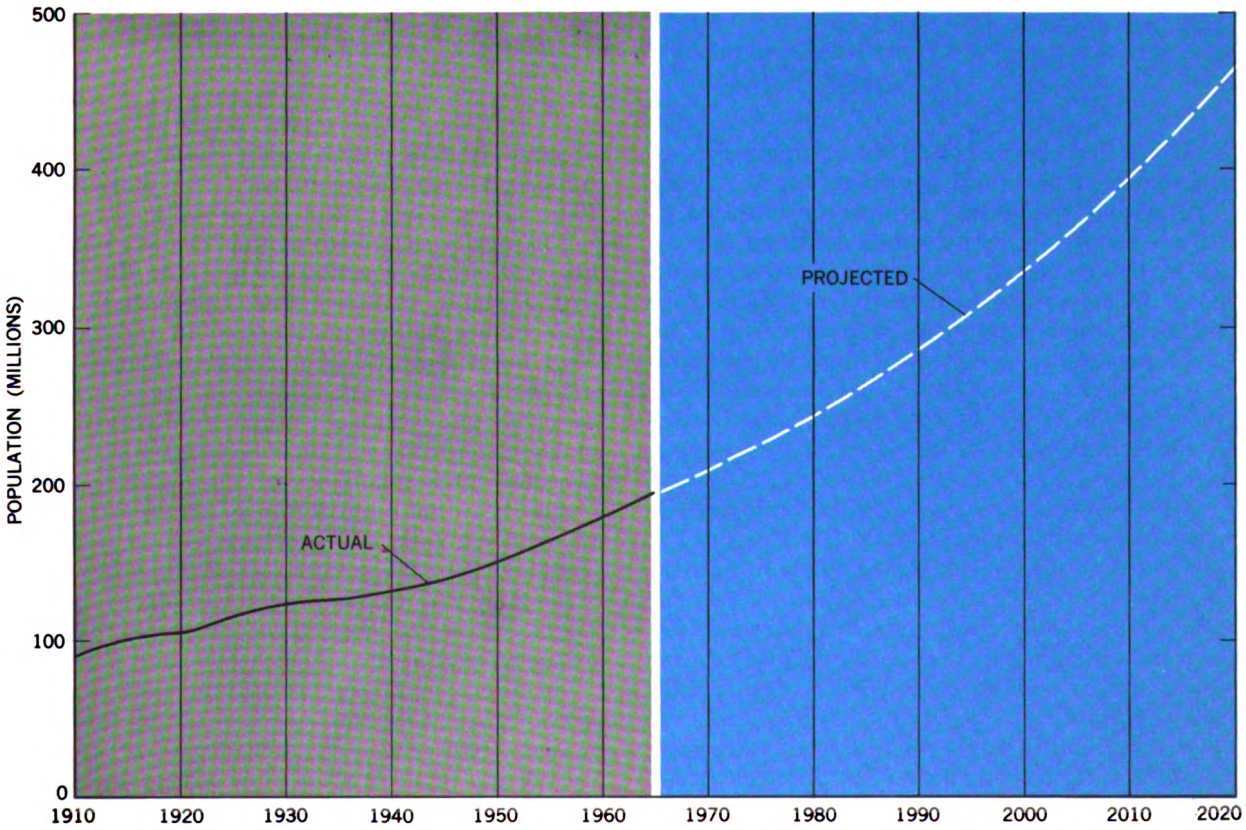
The Congress has directed the Water Resources Council to maintain a continuing study of the adequacy of water and related land resources to meet the requirements in each water resources region. The Council studies the relation of river basin plans and programs to the requirements of larger regions of the Nation, and assesses the adequacy of regional water supplies and the national interest therein. To identify emerging problems in water resources management, a time horizon of about 50 years is used in this National Assessment. Early identification of problems that may occur within a 50-year period of growth will allow time for detailed investigation, for planning, for public discussion, and for decision on major policy issues.

WATER AND RELATED LAND

Population and Economic Growth

The size and geographic distribution of the Nation's population is a major factor in estimating requirements for water and related land resources. For this First National Assessment, a population growth rate of 1.6% per year has been used, resulting in a projected population of about 468 million in the conterminous United States in 2020 (fig. 1–1). In 1965, the Nation's population was 195 million and in late 1967 it passed the 200-million mark. This projection of 468 million by 2020 approximates the population growth rate of the period 1950–65. Birth rates in very recent years suggest a lower rate of population increase. Future assessments will take account of this and other changes.

FIGURE 1–1—*Population of conterminous United States, 1910–2020*



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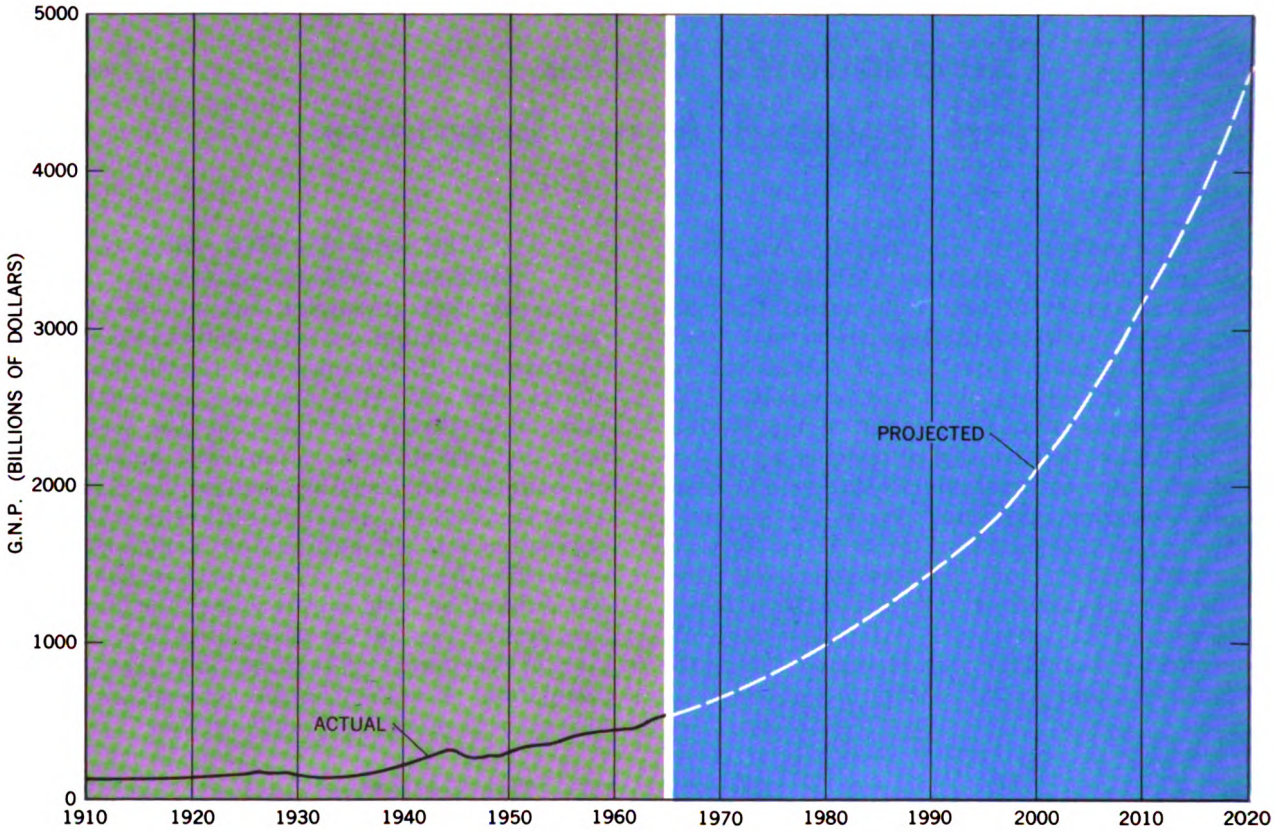

FIGURE 1–2.—*Gross national product (1954 dollars), 1910–2020.*

There has been considerable migration of population from rural to urban areas. About 72% of our population is now concentrated in urban areas. If current trends continue, almost all of the projected population increase would occur in expanding urbanized areas. The transition of rural areas into urban areas will be accompanied by many water and related land use problems. The Council is concerned with these national trends and believes that water resource developments can be used to induce a more desirable population distribution.

The Nation experienced a remarkable growth rate of gross national product (GNP) of 4.7% per year for the 1960-65 period. This was partly accounted for by a fuller utilization of the Nation's labor and capital resources. A projected growth rate equal to that of the 1960-65 period seems overly optimistic, but a rate significantly higher than the 3.0% of the 1910-65 period seems attainable. An annual rate of growth of GNP of 4.0% has been used for this Assessment (fig. 1–2). This rate of growth indicates a GNP of about $4,686 billion (1954 dollars) in 2020 compared with $550 billion (1954 dollars) in 1965.

The projected growth of the Nation's population and economic activity is based on the belief that a viable economy with substantially full employment will be maintained in the face of both international and domestic problems.

In addition to expanding needs for domestic water supplies to match population growth, the major water-using industries which withdraw or consume large quantities of water or add substantially to the pollution problem are expected to require greatly increased supplies in the next 50 years. Changes that may take place in the technology and efficiency of water use will be a major factor in translating this growth into water requirements.

An interregional shift in economic activity has been taking place and, if water and land resources are available, it is expected to continue during the next 50 years. The size of this shift (experienced and projected) can be illustrated

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by comparing the shares of national economic activity at the beginning and end of a span of almost a century. In 1929, the volume of economic activity in the northeastern portion of the country was three times that in the South and West combined. In 2020, the combined South and West areas are projected to be nearly equal in economic activity to the Northeast.

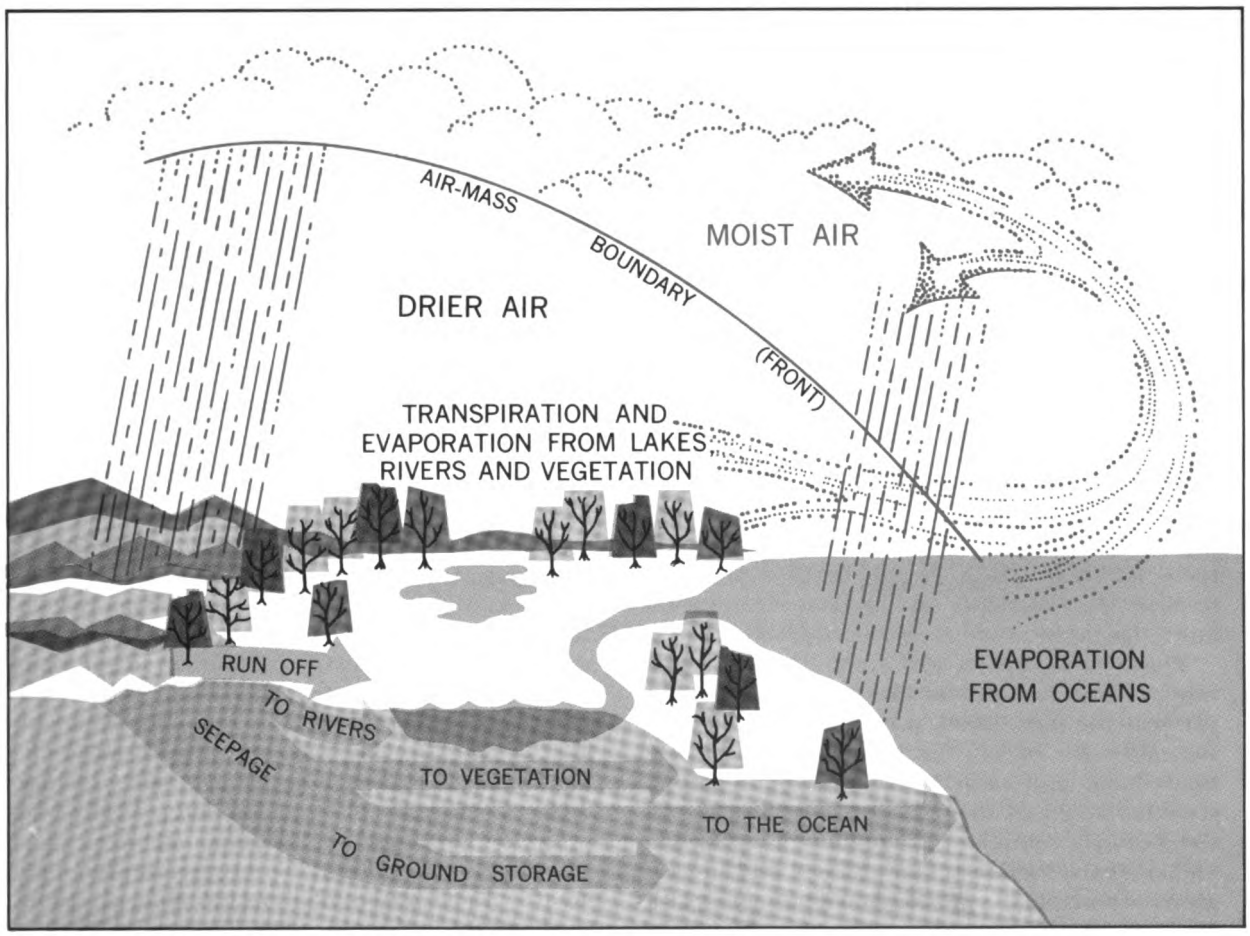
These projected variations in regional growth rates would have an important impact on requirements for water and related land resources.

The Water Resource

The Nation's renewable water resources are derived from an average annual precipitation of 30 inches, equivalent to 4,200 billion gallons per day on the conterminous United States. About 70% of this precipitation is consumed through evaporation and transpiration. A portion of this evapotranspiration provides 80% of our supply of food and fiber and nearly 100% of our forest products. The remaining 30% of this precipitation constitutes the Nation's average annual natural runoff of about 9 inches, or 1,200 billion gallons per day (fig. 1–3). A substantial part of this is physically subject to development under present technology. In addition, large amounts of non-renewable groundwater storage can be developed. The natural runoff of Alaska is estimated at 580 bgd, almost 50% of the conterminous United States. This Alaska resource represents the Nation's largest block of undeveloped water supply.

The distribution of the water resource presents serious problems. Rainfall varies widely from region to region. In any one region, rainfall can vary widely from season to season and

FIGURE 1–3.—*Hydrologic cycle.*



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year to year. Even greater variation can occur in runoff and streamflows. The average runoff in different parts of the Nation is shown in figure 1–4.

The dependability of annual runoff can be measured by comparing the runoff in the one dryest year in 20 years with the average. In general, the areas of least variability (more dependable supply) in annual runoff are in the Northwest, the Northeast, and the Southeast,whereas the areas of greatest variability are in the Southwest and North Central parts of the conterminous United States (fig. 1–5). Even in areas of high precipitation and runoff, a series of dry years may occur, resulting in serious drought problems such as occurred in the Northeast during 1961 to 1966. The availability of both surface and ground waters varies annually, seasonally, and over shorter periods of time. In the extreme, flood and droughts of varying severity and duration are experienced occasionally across the Nation. Flood damage is heavy in areas where intensive development is occurring on the flood plains, although the national total also reflects a predominance of less intensive damage at a vast number of localities. The adverse effects of droughts are particularly felt in areas which are using a high proportion of their water supply each year or where storage and distribution facilities are inadequate to meet prolonged shortages or increased water requirements.

The amount of runoff that is available for development depends on the variability of the annual runoff, groundwater recharge possibilities, the storage capacity of reservoirs, and the evapotranspiration potential, all of which vary from basin to basin. For this Assessment the storage potentials and requirements have not been determined; instead, the quantities of annual runoff in each region with appropriate interregional adjustments are presented as indices of the water resource for comparison with projected requirements.

Groundwater mining in some areas has augmented water supplies; however, this is only a temporary solution to meet local requirements and must ultimately cease as uneconomic pump

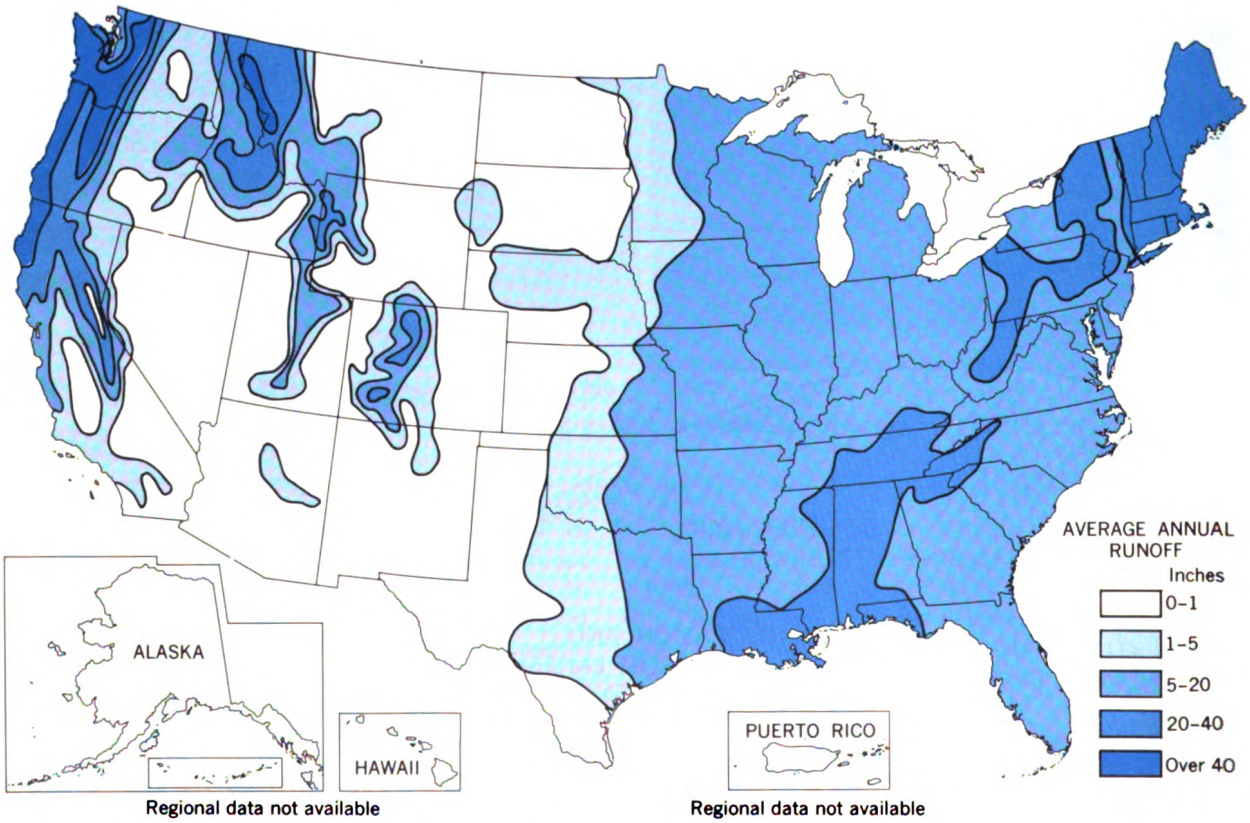

FIGURE 1–4.—*Average annual runoff.*

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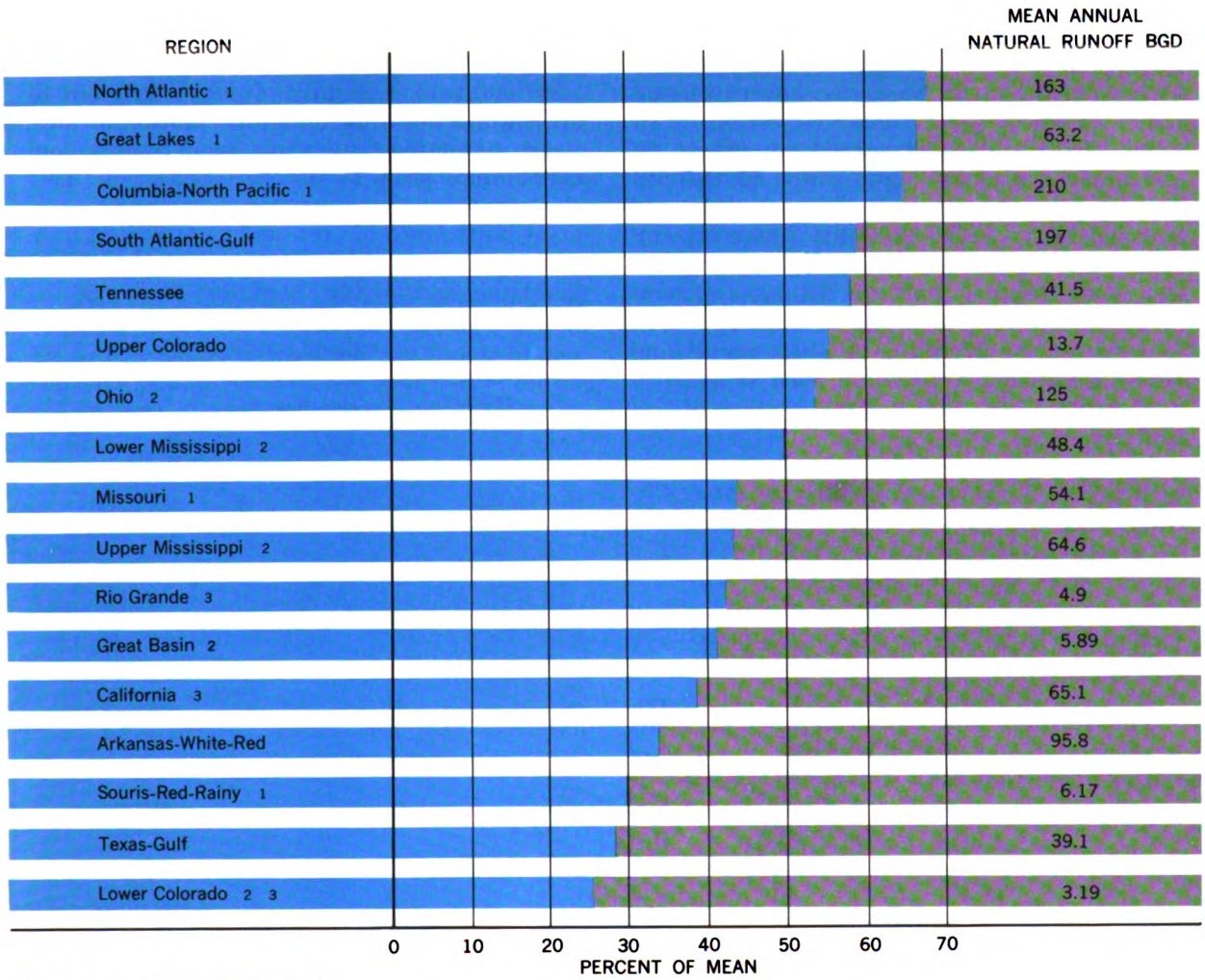

1 Does not include runoff from Canada

2 Does not include runoff derived from upstream regions

3 Does not include runoff from Mexico

FIGURE 1–5.—*The variability in annual natural runoff. In the one dryest year out of 20 the annual natural runoff will be equal to or less than the indicated percent of the mean.*

lifts are reached or groundwater basins are exhausted. Desalination may become a significant means of economically augmenting local water supplies under projected technology; however, its present utilization is limited. Induced precipitation through weather modification offers some possibilities for the future, but again many questions remain unanswered until unlocked by further research. Other opportunities for augmenting natural runoff are through watershed management, snowpack management, evaporation suppression, and the reduction of transpiration through vegetative manipulation.

Natural water quality is affected by geologic, hydrologic, and biologic factors. The most significant natural impurities are sediment and dissolved minerals. The natural quality of water varies considerably from one area to another and, in specific localities, may make the water unfit for some uses. Man-caused pollution, however, has seriously impaired water use over wide areas. This pollution consists primarily of waste discharges (including heat) from domestic, industrial, and agricultural uses; and sediment and other diffused wastes in runoff from urban, industrial (including mining), and agricultural lands; from logging; and from transportation system developments. Changes in stream regimen from upstream water control features may also affect water quality.

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The Related Land

The uses of land resources are related to water supplies and uses in a variety of important ways. The use, treatment, and management of land affect both the quality and quantity of natural runoff, as well as the location and magnitude of water uses. A high percentage of precipitation and stream withdrawals is used on agricultural land for production of food and fiber. Intensive land use for urban and industrial purposes creates concentrated water supply, flood control, and waste disposal problems. Changes in land use cause changes in requirements for water. In assessing the adequacy of water supplies to satisfy requirements, attention must be given to these relationships with management and use of land resources.

The management of the land resource varies with the type of ownership. Private ownership covers 1,406 million acres of the land area of the 50 States and Puerto Rico which totals 2,274 million acres (fig. 1–6). The States own 84 million acres and counties and municipal governments have 18 million acres. Approximately 766 million acres are owned by the Federal Government.

The Nation's land resources hold potential for many different uses. Woodlands, forests, and related wildlands are important yielders of water. In the 11 Western States over 90% of the usable water originates in high altitude forested lands. Much of the Nation's meat production comes from range and pasture lands. These forest and range lands also provide recreation and habitat for wildlife. Future requirements for cities, industries, highways, solid waste disposal, recreation, and many other uses for an expanding urban society will be drawn from this land base.

Of importance to an assessment of the future of irrigation development is the availability of lands that can be cultivated without irrigation.

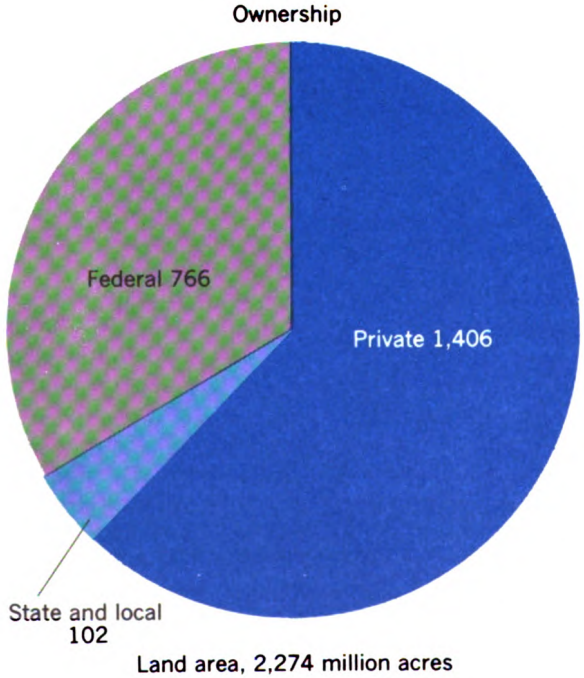

FIGURE 1–6.—*Land ownership, 1965.*

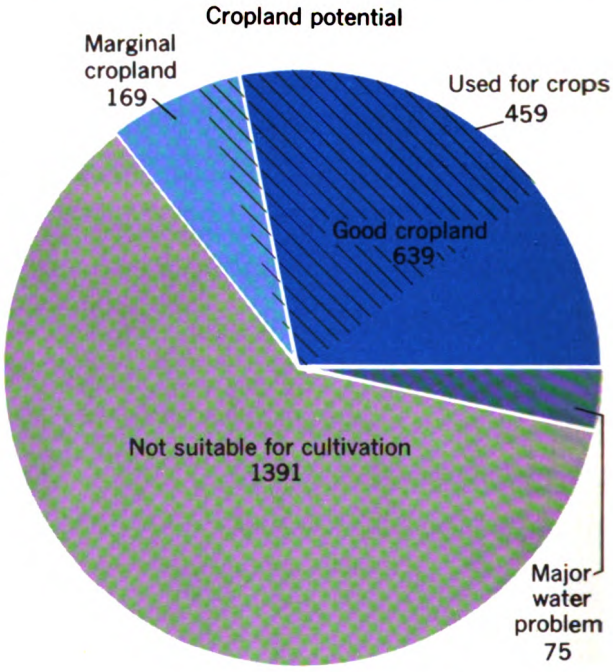

FIGURE 1–7.—*Cropland potential, 1965.*

The Nation has a cropland potential of about 639 million acres which are suitable for regular cultivation with normal conservation practices (fig. 1–7). Another 169 million acres are suitable for limited cultivation with intensive conservation treatment. There are also an additional 75 million acres of private land that could be cultivated with major reclamation works for supplying irrigation water or removing excess water.

Less than 50% of the lands that are suited for cropland is now in this use. The remaining suitable cropland is primarily in pasture and range or forests and woodlands. The demand for products and services from these uses and for increasing urban development will severely limit the amount of this potential cropland which can be made available for cultivation.

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The irrigation potential of the Nation includes millions of acres of private and public lands in the arid portion of the country which could be cultivated for crop production if water supplies were available for irrigation. In addition, there are many million acres throughout the Nation now cultivated but not irrigated which could be irrigated to increase productivity.

Land Use

About one-fourth of the land area in the Nation is used as cropland, one-third as pasture and range, and one-third as forest. Between 2% to 3% is devoted to urban and other intensive uses. The remainder of the land base has multiple uses for recreation, wildlife, public facilities, or includes wildlands having value for water yield and landscape for recreation (fig. 1–8).

The productivity of land in agricultural use is increasing rapidly in response to new and improved technology. Part of this increase will result from increased irrigation, but a larger part will come from more fertilizer, improved varieties, and better practices.

Projected requirements for agricultural and forest products are also increasing. Based on these projected trends of both requirements and productivity, land used for crops is projected to decrease from 1960 to 1980. After 1980, requirements are projected to increase faster than productivity and land used for crops will show an increase. It is significant to note that the projected land base devoted to crops and pasture is about the same in 2020 as in 1960 but is expected to produce enough food and fiber for about 2.5 times as many people. Land expected to shift to urban uses in the future will include much land now in agricultural and forest use.

The national supply of land for most purposes is adequate for sustained economic development. Management and use of land need to be planned, however, to minimize conflicts between uses, to reduce the cost of land use changes, and to enhance related water resources. Interrelationships between land and water clearly indicate that efforts at water and land planning must be coordinated and balanced.

Role of Water and Land Resources in Economic Growth

What does economic growth mean in terms of future requirements for water and related land resources? What influence do water and related land resources have on economic development in various regions?

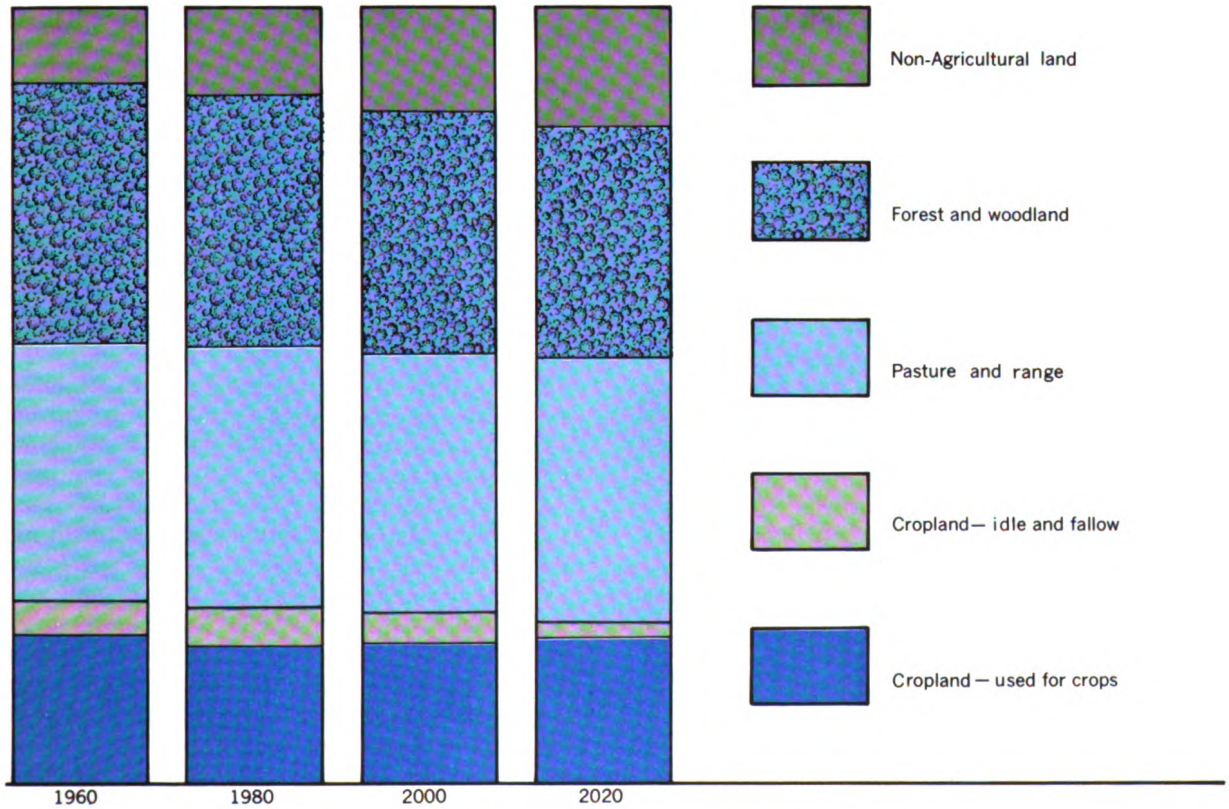

FIGURE 1–8.—*Projected land use, conterminous United States, 1960–2020*

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TABLE 1–1.—*Estimated water use and projected requirements, by purpose, United States*

(Million gallons daily)

Type of use	Used 1965	Projected requirements 1980	2000	2020	Used 1965	Projected requirements 1980	2000	2020
	Withdrawals				*Consumptive use*			
Rural domestic	2,351	2,474	2,852	3,334	1,636	1,792	2,102	2,481
Municipal (public-supplied)	23,745	33,596	50,724	74,256	5,244	10,581	16,478	24,643
Industrial (self-supplied)	46,405	75,026	127,365	210,767	3,764	6,126	10,011	15,619
Steam-electric power:								
Fresh	62,738	133,963	259,208	410,553	659	1,685	4,552	8,002
Saline	21,800	59,340	211,240	503,540	157	498	2,022	5,183
Agriculture:								
Irrigation	110,852	135,852	149,824	160,978	64,696	81,559	89,964	96,919
Livestock	1,726	2,375	3,397	4,660	1,626	2,177	3,077	4,238
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

Requirements for water are derived from the demand of the economy for the products and services obtainable through use of water but are limited by the costs of alternative means of satisfying these demands. Thus, projections of future water requirements involve complex problems of technological change and relative costs of water and substitute input factors. As water becomes scarce or of poorer quality, industrial plants tend to invest in recycling and water conditioning equipment which increases the reuse of water and, thus, reduces their withdrawal requirements. In this assessment broad assumptions have been made to take into account major technological changes that would affect future requirements. Improvements are needed in the methods of making estimates of the effects of such changes.

Current and past trends are for industry, supporting services, and related population to locate in or close to metropolitan centers. Even new cities are usually satellite to existing urban complexes. Continuation of these trends may result in a few huge strip cities including a major portion of the Nation's population and economic activity. The concentrations of people and industrial development in the urban areas of the country have already created highly complex water supply, flood control, and waste disposal problems. Although efforts are under way to maintain viable rural communities, urban problems are expected to intensify as future water demands become increasingly focused and competitive in these areas. Effective solution of urban water use and waste disposal problems requires coordinated planning by the many governmental units involved in these areas. There is need for improved arrangements for the development, financing, and management of water supply and waste disposal systems, flood plains, and other water problems in metropolitan areas.

As the Nation grows, the limitation in water and related land resources available to competing regions becomes more important from a national viewpoint. Currently, we have inadequate techniques for measuring the restraints that inadequate water and related land resources may place on economic growth, or the inducement that adequate supplies may offer. Water shortages, water surplus problems, and water quality deficiencies may influence economic activity in a variety of ways. Shortages of water of suitable quality may render an area unattractive for industrial development. Flood hazards may restrict development. Too much or too little water tends to interfere with development of a viable economy and result in underutilization of resources. When economic activity is frequently disrupted by droughts or floods there may be underutilized plant and labor force and reduced income.

Not much is known about the effects of these constraints on other parts of the region and on the Nation. Strictly from a market point of view, constrained economic activity in one area may be offset to some extent by gains in other areas. The Nation is interested in growth in all regions.

Water and related resource development offers one means of countering the trend to over concentration in urban areas and to correct the deficiencies of undeveloped areas. Dependable clean water supplies, low-cost power, and protection from flood or drought can attract new enterprises and unlock the use of other resources with a resulting increase in employment and income opportunities. In the past, the Nation has

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used water resources development, on a piecemeal basis, to induce community and regional growth. In more recent times, the problems of low-income areas have been attacked through the Appalachia program and in other areas under the Economic Development Act. Under the Water Resources Planning Act we now have the organizational arrangements for a comprehensive approach to planning the use of water resources in regional development.

Comprehensive river basin planning considering the criterion of economic efficiency will give increased attention toward achieving community and regional development goals, including increased employment and income, and national goals for balanced population and economic growth among regions.

WATER USES

This First National Assessment has considered water uses in two categories—withdrawal uses that remove water from its natural course and instream uses that do not. Some uses of water may fall into both categories, such as hydroelectric power and recreation; however, owing to insufficient data, this first Assessment has not considered these refinements. Withdrawal uses consume some water but may return large quantities of water to stream courses or groundwater where it is available for reuse. Both withdrawal and instream uses consume water through direct evaporation or transpiration or by discharge to irretrievable locations such as the ocean.

Withdrawal Uses

Withdrawal uses are primarily for domestic, industrial, steam-electric power, and agricultural purposes (table 1–1). Projections of withdrawal uses require such additional projections as water sources; economic activity and related use rates; water use efficiencies, including recirculation, returns, and reuse; and institutional factors.

Domestic and Municipal

Withdrawals for municipal systems are expected to increase from 24 bgd in 1965 to 74 bgd by 2020 and consumptive use is expected to increase from 5 bgd to 25 bgd. Domestic use per capita served by public distribution systems is expected to increase only modestly (fig. 1–9); therefore, the increase in total withdrawal will relate principally to an increase in population.

However, problems occur in the supply of domestic and municipal water because of local

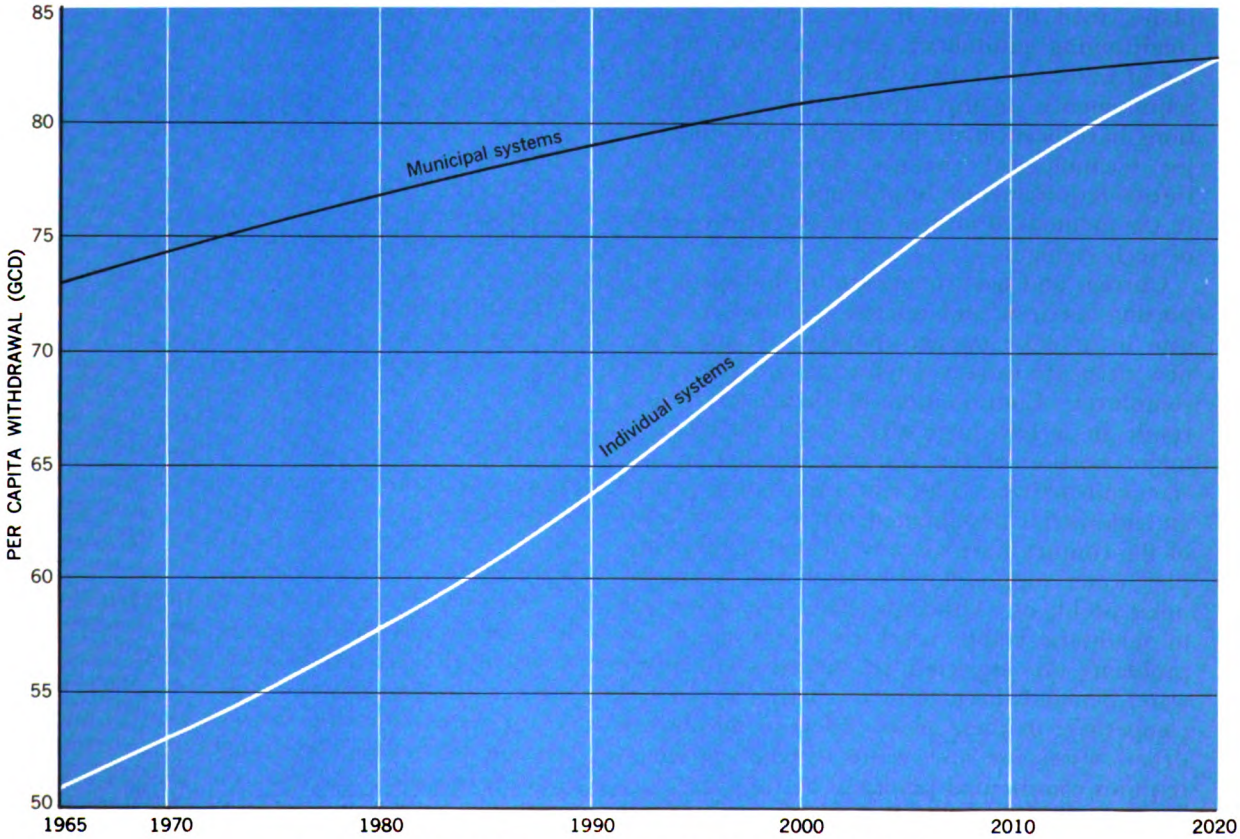

FIGURE 1–9.—*Domestic water withdrawal per capita. 1965–2020*

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and regional variations. The availability of water sources varies from low in semiarid portions of the country to high in the humid portions. Conversely, water demand is relatively higher in semiarid areas, where such things as lawn and garden watering become significant factors.

Despite regional differences in supply available and in use rates, water shortages occur in both humid and semiarid regions. Inadequacies in collection, treatment, and distribution facilities to meet maximum demands during summer months are the principal factors in these shortages. Deficiencies in distribution works may result in low pressure or cessation of service to limited sections of a community. Some municipalities have been faced with systemwide water shortages through a failure to recognize a need for long-range planning.

In 1965, about 46 million people, or about 24% of the total population, were supplied with water from individual and small systems. The continued development of water supply improvement projects in small communities is projected to cause a relative decline in persons on individual and small systems to an estimated level of about 10% of the projected total population by 2020.

Current planning also envisions local-State-Federal cooperation in the provision of major storage and conveyance works to serve groups of communities.

Major storage and conveyance works should be planned giving full consideration to cooperation by local, State, and Federal authorities and to appropriate implementing arrangements, with a view to resolving complex problems of municipal supply in metropolitan areas.

Industrial, Including Steam-Electric Power

The estimates of industrial water use are based on rapid advances in technology (fig. 1–10). In manufacturing, for example, recirculation within the plant is expected to increase from an average of 2.3 times intake in 1965 to 6.3 times intake in 2020. In steam-electric power production, the increased use of cooling towers and other recirculating processes is expected to increase the ratio of water for condensing requirements to fresh water withdrawals from 1.2 in 1965 to 1.9 in 2020.

Industry (other than steam-electric power)

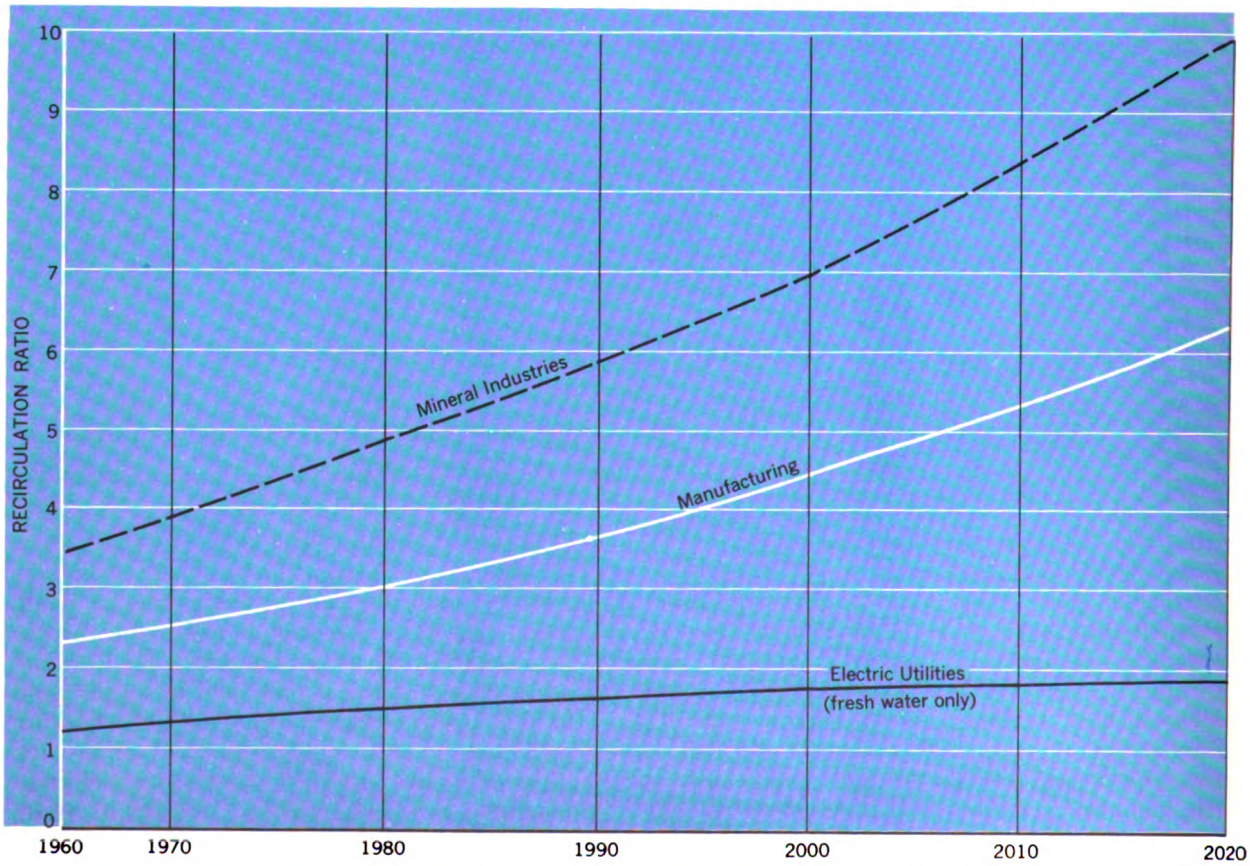

FIGURE 1–10.—*Industrial water recirculation, 1965–2020.*

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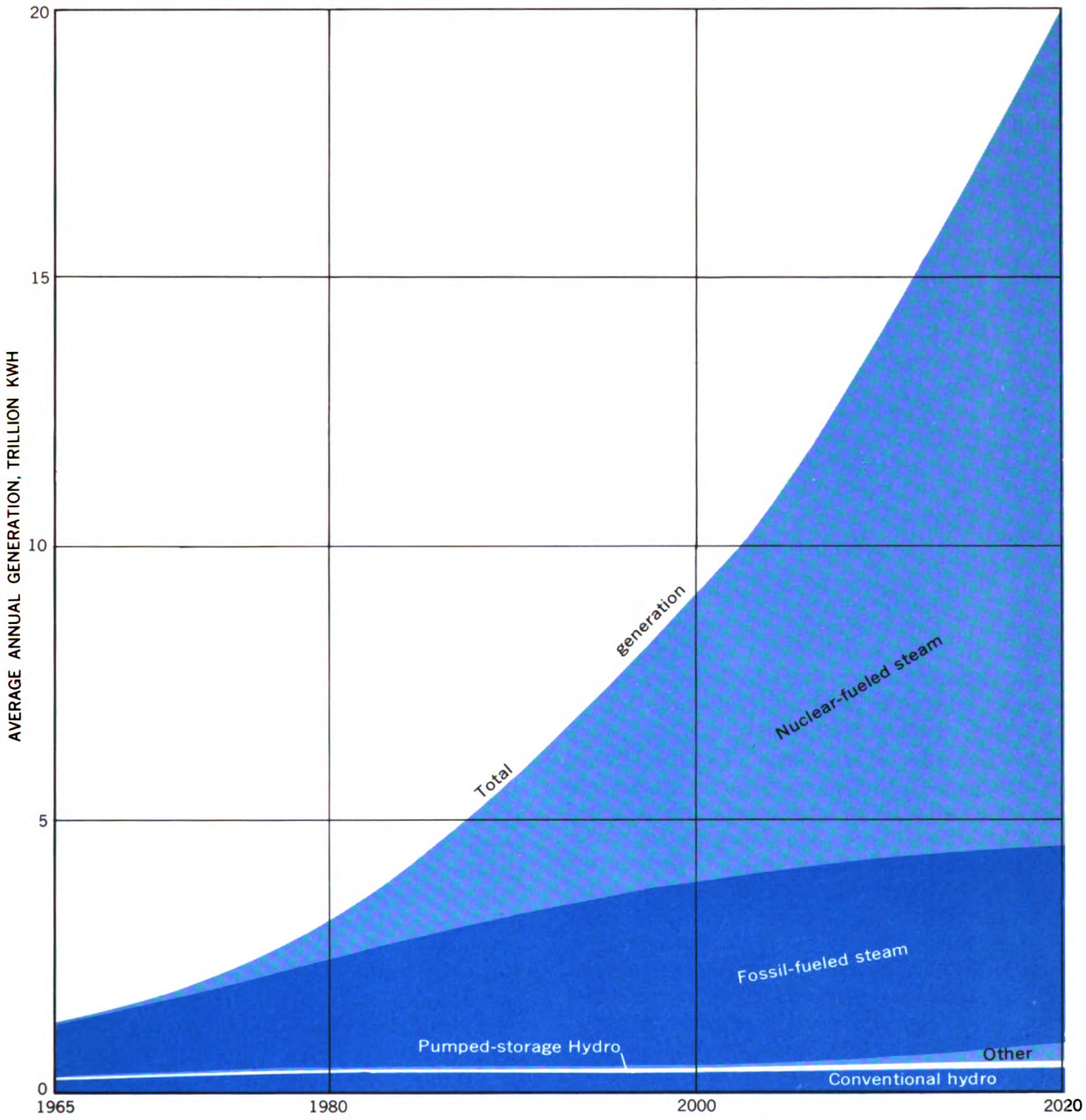

FIGURE 1–11.—*Projected electric generation by types of prime mover, 1965–2020.*

draws about 10% of its water requirements from municipal systems and the remainder is self-supplied. Water withdrawals for these self-supplied industries are expected to increase from 46 bgd in 1965 to 211 bgd by 2020. Withdrawals for self-supplied industry will exceed that for agriculture by 2020, but consumptive use in industry is estimated to be less than 8% of withdrawals.

While electric power requirements are expected to increase at a rapid rate (fig. 1–11), hydroelectric power will provide only a small portion of the total requirements of the future. Steam-electric power, including fossil- and nuclear-fueled plants, is projected to supply over 90% of requirements in 2020. In most regions water withdrawals for self-supplied industries will be exceeded only by those for steam-electric power which is projected to increase its fresh water withdrawals from 63 bgd in 1965 to 411 bgd by 2020. Steam-electric power will also use large quantities of saline water and withdrawals

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from saline sources are expected to reach 504 bgd by 2020. While consumptive use from steam-electric power withdrawals are not high, there are serious potential problems of thermal pollution from these increased uses. These problems are becoming increasingly manifest today.

Steam-electric plants produce waste heat in amounts exceeding the heat converted into electricity. Dissipation of the waste heat requires large flows of water through the plant condensers where the temperature rise ranges from 10° to 20° F. The most economical practice is a once-through system utilizing large quantities of water. When supplies are limited or there are thermal restrictions, more expensive systems are required such as recirculation of the water in reservoirs or ponds, or passing the water through cooling towers. The evaporative cooling towers dissipate substantial amounts of water to the atmosphere, and may contribute in some cases to local fogging and icing problems.

Industrial and steam-electric power uses will result in thermal and other pollution problems unless a high level of waste treatment is achieved. Total required capital investment in industrial water supplies and industrial waste treatment and cooling water facilities for steam-electric generators between 1965 and 2020 is estimated at about $150 billion.

As knowledge of the effects of heat additions on streams and their ecology increases, concern over thermal pollution heightens. The projected increases in water use for steam-electric power indicate that thermal pollution is one of the most serious long-range water resource management problems.

A large amount of research and study is under way to devise means of minimizing the adverse effects of thermal discharges on water bodies and of making beneficial uses of waste heat. Utilities planning the construction of steam-electric plants, particularly nuclear plants, are sponsoring extensive research studies. In Maine and Long Island Sound, studies are being made of possible use of waste heat to increase the harvest of shellfish. Consideration is also being given to using heated water for irrigation purposes.

Among the subjects for which more research is needed are the effects of heat discharges on aquatic life; possible beneficial use of waste heat; the patterns of heat dissipation in streams and reservoirs; the optimization of mixing zones; the capability of thermally stratified zones in reservoirs to provide cooling water supplies; and improvements in the design of waste heat disposal systems, particularly nonevaporative cooling systems. High priority should be given to research on alternative methods of converting energy into electric power and other industrial processes that would have less adverse water or air pollution effects. A control system is needed to provide an effective and equitable means of assessing and controlling potential thermal and other pollution loads.

Provision should be made for control of industrial and cooling water withdrawals and discharges for steam-electric power and other industrial plants.

Agricultural

Agricultural water use includes use for irrigation and livestock. Irrigation is practiced on about 10% of the farms of the Nation. In the dryer part of the country, irrigation makes the difference between low producing range and highly productive cropland. In the humid areas, irrigation can prevent crop failures in drought years and increase yields and improve product quality even in average years. Irrigation is also used for both frost protection and the control of high temperatures on specialty crops.

For this First Assessment the Council has developed estimates of irrigated acreages and water withdrawals and consumptive use for 1965 and projections have been developed for 1980, 2000, and 2020. The estimates of irrigated land are for productive areas that are developed for irrigation and may differ from some previously published estimates. The Council has projected irrigation on the basis of past trends for private development and long-range plans for public development. Some of the regional groups participating in this Assessment have reflected regional goals in their irrigation estimates which result in different projections of irrigated acres from those made by the Council. The acreage of productive irrigated land was estimated at 42 million acres in 1965. This acreage is projected to reach 62 million by 2020.

It is estimated that withdrawals of 111 bgd were used for irrigation in 1965, accounting for 41% of total withdrawals. Irrigation consumptive use accounted for 83% of total consumptive use. While total withdrawals for irrigation in 2020 will be less than fresh-water withdrawals for self-supplied industry or for steam-electric power, irrigation will remain by far the largest consumptive user of water. In contrast to improvements in efficiency anticipated in industrial uses, irrigation efficiency as measured by withdrawal per acre is expected to show only modest

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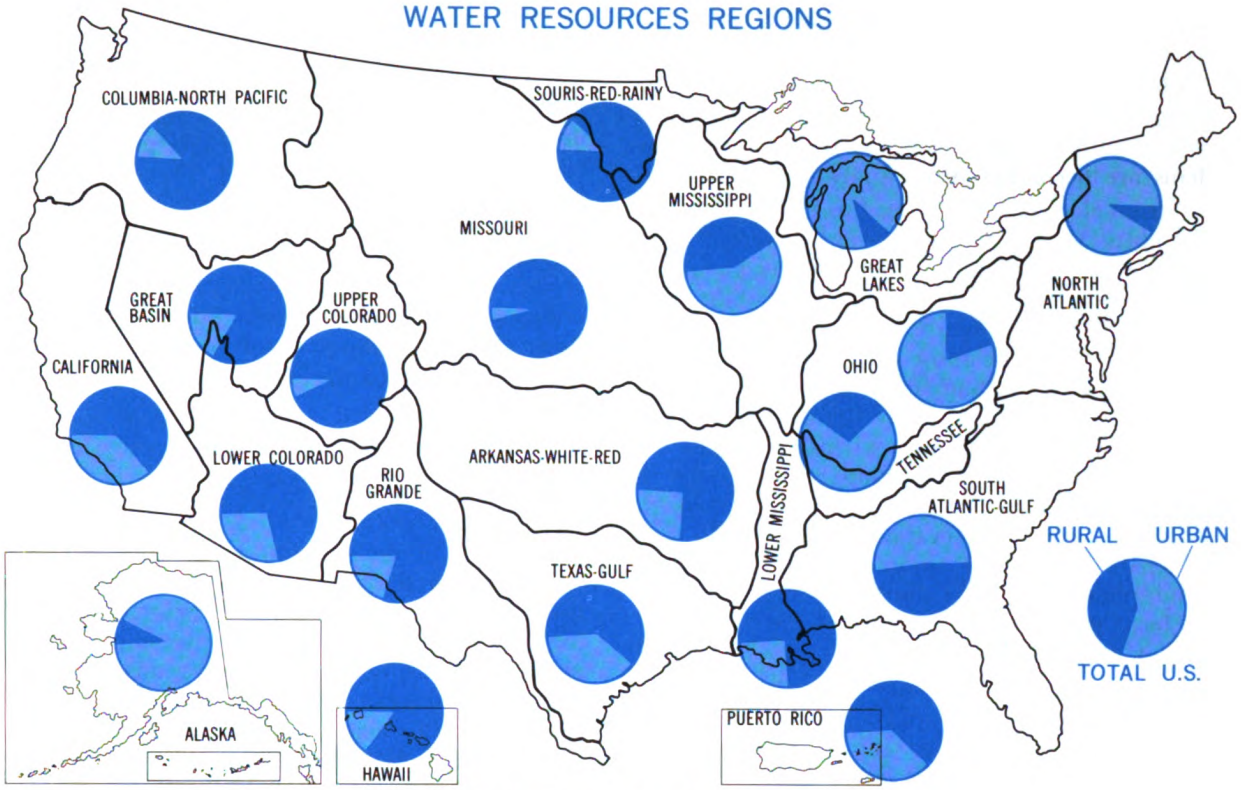

FIGURE 1–12.—*Rural and urban withdrawals, 2020.*

improvement. In many areas now being irrigated, increased efficiency in water use may be the only economic means to provide adequate water for optimum plant growth.

Water for livestock makes up a small portion of total agricultural water use, but its distribution and availability in dry periods is important in the use of large areas of range and pasture lands.

Projected regional water withdrawals in 2020 for rural uses (irrigation, livestock, and rural domestic uses) are compared in figure 1–12 with regional withdrawals for urban uses (municipal, industrial, and steam-electric power uses).

National policies regarding irrigation, drainage, and other agricultural water management measures are important factors in the assessment of the adequacy of water supplies. Irrigation is a major use in water-short regions. As pointed out before, portions of the remaining cropland potential of the Nation can be realized only by major reclamation programs to overcome water deficiencies or water excesses.

The Nation has a long history of Federal assistance to irrigation projects in the West and a somewhat shorter history of Federal technical, cost sharing, and credit assistance to private irrigation, drainage, and other agricultural water management measures in all parts of the country. These programs have been justified in terms of regional and rural area development, settlement of family farms, economic stability, more effective use of resources, crop production, and improvement of efficiency and income of farm enterprises.

Questions have been raised regarding the need for these various forms of Federal assistance in relation to the outlook for national food and fiber requirements as indicated in the 1967 report of the National Advisory Commission on Food and Fiber. Similar questions concerning their relation to interregional and interpersonal income distribution were raised in the 1967 report of the President's Commission on Rural Poverty.

The Council in its comprehensive framework studies will relate irrigation and drainage potentials to projected national food and fiber requirements and regional social and economic goals. The Council intends to undertake a national study of agricultural water management policy in relation to needs for agricultural production and regional development.

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Instream Uses

In this First National Assessment water requirements for instream uses have not been compared with potential flows. Lack of comparable data on instream uses has prevented meaningful analyses and comparisons. In future assessments a more complete analysis of the adequacy of flow for instream uses will be undertaken. However, a limited analysis of hydroelectric power, navigation, recreation, and fish and wildlife uses has been included.

Hydroelectric Power

Except for Alaska, sites available for economical multiple-purpose projects, which include conventional hydroelectric power development, are becoming relatively scarce in the United States and there are increasingly difficult problems involved in their development. However, potential sites for pumped-storage projects exist in most areas of the Nation, although pumpback-energy requirements affect their widespread use. Conventional and pumped-storage hydroelectric plants with an installed capacity of 44 million kilowatts constituted 18% of the total electric power supply in 1965. By 2020, the total hydroelectric capacity is projected to grow to more than four times that amount; however, total power demands are increasing so rapidly that by that date it is estimated that these hydroelectric plants will constitute only about 5% of the total capacity.

The use of water in hydroelectric power production is principally an instream use converting the energy of falling water into electricity. The effects on the streams and on other water uses relate primarily to impounding and releasing flows to meet multiple-purpose and power needs. Pumped-storage developments may be either instream or off-channel, but the process is reversible and little water is lost from the watercourse. Except for the initial filling and evaporation losses from reservoirs, conventional or pumped-storage developments do not consume significant amounts of water except in arid areas where the evaporation losses may be a significant factor.

Conventional and pumped-storage hydroelectric sites should be included in a program for reservation of reservoir sites.

Navigation

About 15% of the tonnage of intercity commerce in the United States is waterborne. Inland waterways (including intracoastal and Great Lakes navigation) will continue as a significant part of the Nation's transportation system. Present indications are that the mileage of improved inland waterways will probably increase from 23,000 miles now in use to perhaps 28,000 miles by 2020. Inland waterborne commerce is expected to maintain its share of total intercity commerce. Waterborne tonnage is projected to increase about 6 times in the next 50 years (fig. 1–13). Thus, traffic on the existing inland waterways will greatly increase in density. This would indicate a projected need

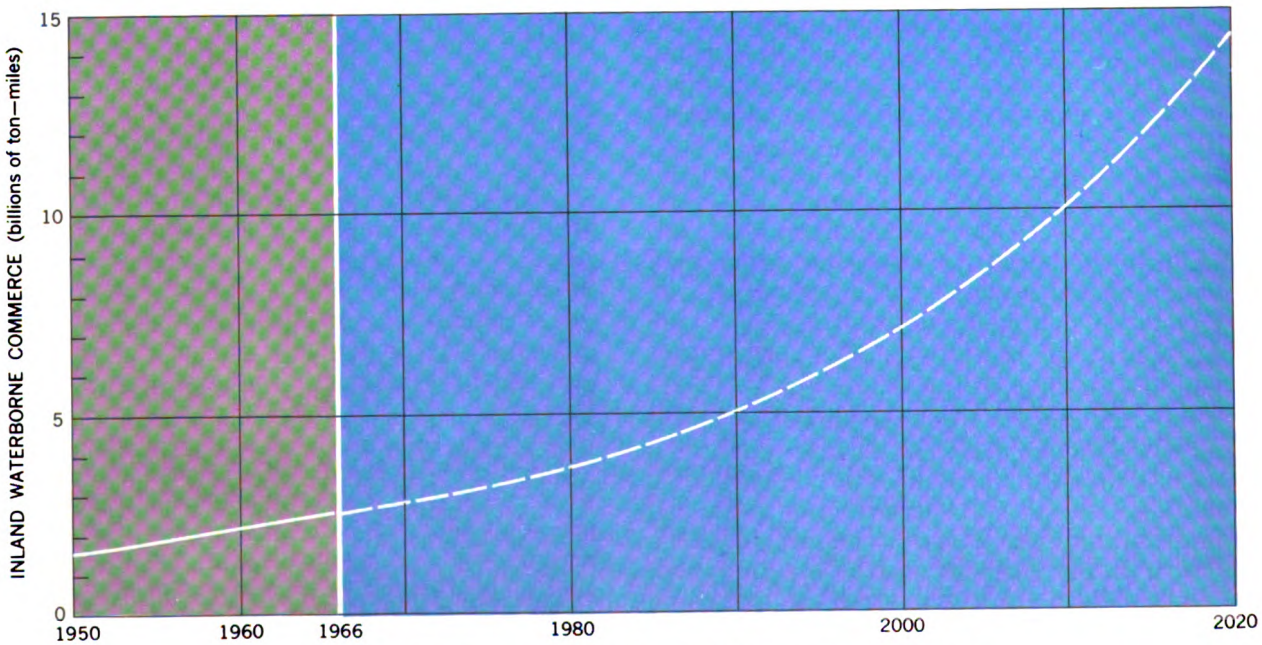

FIGURE 1–13.—*Projected waterborne traffic on inland waterways, 1950–2020.*

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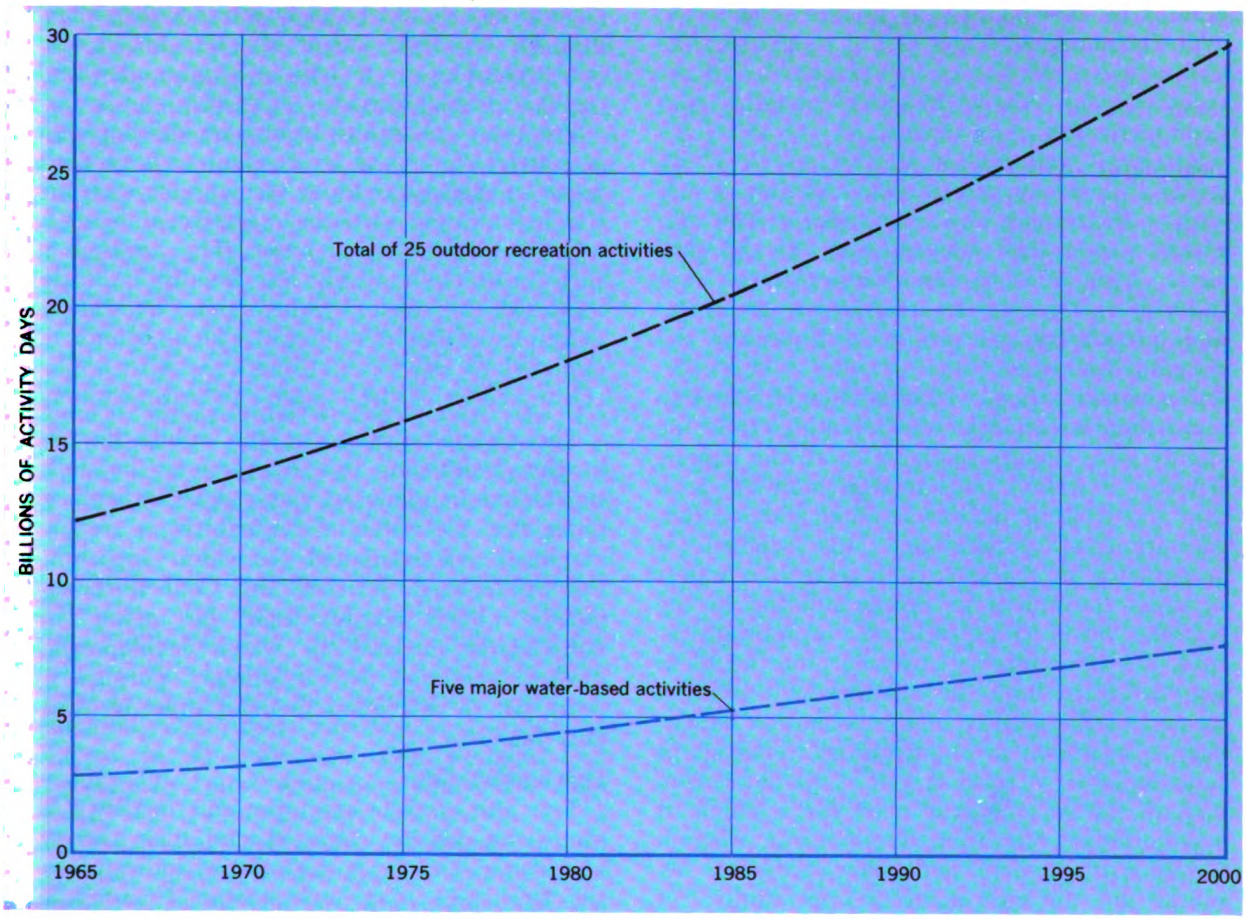

FIGURE 1–14.—*Projected outdoor recreation activities, 1965–2000.*

for substantial waterway improvements, especially of locks and navigation aids. Also, as presently foreseen, the use of the waterways for recreation will be of increasing importance and require facilities and procedures to safely and efficiently handle the recreation load in a manner compatible with commercial traffic. The number of pleasure craft is expected to increase from about 8 million in 1966 to 30 million by 2020.

Improved waterways generally have been located in river systems having a relative abundance of water. As withdrawals and consumption of water for other purposes increase in the future, the water requirements and operational procedures for both commercial and recreational navigation on improved waterways may take on new and more critical dimensions. These will probably result in requirements for added information on the flows and related conditions of the parent streams and on the navigation improvements, facilities, equipment, and traffic patterns.

The Council recognizes the need for a broadly based, long-range study of the inland navigation system, including the Great Lakes and intracoastal waterways. Such a study would consider the system as it relates to regional and national transportation requirements and other multiple-purpose uses, including recreational boating.

Recreation

About one-fourth of all outdoor recreation is and will continue to be dependent on water. Participation in swimming, fishing, boating, ice skating, and water skiing accounted for 2.8 billion activity days in 1965 and is projected to increase to 7.7 billion by 2000 (fig. 1–14). Further, the juxtaposition of water and land enhances the recreation experience afforded by such outdoor activities as camping, picnicking, and walking for pleasure. Two-thirds of all designated publicly administered recreation areas either have a body of water within their

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boundaries or are adjacent to accessible water. Water and related lands play a significant role now and will be increasingly important in the future as the resource base for providing outdoor recreation opportunities.

There is competition for water. The industrial economy which provides individuals with more income and more leisure time also places greater demands on water for all purposes. This same economy concentrates both industry and people, creating urban complexes and intensifying the problems of meeting the demands for water.

Nationwide, there would be enough water to serve the recreation needs beyond 2000 if the supply were equally available to all the people. There is a serious imbalance in both the location and types of recreation water and the concentration of population. This problem is accentuated by the scarcity of recreation waters in areas convenient to people residing in the Nation's larger cities. Without appropriate action, this situation will become more acute in the future, in both the quantity of recreation water and the quality of the recreation experience as measured in opportunities to engage in pursuits under natural as well as manmade conditions. There is urgent need for a balanced water-oriented recreation development program which will preserve and make accessible resources for the enjoyment of opportunities of all types.

The impact of outdoor recreation on the economy of the Nation is significant. Leisure time, personal disposable income, travel, and the purchase of recreation equipment are increasing. The economic aspects of recreation as an industry should be fully considered in planning for the development of water and related land resources as a part of community and regional development.

Programs for multiple-purpose development of water and related land resources have done much to increase outdoor recreation opportunities in harmony with the objective of meeting other public needs for water. The location of such projects, however, has usually been determined by factors other than recreation. Multiple-purpose developments alone cannot be expected to provide all Americans with opportunities to enjoy the Nation's recreation waters.

The Council urges that the public interest in the quality of the environment be fully considered in planning water developments in order that the potential for natural as well as manmade water-oriented recreation opportunities be realized. Further, the Council recommends that consideration be given by non-Federal interests to water developments having recreation as the primary purpose in areas where recreation demand exceeds available facilities.

Fish and Wildlife

Fish and wildlife resources add quality and vitality to our environment, and their variety, abundance, and vigor are positive indicators of the health of that environment. Commercial fishing, sport fishing, hunting, and fur trapping are important sectors of our national economy.

Water and related land developments properly planned and operated have provided and can continue to provide widespread and important fish and wildlife benefits. By careful

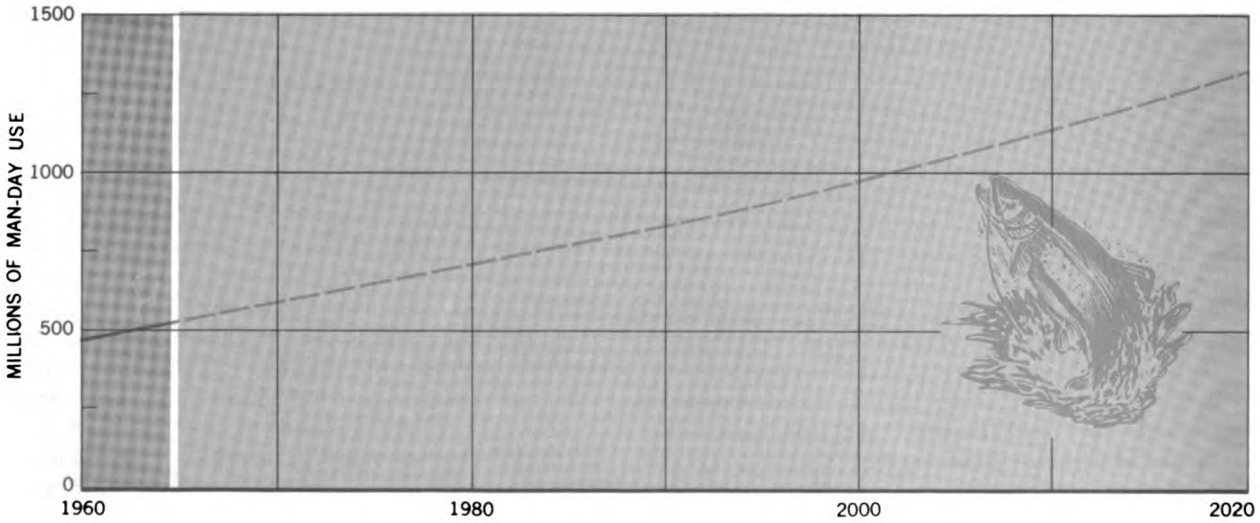

FIGURE 1–15.—*Projected fresh water sport fishing, 1960–2020.*

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planning, possible harmful effects of these developments can be ameliorated and often the habitat can be enhanced. If fish and wildlife are to maintain their important place in our life and economy, every opportunity must be taken to improve their habitat and minimize damage to their habitat in the development of water and related lands.

About 40% of our people engage in outdoor recreational activities involving fish and wildlife resources. A substantial proportion of this activity takes place on privately owned land. Millions of others in urban areas would participate if opportunities were available. User days of fresh-water sport fishing are expected to increase sharply as a greater proportion of an increasing population takes part in this sport (fig. 1–15).

Urban expansion on shores of streams, lakes, estuaries, and on related wetlands supplants important fish and wildlife habitats and sites for recreation. Dredging and filling for other land and water uses and improvements also can adversely affect these rich fish and wildlife resources in some instances. Our wetlands, acre for acre the most productive fish and wildlife habitat of the Nation, are disappearing at an alarming rate. Further loss of wetlands to agricultural, urban, industrial, and transportation uses is of major concern. Improvement of wetlands habitat will help offset these losses.

While there has been considerable progress in Federal-State legislation and programs to improve the fish and wildlife habitat, the Council recognizes that much remains to be done to make these policies effective.

The Council urges that water resources planning (1) consider more fully the potentials for increasing public enjoyment of fishing, hunting, and related recreation; and (2) give increased consideration to preservation and enhancement of estuaries, natural lakes, wetlands, and free-flowing streams.

MANAGEMENT OF WATER AND LAND

Management of water and related land encompasses the management of water supply, distribution, and use; water quality and health aspects; floods and flood plains; watersheds and watercourses; and beaches and shores. These factors are discussed separately; they are closely interrelated, however, and all must be considered in comprehensive water resources development and management programs.

Water Supplies

The management of water quantity includes the storage, conveyance, distribution, and use of water. In the United States, there are about 1,400 major reservoirs and many more minor reservoirs, thousands of miles of conveyance and distribution systems, and millions of wells to control and supply water for various uses. In addition to structural developments, water quantity management includes such things as new technology for augmenting water supply, water allocation procedures, methods for improving water use and reuse, and system operation for optimum beneficial control and use.

Management of water resources, sufficient to meet the needs of an expanding population and economy, will require management of the water that falls on the land in combination with more fully developed systems of storage reservoirs to provide control of periodic and seasonal fluctuations of streamflow. Multiple-purpose water development should embrace as many uses as possible in each project. The number of potential reservoir sites of the Nation is physically limited and these are being preempted in many cases by incompatible development. For some of the Nation's water resources regions, this is an especially serious matter. A program for reservation of storage sites on the public domain has been under way and is also possible on other Federal lands. Some State, local, and private efforts are being made to reserve sites. However, no national program or policy exists with respect to reservation of the many other favorable sites which are in private ownership. Foreseeable requirements for large amounts of reservoir storage emphasizes the need to preserve and/or reclaim these potentials.

The Council recommends a study to assess the magnitude of the problems and to ascertain if it is feasible to propose that the policy of reserving desirable reservoir sites on public domain lands be broadened through necessary Federal and State legislation to preserve favorable sites on other lands. Such study should consider (1) identification of potential sites that will be needed in the future for Federal or non-Federal development; (2) restriction of future incompatible development through purchase, acquisition of rights, easements, land use controls, or combinations of these means; and (3) reclamation through a long-term program of a limited number of key reservoir sites now presently encumbered or partially developed.

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As water requirements expand and supplies become scarce and more costly, alternatives such as desalting will become more attractive. Prospects for increasing efficiency of desalting technology and declining costs hold enough promise that this source of water supply should be given careful consideration in comprehensive planning for areas with a deficiency of fresh water. Research and development should continue to be given strong Federal support.

At this time, weather modification must be viewed as a potential means for augmenting runoff. Further research is needed on unresolved questions concerning methods and systematic procedures for insuring success.

The manipulation of forest and related vegetation in the high mountains will increase water yields in areas where the principal water supply is obtained from snowpack. In addition, conversion from undesirable brush species to grass and management of phreatophytic vegetation are significant measures to reduce nonbeneficial consumption.

Floods and Flood Damages

Flood management considers such measures as flood control structures and measures including reservoirs, channels, levees, and land treatment; identification and management of lands and facilities in the flood plain; flood insurance; flood-warning systems; and disaster operations.

While flood-plain lands make up only 5% of our land area, a large proportion of the Nation's population and tangible property is located in these areas. Based on the current status of flood control works in upstream and downstream areas and projected conditions of flood-plain use and development, the total annual flood damage potential for the Nation is anticipated to increase from $1.7 billion in 1966 to $5.0 billion in 2020 (fig. 1–16). Over $2 billion

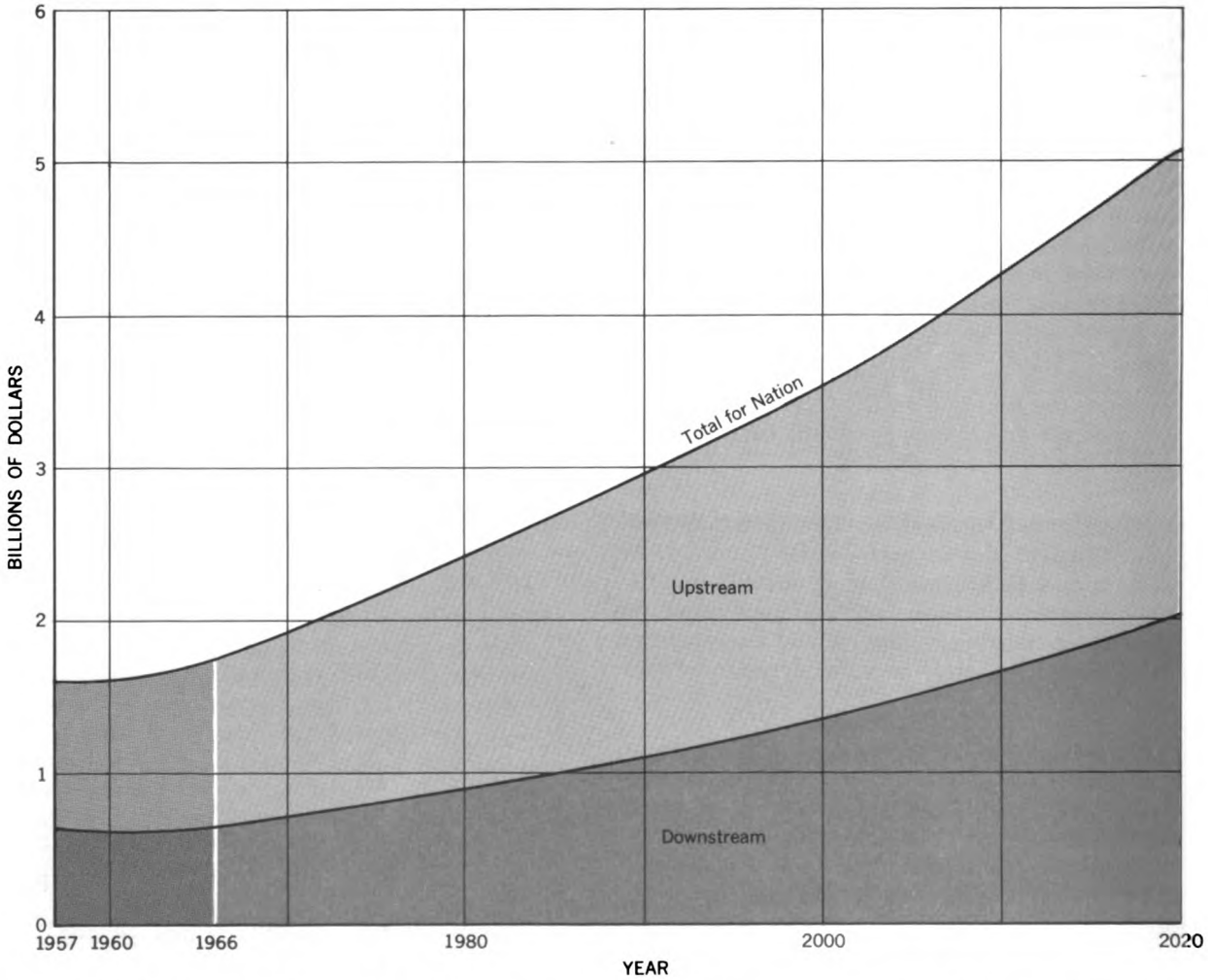

FIGURE 1–16.—*Projections of potential flood damages without flood plain management or new flood protection works, 1957–2020.*

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would occur in downstream areas and almost $3 billion in upstream areas. Construction programs for flood damage abatement, if continued at rates consistent with past trends, at best would only stem this upward trend in flood losses and hold the residual losses by 2020 to $2 billion annually. An estimate has not been made of the damage reduction that could be achieved by an accelerated program of flood-plain management.

The opportunities for further reduction of flood losses are obviously great and the responsibilities of State and Federal governments are well established. The President has sent to the Congress a Unified National Program for Managing Flood Losses which offers a broad, soundly conceived program to solve the flood problem, and by Executive Order directed all Federal agencies to take account of flood hazards in locating Federal installations and extending credit.

Concentrated efforts are being made and will be expanded to identify existing flood problems; to accelerate performance of flood-plain information studies to delineate flood hazard areas and provide technical data as a means of assisting local interests in regulating the use of flood-plain lands and developing suitable flood proofing measures; to develop more accurate estimates of the Nation's flood damages; and to develop practical plans for instituting a flood insurance program. Significant legal and organizational problems must also be resolved. Many Federal, State, local, and private interests are concerned. A unified flood-plain management program will require complex organizational arrangements as well as technical solutions.

The Council will direct its planning policies, standards, and procedures toward cooperative Federal, State, and local action for a unified program of flood-plain management, including flood control structures and measures, land use regulation, flood proofing, flood warning, and flood insurance.

Water Quality

Growing concern with the rapidly mounting pollution loads imposed on the Nation's streams, lakes, and coastal waters has stimulated a vast and vigorous national effort to control and abate water pollution to restore or enhance polluted waters and to preserve existing high water quality to meet the beneficial uses demanded of this natural resource.

Standards of water quality have been adopted by all States and Territories for all of the Nation's interstate and coastal waters and are now being reviewed by the Secretary of the Interior as to conformance with the provisions of the Federal Water Pollution Control Act. As of June 1, 1968, the Secretary approved, with some exceptions, the standards submitted by 32 States and 3 other jurisdictions, thus making them enforceable. The standards for the remaining States and jurisdictions are in various stages of preapproval review and processing.

In the process of setting water quality standards for interstate and coastal waters, many States further chose to adopt standards for their intrastate waters as well. Thus, it is safe to state that for the first time in history explicitly stated water quality criteria and goals are being made applicable, and enforceable at various governmental levels, to the vast majority of the Nation's waters—be these creeks, rivers, streams, lakes, Great Lakes, or estuarine and coastal waters.

Because water quality is the underpinning basic to the success of all beneficial uses made of the water resource, sound water quality management has become increasingly important. Such management must employ the wide range of tools available; these include collection and treatment of municipal and industrial waste to the degrees required, land treatment and other control measures for dispersed sources of natural pollution, instream aeration, temporary detention of effluents during critical low flow periods, and reservoir storage for flow regulation.

Nationwide, the control of pollution from municipal and industrial sources is the most formidable task to be undertaken in achieving the goals specified in the water quality standards program. The provision of facilities for municipal and industrial waste treatment and to cope with cooling water requirements is lagging behind present and anticipated needs.

Projected capital outlays for waste treatment, sanitary sewers, and water cooling requirements are estimated at $20 billion (1968 dollars) for the 5-year period 1969 to 1973. This investment would catch up on the backlog of needs so that the annual rate to keep up with population and industrial growth could be somewhat less after 1973.

Major sources of pollution are return flows from municipal, industrial, power, and agricultural withdrawals and runoff and sediment from lands used for urban, mining, agricultural, logging, and other purposes. Water quality problems are prevalent in every region of the country. The waste loads from municipal systems alone are expected to increase nearly four

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times over the next 50 years (fig. 1–17). Even if municipal and industrial waste loads are substantially reduced through treatment, pollution problems may continue to exist in densely populated and highly industrialized areas where assimilative capacity of receiving waters is exceeded.

Cooperative, Federal, State, and local government planning efforts are being developed to identify institutional and financial arrangements for immediate and long-range water quality management actions on basin- and regionwide bases as well as to find technical solutions to pollution problems.

In conjunction with the planning efforts and the development of water quality management programs, work is under way to develop complete and definitive information on waste loads discharged by municipalities, industries, agriculture, and other sources. Federal-State monitoring, surveillance, and data collection programs are being reevaluated to establish adequate and uniform measurements.

The Council urges continued vigorous pursuit of cooperative Federal, State, and local programs for achieving effective water quality management, including adequate pollution abatement investment, data collection, monitoring, surveillance, improved technology, and adoption of water quality standards. Priority should be given to identification of opportunities for streamlined water quality management through more efficient management arrangements for river basins. Better methods must be developed for identification and evaluation of benefits which will accrue from management and improvement of water quality, including their relation to the costs of these measures.

Public Health

Protection of the public health requires not only a recognition of diseases, such as encephalitis, hepatitis, and gastroenteritis, which arise in association with water and related land resources, but also consideration of the potentially insidious health effects of new substances in the water environment. Recent data indicate that individual case totals of diseases arising in association with water resources run into the thousands each year.

Public health problems are indicated with respect to provision of drinking water supplies, marine and other food production, and disease vectors. The National Drinking Water Standards cover only traditionally known contaminants and are based upon the use of relatively unpolluted water as the raw water source. Additional study and attention should be given to the health protection of drinking water supplies and to other health protection measures in the planning, design, construction, and operation of water resource development projects by Federal, State, and local governments.

The Council finds that there is a need for increased study, research, and investigation regarding the impact on human health of water resource development and use. The National Drinking Water Standards should be revised as necessary to make it possible to protect against any new hazard. Strengthened Federal, State, and local attention should also be given to implementing known public health protection measures with regard to water and related land uses.

Watershed Management

The protection and management of the Nation's watersheds to maintain and enhance the quantity and quality of water is an important and continuing task. Soil erosion with its resulting effects through sedimentation remains a challenging problem in agricultural and urban areas. In water-short areas water yield, both surface and subsurface, is a critical factor. In many regions the competition for land to serve a number of important functions will require sound planning and application of conservation measures and improved management systems designed to provide for multiple use of both private and public lands. Some of the more critical soil and water conservation problems exist in metropolitan areas and proper planning for resource management as a part of the comprehensive planning process is necessary.

Although substantial progress has been made in protecting and managing watershed areas, a wide range of treatment needs for both private and public lands exists. By 1980, approximately 60% of the cropland, 75% of pasture and range, and 50% of forest land, and nearly all of the 30 million acres of land which will change from agriculture, range, or forest use to urban and builtup areas will require conservation treatment. Watershed lands require carefully designed and widely applied management programs to meet the demands for high quality water, food and fiber, recreation, wildlife, a pleasant and attractive environment for rural and urban residents, and opportunity for economic growth. In view of the importance of watershed land to the water resource and the

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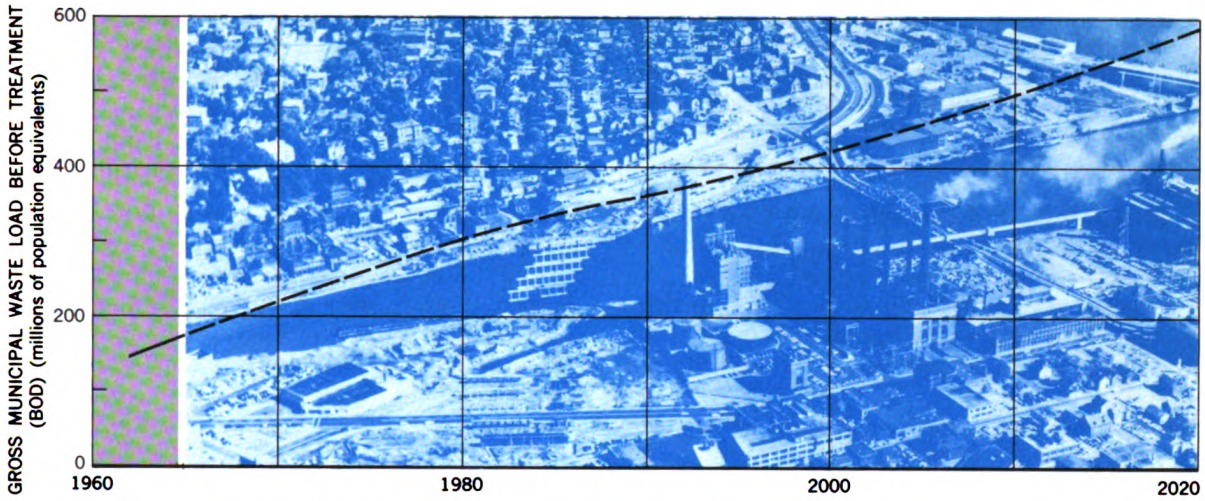

FIGURE 1–17.—*Projected municipal waste disposal requirements, 1960–2020.*

national economy, increased emphasis should be given to watershed protection and management projects.

The Council finds that increased emphasis is needed on adequate land treatment and management of agricultural and other water-related lands to protect streams and water supplies from siltation and other adverse quality changes and that increased attention should be given to planning for land changing from agriculture and forest to urban development to avoid erosion and sedimentation.

Beach, Shore, and Riverbank Protection

The tidal shorelines, 89,000 miles; the Great Lakes shorelines, 4,800 miles; the shorelines of fresh-water lakes over 10 square miles, 5,500 miles; and the shorelines of streams estimated at 3,000,000 miles constitute assets of great value to the Nation. At the water's edge the land resources are directly related to and dependent on the use of water resources.

Shorelines and riverbanks were used and enjoyed by the earliest inhabitants of this continent. After many years of efforts to prevent shore erosion and loss of coastal land, Congress established the Beach Erosion Board in 1930 (now the Coastal Engineering Research Center) to develop programs in cooperation with States to prevent erosion of shores of coastal and lake waters. Substantial progress has been made in selected areas.

Estimates of population growth indicate a faster rate of growth close to beach, estuary, and riverbanks because of a preference by people to live close to the water. This preference points up the need for an expanded program—Federal, State, and local—for shore and riverbank protection.

The Council recognizes that increased emphasis should be given to a comprehensive approach to shore and bank protection that seeks solutions to the total problem through proper management, including protective measures. A national program of appraisal and data collection is needed to provide up-to-date quantitative as well as qualitative information.

Land Drainage

Better land drainage for agricultural use and forest use in certain situations results in improved soil structure, better utilization of available moisture, accelerated and improved microbiological processes, less compaction of soil, improved soil salinity control, and deepened rootzone.

Where there is need for more agricultural production, land which is otherwise suitable for crop production may be drained and brought into production. Land drainage also facilitates construction and maintenance of roads, railroads, urban areas, airports, parks, and recreation areas. Reclamation of wetlands may be the most economic source of new lands for these developments.

There is often a conflict between such development and preservation of wetlands in their natural state for fish, wildlife, timber, and recreation. The remaining wetlands of the United States have withstood a century of national expansion and development since passage of the Swamp Land Acts. It has only recently been recognized that undisturbed marshes, swamps, and overflow lands have a significant relation to the environment. Some of these values can be measured in economic terms; others are intangible but of increasing importance to our modern society.

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Although there is a large potential of lands that could be and may need to be drained for agricultural or urban uses, the Council recognizes that these lands also must be carefully appraised for their values as natural wetlands to determine in each case their highest use.

The Nation's growing population will demand multipurpose water resources development which could require a high degree of structural control of river systems in many parts of the country. On the other hand, future generations should be assured of substantial

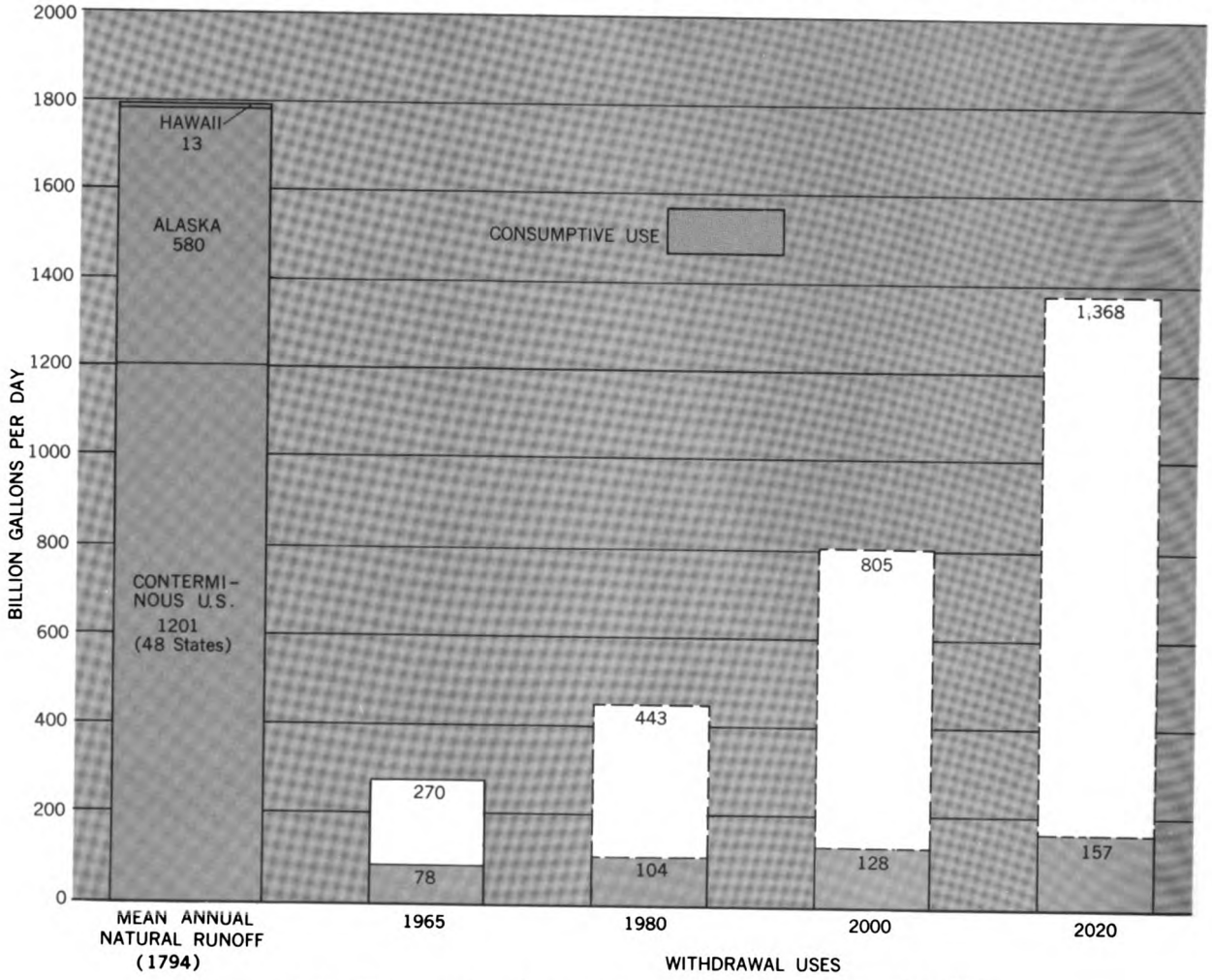

FIGURE 1–18.—*Water supply and projected water use, United States, 1965–2020.*

Preservation

Lands are related to water resources planning and development insofar as the use of these related lands affects water management. Because certain land uses affect locational aspects of water use, and may affect such other management considerations as water supply, water quality, floods, and watersheds, land-use management is closely related to water resources planning and development. Of particular concern is the enhancement, preservation, or reservation of lands for outdoor recreation, including boating, hunting, and fishing; for wilderness; for the quality of their scenery; and for protection of fish and wildlife.

areas of preserved scenic and wild rivers, wilderness, wetlands, natural estuaries, beaches and shores, and other areas of natural beauty. Often there is an interdependence between preservation and development. The benefits of development projects that change nature's patterns must be weighed against disruptions of the natural environment.

The Council recognizes the desirability of preservation of wilderness areas, scenic rivers, and other water-related beauty areas in the Nation's river basins. The Council supports studies, participated in by appropriate agencies, to identify potential areas for preservation for

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such purposes. These areas should be systematically analyzed to determine the public interest in their preservation or development.

ADEQUACY OF WATER RESOURCES

The "adequacy" of water resources should be measured by detailed comparisons of water supplies with current and projected demands at point of use. Involved would be the amounts of water available, the variations in available supply in both time and place, the costs of storage and other control works, the problems of projecting economic growth and related water requirements and pollution loads, the limits water may place on economic growth, the competition between water uses, and many other aspects. This First National Assessment has been able to only partially catalogue these measures of adequacy because of limited data and analytical procedures. It has been possible, however, to compare available statistics on water supplies with projections of water withdrawal requirements to indicate problems of water management and with projections of consumptive uses to indicate problems of water shortages. This has been done for broad regions which mask many variations within the region.

The Council has been assisted in this effort by field groups of Federal and State experts who prepared an analysis of the water problems in each region. The lack of detailed data is partially offset by the judgment of these field experts.

National View

The conterminous United States has a natural runoff averaging about 1,200 bgd. Withdrawals were estimated at 270 bgd in 1965 and about 1,368 bgd in 2020 (fig. 1–18). Consumptive use, on the other hand, was 78 bgd in 1965 and is estimated at 157 bgd in 2020. These estimates were based on greatly increased water use efficiencies. The large withdrawals estimated for 2020 in relation to runoff indicate that even with increased in-plant recycling a large increase in reuse of water would be required. There would be a need for increased investment in water development, water conditioning, waste treatment, and water management to meet the estimated requirements.

The national view, of course, covers up many regional and local problems. The following discussion attempts to assess the adequacy from a regional view.

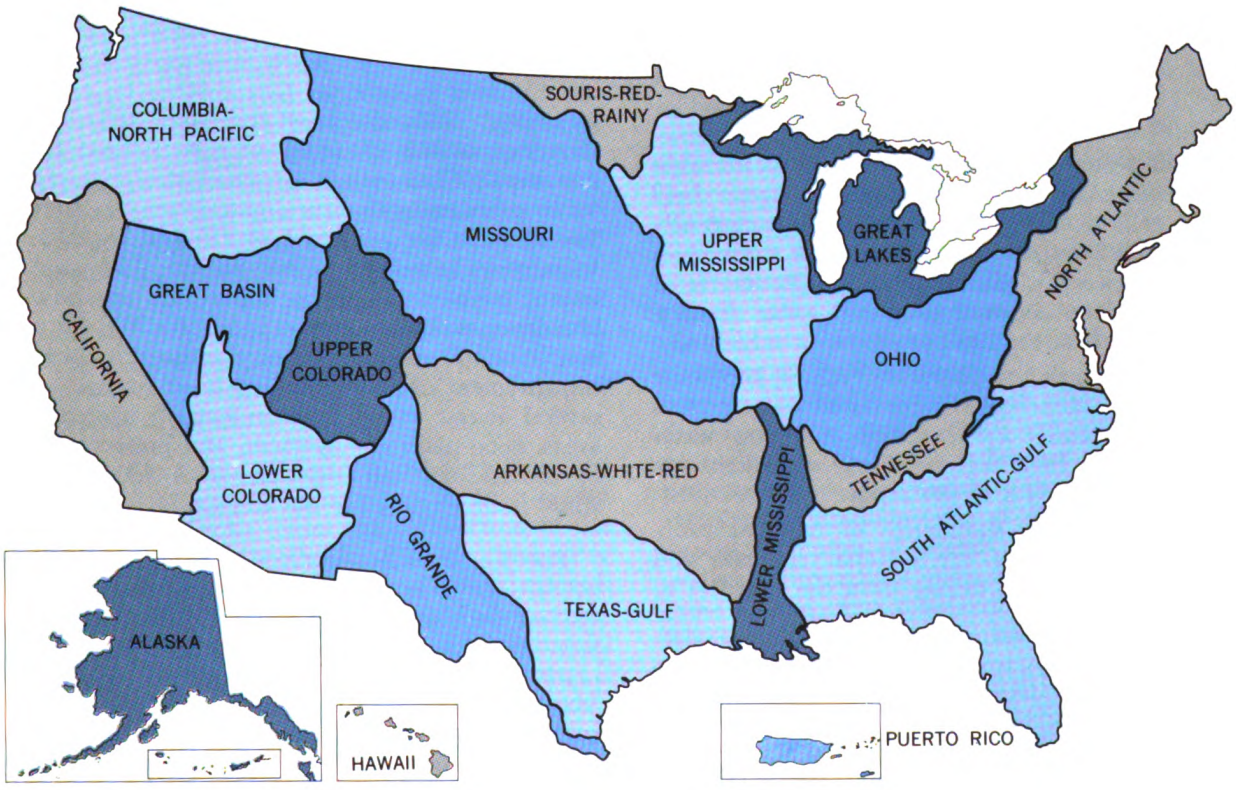

FIGURE 1–19.—*Water resources regions used in the first National Assessment.*

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TABLE 1–2.—*Estimated water use and projected requirements, by regions, United States*

(Million gallons daily)

Region	Used 1965	Projected requirements 1980	2000	2020	Used 1965	Projected requirements 1980	2000	2020
	Withdrawals				*Consumptive use*			
North Atlantic	37,467	54,920	113,860	236,290	2,023	2,870	4,960	8,490
South Atlantic-Gulf	20,560	53,180	87,440	130,190	2,695	3,395	5,655	8,265
Great Lakes	25,119	47,893	96,594	190,960	1,199	1,881	3,183	5,484
Ohio	28,255	41,749	65,109	90,163	1,134	1,619	2,539	3,623
Tennessee	5,767	12,252	13,877	18,106	331	572	834	1,132
Upper Mississippi	8,179	14,800	30,587	41,266	770	1,103	1,778	2,624
Lower Mississippi	5,571	12,816	27,967	39,442	1,470	3,012	4,453	6,251
Souris-Red-Rainy	391	936	2,002	2,758	77	215	494	544
Missouri	19,344	23,264	27,876	31,572	10,554	13,160	14,979	16,378
Arkansas-White-Red	9,410	17,279	25,336	31,589	5,874	8,482	10,587	12,329
Texas-Gulf	16,410	29,080	57,330	92,640	7,289	9,435	10,890	12,300
Rio Grande	7,289	8,330	9,510	11,680	4,403	4,676	4,991	5,466
Upper Colorado	4,017	5,675	6,575	6,725	1,982	2,700	3,100	3,140
Lower Colorado	6,913	8,497	8,428	8,889	3,448	4,075	4,645	5,310
Great Basin	5,115	7,055	7,550	7,800	2,253	3,299	3,562	3,776
Columbia-North Pacific	29,631	41,407	90,135	156,735	10,521	13,581	17,325	21,616
California	37,300	56,290	120,510	244,760	20,944	29,205	32,660	38,190
Alaska	162	535	901	4,206	12	50	96	184
Hawaii	1,597	2,658	4,698	8,587	533	728	1,000	1,368
Puerto Rico	1,120	4,010	8,325	13,730	270	360	475	615
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

A Regional View

The water resources regions used in the First National Assessment are shown in figure 1–19 and are essentially the same as those currently being used by the Water Resources Council in its framework planning program. Estimates of present water use and projected water requirements in these regions are shown in table 1–2.

Field groups composed of Federal and State experts in each region were asked to prepare a statement about current and emerging water problems in their region. These statements are included in part 6 of the report.

The following summaries of regional problems are based on the regional chapters and additional analyses drawn from the chapters in parts 4 and 5.

The *North Atlantic* Region contains the largest urbanized complex in the Nation—a complex that can be expected to continue to grow toward formation of a continuous urban area from north of Boston to south of Washington—with a regional population of over 100 million by 2020. Natural runoff averages 163 bgd. Large quantities of water will be needed for municipal, industrial, steam-electric power, waste dilution, agriculture, and recreation uses. Withdrawals are projected to 236 bgd by 2020, with over half from saline water. The most urgent problems requiring immediate attention are drought-proof water supplies for the large metropolitan areas and heavy industrial users, improvement of water quality, flood control on several major rivers and numerous upstream areas, flood-plain management, and preservation of coastal and estuarine areas. A framework study is under way for the Region.

The *South Atlantic-Gulf* Region encompasses 24 distinct river systems and numerous minor systems with an average natural runoff of 197 bgd. Anticipated regional growth is expected to place increasing demands on the management of the Region's water and related land resources. Water withdrawals are expected to increase from 21 bgd in 1965 to 130 bgd in 2020. Recreation needs will double, and there is need for comprehensive flood-plain management. Other

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problems are increasing pollution loadings and the need for protection of beaches, estuaries, and wetlands.

The *Great Lakes* Region has a natural runoff of 63 bgd. In addition, the natural runoff from Canada is about 64 bgd and the Lakes themselves produce about 26 bgd in net precipitation. The northern portion of the Region should continue to have abundant supplies of good quality water through 2020. In the southern portion of the Region, however, withdrawals are currently in excess of the interior basin water supplies and part of the requirements are supplied from the Great Lakes. This use of Great Lakes water will increase as regional water withdrawals are estimated to increase to 191 bgd by 2020, more than 3 times the regional runoff. In addition to problems of the interior basins, the expansion in water use will pose serious water quality and lake level problems on the Great Lakes system. A regional framework study has been started.

The *Ohio* Region has an average natural runoff of 125 bgd, but variations of availability and need occur each year. Many smaller tributaries go dry in summer, and flow deficiencies in lower reaches restrict water uses. At other times, excess flows cause extensive flood damages. Groundwater aquifers can supply water of satisfactory quality in many areas, particularly for smaller communities and light industry. Withdrawals are estimated to increase from 28 bgd in 1965 to 90 bgd in 2020. The framework study of the Region has identified extensive investments that will be needed by 2020 for control of high and low flows, outdoor recreation and fish and wildlife facilities, agricultural land treatment, irrigation and drainage, and navigation. Also urgently needed are major investments in municipal and industrial water systems, waste collection and treatment facilities, and corrective measures applicable to dispersed sources of pollution.

The *Tennessee* Region has an average natural runoff of 42 bgd which is controlled by a system of large reservoirs under the jurisdiction of the Tennessee Valley Authority (TVA). The water is used to generate hydroelectric power through as many as 14 reservoirs in series, and to maintain navigable depths for a 750-mile commercial waterway. The regionwide supply of water is adequate for all anticipated needs, but additional seasonal regulation will be necessary in local areas. Water withdrawals are expected to increase to 18 bgd by 2020. Pollution must be curtailed, and orderly development of residential, recreational, and industrial lands along the waterfronts must be effectuated. Upstream watershed treatment and development is needed. One of the questions facing the Tennessee Region is whether present and potential water use requirements and conflicts necessitate changes in water rights and in the organizations for administering such laws and dealing with water problems generally.

The *Upper Mississippi* Region has an average natural runoff of 65 bgd. Water supplies are expected to be adequate to 1980. Beyond that date, water supplies for some areas will become scarce and transfers between basins within the Region may become necessary. Water withdrawals in 2020 are expected to increase fivefold to 41 bgd. Groundwater supplies are plentiful and relatively untapped. Maintenance of adequate water quality is a major problem of the Region. Flood control in both upstream and downstream areas is a major concern for the Upper Mississippi Region. The floods of 1965 and 1967 caused millions of dollars of damage. Conflicts between drainage of the land for more intensive use and needs for fish and wildlife propagation will increase. A framework study is nearing completion for the Region.

The *Lower Mississippi* Region occupies a strategic area in the development of the Nation's economy. Industry and commerce are expected to become increasingly attracted to the area because of the enormous capacity of the Mississippi River to satisfy water supply, navigation, and waste disposal requirements. Municipal growth and the development of a highly complex and intensive agricultural industry will also contribute to the Region's economic growth. One of the greatest natural assets of the Region is the rich, fertile soils of the valley alluvium of the Mississippi River. The Region may be considered "water rich" but even with this favorable supply there are problems of management to assure efficiency in meeting projected needs. Groundwater in the Mississippi alluvium is abundant and at relatively shallow depths. Supplies of deeper artesian water are available throughout most of the Region. Because of the large discharge of the Mississippi River, this Region has the lowest ratio of withdrawals to supply, except for Alaska. Measures to reduce floods, improve drainage, and improve water quality are needed.

The Souris-Red-Rainy Region has a natural runoff averaging about 6 bgd. Water with-

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drawals are expected to increase over sixfold to 2.8 bgd by 2020. There will be large increases for irrigation, but much of this will be supplied from the Missouri Region through the authorized Garrison diversion project. Measures needed for flood protection, drainage, irrigation, and soil conservation must be balanced against the preservation of wetlands and wildlife resources and development of recreation. Floods are a major problem. The problems of stream and lake pollution are expected to increase. A regional framework study is under way.

The *Missouri* Region has a natural runoff of 54 bgd. Some portions of the area have great excess of water while other areas are nearly arid, and droughts and floods are the most serious water problem. Water withdrawals are estimated to increase from 19 bgd in 1965 to 32 bgd in 2020. Consumptive use is expected to be about one-half of withdrawals. Increasing demands on available water and land resources will create problems in resource development, management, and control, and will lead to increased competition among uses for available supplies. To meet foreseeable requirements and to improve present conditions, water resources development will need to be continued at an increasing rate. Shortages of water are being experienced in some areas of the Region now; and should further shortages be allowed to develop, local economic development and growth will be limited. A framework study is under way for the Region.

The Arkansas-White-Red Region has an average runoff of 96 bgd. Withdrawals are expected to reach 32 bgd by 2020, with consumptive use at 12 bgd. Water shortage problems occur in the western part and portions of the central part, which, if uncorrected, can be expected to restrict future economic development. In much of the central portion, poor quality due to salinity is a limiting factor. Excess water is a major problem in the east, and flood problems and bank erosion exist throughout the Region. In general, there are two major water problems: (1) water is not available in sufficient quantities in the particular area in which it is needed; and (2) considerable water is unfit for agricultural, municipal, industrial, and other uses because of salinity and municipal and industrial pollution.

The *Texas-Gulf* Region has a natural runoff of 39 bgd. Withdrawals in 1965 were 16 bgd, with almost one-half from groundwater. In major use areas, the groundwater storage is being depleted with rapid increase of pumpage for irrigation and other uses. The situation is already critical in parts of the High Plains, north-central Texas, the Winter Garden, and in some coastal areas of Texas and Louisiana. Accompanying salt-water intrusion and land subsidence are also significant in some coastal areas. The future economy in most of the Region will remain agriculturally based. Much urban and industrial growth depends on it. There are serious problems of providing water for industrial, agricultural, and population growth along the coast and in many other areas. Withdrawals are expected to reach 93 bgd by 2020. Expanded reservoir storage in eastern areas and water transmission facilities are being considered to meet anticipated requirements of water-short areas to the west. Large deficits in supplies for future water needs in western portions of the Region will exist even with optimal development within the Region. Proposals are being made to investigate sources of supply outside the Region and the feasibility of large imports to these western areas is being actively considered. Substantial needs remain for flood control, watershed protection, drainage improvement, navigation, and water pollution control. The commercial and sports fishery, recreational, ecological, and other values of important coastal waters will be included in regional water development.

The *Rio Grande* Region has an average natural runoff of 5 bgd. The Region has many water problems, including (1) water deficiencies and groundwater storage depletion, (2) poor quality because of mineral pollution, (3) heavy sediment loads in many tributaries, (4) excessive nonbeneficial consumptive use of water, and (5) frequent floods causing extensive damage. While progress has been made toward solving these problems, they cannot be solved entirely by localized action. Solution requires planning and action by local groups, States, and the Federal Government with international cooperation. Plans for augmenting water supplies by importation, desalination of brackish supplies, watershed management, phreatophyte control, or other means are essential for full development of urban, industrial, and irrigation potentials. Unless the Region's water problems are solved, the projected rates and patterns of economic growth cannot be maintained.

The *Upper Colorado* Region is one of extreme contrasts, varying from high, snow-covered

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mountains and plateaus of the north to dry deserts on the south. The Region's average natural runoff of about 14 bgd serves water users in six other Regions and Mexico. Two percent of the Region's land is used for irrigated cropland. These agricultural areas contain most of the 350,000 inhabitants. Mining and agriculture, particularly livestock raising, are the principal industries of the Region. Oil refining, lumbering, transportation, trade, tourism, recreation, and construction are growing in importance. The entire economy of the Region is dependent upon a limited water resource. Since there is a tremendous variation in the annual flow of the river, the Region depends on streamflow regulation for a firm water supply. The partially constructed Colorado River Storage Project will provide regulation to overcome annual variations but cannot overcome longer run droughts. There are local agricultural areas in need of supplemental water. Production of more forage crops would make possible better use of range lands. Parts of the population exist in a chronically depressed economic condition. With additional water supply, opportunities exist for increasing the land under irrigation, increasing mining exploration and development of oil shale and other mineral resources, expanding the utilization and processing of forest products, and expanding recreation developments. A regional framework study is under way.

The *Lower Colorado* Region has one of the highest population growth rates in the Nation. The economy is based on manufacturing, tourism, irrigated farming, and livestock. The average natural runoff originating in the Region is about 3 bgd. The dependable water supply for the Lower Colorado Region, including flows from the Upper Colorado Region, is inadequate to meet the needs of the existing economy. Virtually all dependable and readily available surface-water resources are fully utilized and groundwater resources are being depleted. The Colorado River provides water for nearby irrigation, municipal, and industrial uses. In addition, the river serves a portion of California and provides water for delivery to Mexico under the Treaty of 1944. At present, almost 3 bgd are being mined from underground basins. Projected economic growth indicates that the water-supply deficiency of the Lower Colorado Region will increase in the future. Facilities to fully utilize the Arizona and Nevada apportionment of Colorado River water would help to reduce the regional deficiency. There are limited possibilities for increasing usable water supplies within the Region, such as increased efficiency of use and reuse, sewage reclamation, watershed management, including phreatophyte control, evaporation suppression, and weather modification. Consideration should also be given to desalting of sea water or importing of fresh-water supplies. A framework study is under way in the Region.

The *Great Basin* Region has an average annual runoff of about 6 bgd. The Region has natural or imported water supplies adequate to support a thriving economy only on the eastern and western borders of the Region and in the Humboldt River basin. The mountains adjacent to these areas produce an estimated 80% of the Region's total runoff. With proper development and management of the water available to the Region, including increased efficiency in use, authorized imports, and anticipated authorizations for already-identified developments, it is estimated that sufficient water will be available to meet demands in the more rapidly growing areas until about 2000. There will be, however, areas where significant water shortages will occur before this date. After 2000, additional water imports will be needed to sustain the projected economic growth of the Region. A framework study has been initiated for the Region.

The *Columbia-North Pacific* Region is a diverse Region, with elevations ranging from sea level to over 14,000 feet, and rainfall ranging from less than 8 inches to over 200 inches. Summers throughout the Region are dry. The average natural runoff originating in the Region is 210 bgd. An additional 48 bgd originates in Canada. With few exceptions, the quality of the water is good. The present water supply is generally adequate; but there are localized seasonal shortages for virtually all uses. Total consumptive use is projected to increase to 22 bgd by 2020. Withdrawals will increase to 157 bgd. One of the largest uses will be for irrigation. Another large use will be for steam-electric powerplants under projected technology. It is expected that by 1975 over 1 million kilowatts of steam-electric capacity will have to be installed annually, and by 2020 withdrawals for cooling water are expected to be 45 bgd from fresh water and 53 bgd from saline sources. Instream demands for fish and wildlife, recreation, navigation, and quality control are expected to increase with increases in population and industrialization. Although water supplies are gen-

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erally adequate to meet projected consumptive uses for 2020 over much of the Region, serious shortages will occur in some of the interior basins of eastern Washington and Oregon and southern Idaho. A regional framework study is under way.

The *California* Region is expected to continue its recent rapid growth rate. Projections indicate that by 2020, population will increase more than three times to about 64 million persons. Average natural runoff in the Region is 65 bgd and imports from the Colorado River amount to over 4 bgd. Economic development by 2020 will require water supplies for withdrawal uses totaling about 245 bgd of which some 38 bgd will be consumed. Of this amount, steam-electric power uses are expected to require withdrawals of 195 bgd of saline water. There are sufficient natural water supplies within the Region to meet these water requirements, but additional surplus supplies in the northern portion would have to be transported to the water-deficient southern portion. Water from other sources such as desalination and wastewater reclamation may prove to be economically favorable alternatives. Provision of the needed water supplies, together with necessary flood protection, water quality control, drainage, water-related recreation, fish and wildlife protection and enhancement, watershed management, protection against health hazards, and other related services, will provide many of the physical elements necessary for sound economic growth. A framework study is under way for the Region.

The *Alaska* Region's water resources are extensive and impressive. The average natural runoff is estimated to be 580 bgd and an additional 130 bgd enters the Region from Canada. There are also extensive supplies of groundwater. Though the water supplies are generally well distributed throughout the Region and adequate to meet any foreseeable need, they are seasonally deficient in local areas. Projections of population growth and economic development in the Region indicate water demands will increase rapidly, particularly for municipal and industrial uses. Near-future economic growth involves industries which extract and process mineral, forest, and fishery resources and which are large water users. In general, the available supplies greatly exceed the projected demands, and the Region will have a water surplus for many years except in local areas of intensive development. In their natural state, water and related land resources have outstanding values and form an important part of the Region's scenic attraction and recreation potential. They support large populations of migratory waterfowl and other game species and prime commercial and sport fisheries. Water resource development plans must give full consideration to preservation and enhancement of these natural values, which may constitute optimum use in many cases.

The *Hawaii* Region is unique in its history, geography, demography, geology, and climate. This uniqueness has shaped the Region's development and will continue to do so. Gross water resources appear to be ample for all present and future needs, assuming adequate research and planning and proper management and conservation. Major population growth is expected to be concentrated on Oahu, principally in the dry leeward areas contiguous to the present urban and suburban developments. In order to provide for future water requirements, it is essential to prevent overdraft and quality deterioration of Oahu's basal aquifer, to minimize leakage, and to assure adequate recharge. Other major emerging problems relate to the development of adequate water supplies for expansion of existing resort areas and the establishment of new resort areas outside of high-density Waikiki, and to the development of irrigation water supplies for new croplands required to maintain present and anticipated production levels, considering some displacement by urban and resort developments. Watershed protection and management, flood prevention, and flood control measures, important generally, are particularly significant in resort areas located near streambeds and natural drainage channels. Pollution control of coastal waters also is important to Hawaii's visitor industry.

The *Puerto Rico* Region has adequate water resources for all anticipated uses to 2020. The natural water supply, however, is poorly distributed in time and location, and many areas of the Region suffer frequently from lack of adequate supply for domestic and irrigation uses. Additional water development projects are required immediately to alleviate this problem. The anticipated population and economic growth will place heavy burdens on the development of water resources. Watershed protection and management is badly needed in steep intensively used areas. The development of additional water supplies as well as management of its quality will have to be planned carefully to assure its availability for future uses.

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Summary

To summarize existing and emerging water management problems, the 20 regions have been given a rating as to the relative severity of 10 problems (fig. 1–20). While this is a subjective judgment, it does indicate the pattern of problems in different regions. The 10 problems used in figure 1–20 are as follows:

Adequacy of average natural runoff—A comparison of projected consumptive use with natural runoff, which includes perennial yields of groundwater aquifers.

Groundwater storage depletion—An indication of the extent that use of groundwater would exceed recharge.

Water quality:

Wastes—An indication of pollution loading and of investment required for alleviation.

Heat—An indication of waste heat discharges from industrial and steam-electric cooling requirements and of investment required for alleviation.

Salinity—An indication of the relative severity of the salinity problem from both natural sources and man-caused sources.

Sediment—An indication of the relative severity of sediment from land and streambank erosion both natural and man-caused.

Flood damages—An indication of extent and severity of flood damages as related to income.

Watershed lands—An indication of the need for watershed treatment.

Beach, shore, and riverbank erosion—An indication of the extent and severity of the problem.

Wetlands—The extent of potholes, fresh and salt water marshes, and estuaries and the severity of the problem of development versus preservation.

Water-Short Regions

The estimated average annual fresh water supply available in each region is compared with current and projected annual withdrawal and consumptive uses in figure 1–21. The esti-

	Adequacy of annual natural runoff	Ground-water storage depletion	WATER QUALITY				Flood damages	Watershed lands	Beach, shore, and riverbank erosion	Wetlands
			Wastes	Heat	Salinity	Sediment				
North Atlantic	▲	▲	▲	▲	●	▲	▲	▲	●	●
South Atlantic-Gulf	●	▲	●	▲	●	●	●	●	▲	▲
Great Lakes	▲	●	▲	▲	●	▲	●	●	▲	▲
Ohio	▲	●	●	●	●	▲	●	▲	●	●
Tennessee	●	●	▲	▲	●	▲	▲	▲	●	●
Upper Mississippi	▲	●	●	●	●	▲	●	▲	●	●
Lower Mississippi	●	●	▲	●	●	▲	●	●	●	●
Souris-Red-Rainy	●	●	▲	●	▲	●	●	●	▲	●
Missouri	●	●	▲	▲	▲	●	▲	●	●	●
Arkansas-White-Red	●	▲	▲	●	▲	●	●	●	▲	●
Texas-Gulf	●	▲	●	▲	●	●	▲	●	●	●
Rio Grande	▲	▲	●	●	▲	▲	▲	●	▲	●
Upper Colorado	▲	●	▲	●	▲	●	●	▲	●	●
Lower Colorado	▲	▲	●	●	▲	▲	▲	●	▲	●
Great Basin	▲	▲	●	●	▲	▲	●	▲	●	▲
Columbia-North Pacific	▲	▲	▲	●	●	●	●	▲	▲	●
California	●	●	●	▲	●	▲	●	●	●	▲
Alaska	●	●	▲	●	●	●	▲	●	●	▲
Hawaii	●	▲	▲	●	●	●	●	▲	●	●
Puerto Rico	●	●	▲	●	●	●	●	●	▲	●

●—Minor problem in some areas.

▲—Moderate problem in some areas or minor problem in many areas.

●—Major problem in some areas or moderate problem in many areas.

▲—Severe problem in some areas or major problem in many areas.

FIGURE 1–20.—*Summary of existing and emerging regional water management problems.*

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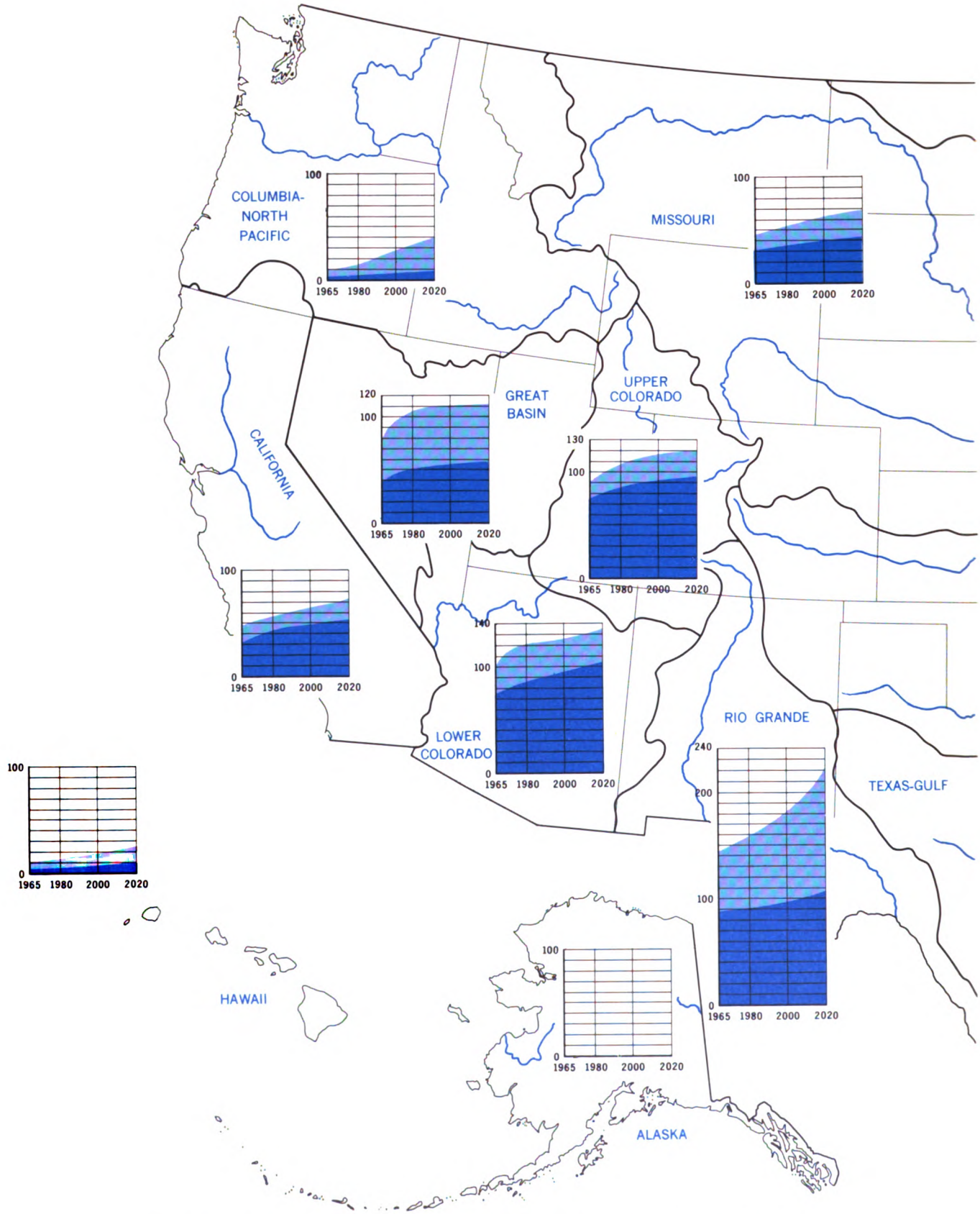

FIGURE 1–21.—*Regional indices of projected water withdrawals and consumptive uses, 1965–2020 (estimated average supply equals 100).*

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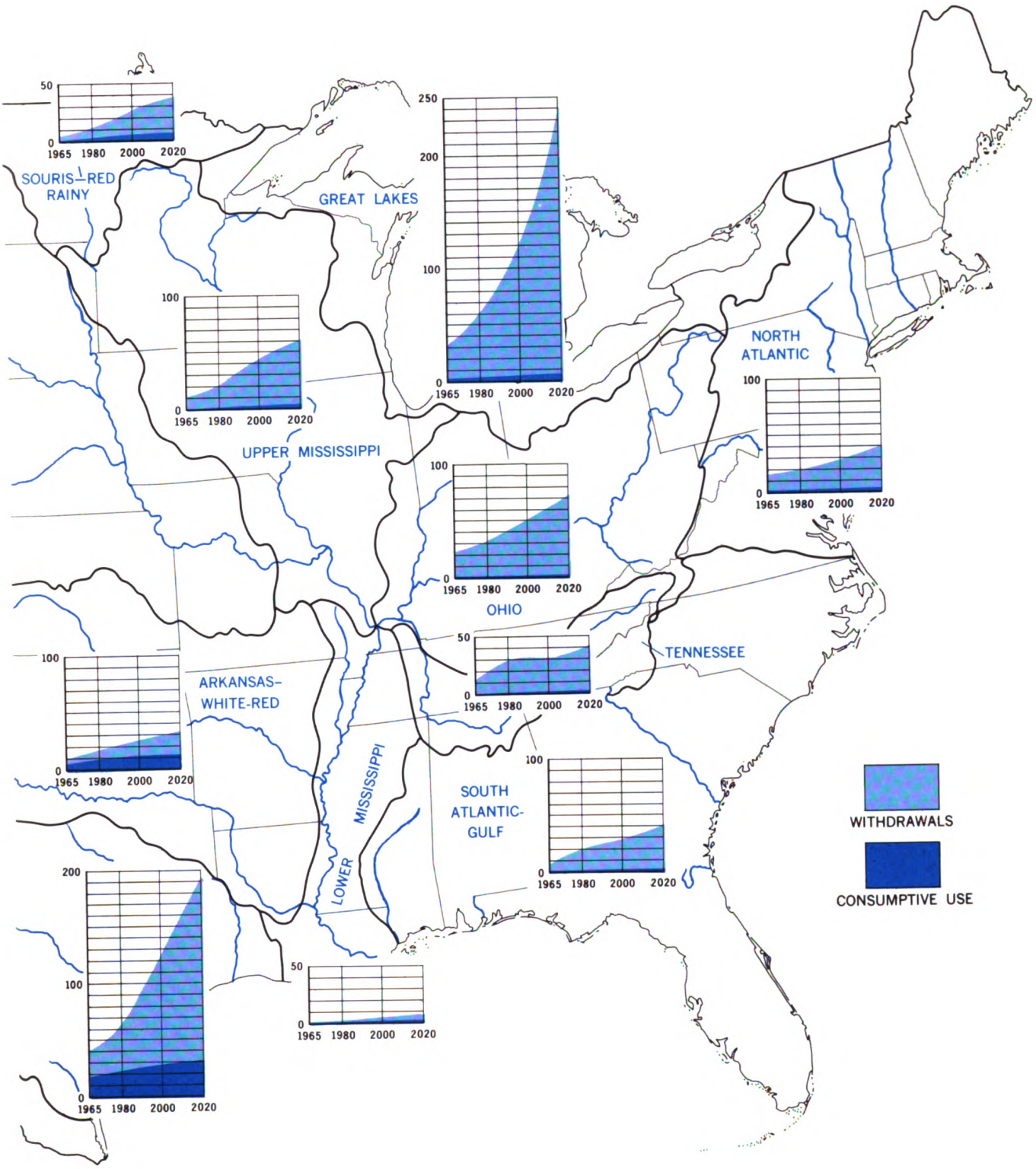

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mated water availability in each region was derived by adding imports and net flow from upstream to natural runoff. Exports and downstream requirements were added to regional requirements as appropriate. Uses of saline water for steam-electric power which are particularly important in coastal regions were excluded.

In interpreting figure 1–21, attention must be given to the following points: (1) the water use figures include use of mined groundwater, which is particularly prevalent in southwestern regions and cannot continue indefinitely; (2) the water use requirements include some saline withdrawals by self-supplied industries; (3) the water use figures do not include phreatophyte and other channel losses which are particularly important in the arid regions; (4) the water use data do not include requirements for instream uses; and (5) the data do not reflect seasonal variations or within-region locational aspects of supply-use comparisons.

When the regional withdrawal index is 100 the region is withdrawing an amount of water equal to the estimated supply (fig. 1–21). Since these withdrawals are not located at one point in the region some parts will be reusing return flows of upstream withdrawals. The withdrawal index gives an indication of water management and pollution control problems, but not necessarily, of water shortage.

The regional consumptive use index on the other hand does give an indication of water shortage. When the existing or projected index is 50 the region would be consuming 50% of the available supply. The consumptive use index understates the watershortage problem because account has not been taken of seasonal shortages. Also, the regional indices are based on averages for large regions and cover up the seriousness of water-shortage problems in local areas.

There are many local areas in all parts of the country where shortage of water restrains economic activity, but these areas cannot be identified with the general approaches used in this analysis. Even with this limited analysis, however, the Council has identified several regions in which existing water resources are now inadequate or over the next 50 years will not sustain the patterns and rates of growth experienced in recent years and projected over the next 50. The effect of water shortages, unless counter measures are taken, will be an adjustment in the pattern of economic activities. In some cases it may mean a slowdown in the rate of increase in total economic activity in the region.

In view of the present and projected inadequacy over the next 50 years of the water supplies available to meet requirements in several regions, the Council finds that alternative means of alleviating such water shortages and the national interest therein should be identified and considered. Any study of such alternative means should include consideration of transfer of water between basins, interstate and international terms and conditions of such possible transfers, protection of areas of origin, economic alternatives available to the areas of need, and the national interest in both areas of origin and need.

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PART 2

Introduction

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Introduction

AUTHORIZATION

The Water Resources Planning Act of 1965 (PL 89–80) established the Water Resources Council. The purpose of the Council is to effectuate the policy of the United States set forth in the Water Resources Planning Act to encourage the conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis by the Federal Government, States, localities, and private enterprise with the cooperation of all affected Federal agencies, States, local government, individuals, corporations, business enterprises, and others concerned.

Section 102 of the Act, provides that the Council shall:

> (a) maintain a continuing study and prepare an assessment biennially, or at such less frequent intervals as the Council may determine, of the adequacy of supplies of water necessary to meet the water requirements in each water resource region in the United States and the national interest therein; and
>
> (b) maintain a continuing study of the relation of regional or river basin plans and programs to the requirements of larger regions of the Nation and of the adequacy of administrative and statutory means for the coordination of the water and related land resources policies and programs of the several Federal agencies; it shall appraise the adequacy of existing and proposed policies and programs to meet such requirements; and it shall make recommendations to the President with respect to Federal policies and programs.

This provision of the Water Resources Planning Act grew out of a recommendation of the Senate Select Committee on National Water Resources. The Committee in its 1961 report recommended that the Federal Government should prepare biennially an assessment of the water supply-demand outlook for each of the water resource regions of the United States, as a means of informing the Congress and the public of current and prospective public action needed to meet future demands.

PURPOSE

The purpose of a periodic assessment of the water supply-demand outlook of each of the water resources regions of the United States is to keep the Executive Branch, the Congress, and the public informed of current and projected regional and national water and related land resources needs and of current and prospective public action necessary to meet those needs.

Under section 102 (a), the National Assessment will provide a means of summarizing information arising from project operation and regulation in relation to national and regional planning projections. It will utilize much of the data made available by the comprehensive planning studies, and, in turn, provide those studies with up-to-date national, regional, and basin projections of demographic, economic, and land use activity. Moreover, it is expected that the Assessment will be able to keep significant portions of completed regional framework studies valid by means of continuous updating. In addition, the Assessment will be one of several means available to the Council to make and report the studies and recommendations provided for in section 102 (b).

The National Assessment will also complement the Planning-Programing-Budgeting System (PPBS) currently being implemented within the Federal Government. Whereas the PPBS operates within a limited time horizon of 5 to 10 years to allocate the efforts of the Federal Government, the National Assessment will survey a time horizon of about 50 years in order to better illuminate emerging problems in water resources development. Rather than becoming involved in the annual decision process with regard to authorizations or appropriations for specific projects, the Assessment will provide information for those who are concerned with the broader long-range implications of national policy, planning, and research for water and related land resources.

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PREVIOUS ASSESSMENTS

Commissions have been formed to study water resource development in the United States since early beginnings of the Nation. During the past 60 years, over 20 commissions or committees have looked into national water policies and problems. With possibly two exceptions, these study groups did not cover all the various regions of the Nation, provide comprehensive treatment of all the various water utilization or management functions, and provide projections of future availability and requirements for water.

Probably the first truly comprehensive and national effort to assess the Nation's water resources was performed by the Water Resources Committee of the Natural Resources Committee between 1935 and 1937. The Natural Resources Committee was organized by President Roosevelt in 1935 to develop long-range plans and policies for construction of public works; and it, in turn, instructed the Water Resources Committee to undertake a national study by drainage basins and to outline in broad terms development and control measures to solve the indicated problems.

The studies of the Senate Select Committee on National Water Resources between 1959 and 1961 were a comprehensive national assessment of the Nation's water resources. This Committee was established by the Senate in 1959 under the chairmanship of Senator Kerr of Oklahoma, and was directed to study the extent to which water resources activities in the United States are related to the national interest and the extent and character of governmental and nongovernmental water resources activities required for all purposes between then and 1980. Its far-reaching studies and recommendations have led to significant national legislation in the field of water resources.

PHASED APPROACH

In January 1967, the Council approved the "General Plan for the National Assessment of Water and Related Land Resources," the "Work Plan for the First National Assessment," and the "Proposed Program for the Continuing National Assessment."

The plan provided that in order to support the functions of the Council, the Assessment, for a given basin, must:

1. Identify present and future water supply and requirement problems as they occur or are projected;
2. Identify water quality problems and relate present or projected water quality to established standards;
3. Identify flood problems;
4. Identify drought problems;
5. Test the probable consequences of alternative water policies;
6. Identify institutional and organizational problems in the development and management of water and related land resources;
7. Provide an inventory of water and related land resource plans, projects, and investment schedules; and
8. Provide for periodic reporting of current and projected use of resources and economic activity in each river basin.

Because of time and data limitations, the program for achieving these objectives has three phases. Each phase meets the above objective and the level of detail, and thus the quality of the study, will improve as time and data allow. The three phases are defined as follows:

Phase I—Initial assessments of the adequacy of the national water supply based on readily available data and limited analyses.

Phase II—More fundamental analytical frameworks for the assessment and more detailed measures of adequacy requiring substantial data inputs.

Phase III—Continuing refinement of phase II exploring the relationships of the water supply-use comparisons and the measures of adequacy to economic factors, differences in productivity, institutional constraints, and other factors.

APPROACH TO THE FIRST ASSESSMENT

The First National Assessment utilizes available information to establish water supply and use in base year 1965, and it projects general trends in major regions. The "adequacy" of water supply involves the amounts of water available, the variations in available supply in both time and place, the problems of projecting economic growth and related water requirements and pollution loads, the limits water may place on economic growth, the competition between water uses, and many other aspects. The First Assessment includes only limited measures of adequacy due to data constraints. However, it is possible to approach the problem quantitatively by comparing available statistics on water supplies with available statistics on current and projected water requirements. Another

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approach is to use the accumulated experience and judgments of field personnel as to the most critical water problems. In this first Assessment, the Council uses both approaches.

The estimated annual quantity of water in major water resources regions and subregions available a certain percentage of the time is compared with estimated present annual water requirements for various uses. Available supply is also compared with water requirements for projected conditions by major regions. This approach has some shortcomings. Water supply problems are often local, sometimes regional, but seldom national in scope. They are often short-run but can become of much longer duration. Many problems may be overlooked when a particular level of geographic detail and time duration is chosen. It is felt, however, that this is a useful study in spite of these limitations.

The level of geographic breakdown adopted for this Assessment consists of the 20 water resources regions presently in use in comprehensive river basin planning (fig. 2–1) and 110 subregions. Annual water supplies available 50, 90, and 95 years out of 100 for natural runoff conditions have been estimated for each region and subregion. The average annual flow is used as an indicator of the maximum theoretical supply with development. The 95 percentile flow is used as an indicator of the low flow. Water supplies, in addition, include such things as estimates of annual recharge of aquifers, basin imports, and desalting facilities. Water uses include the quantities of water withdrawn and consumed in 1965 in each region and subregion. For the most part, instream uses have been discussed only qualitatively.

Economic projections have been made for the 20 water resources regions. These projected levels of economic activity are used as indicators to point out which regions are likely to have long-run water problems. Most of the water supply problems that can be identified on this level of geographic and temporal breakdown are long-run problems. Thus, comparisons between the projected quantities of water required by major regions in 1980, 2000, and 2020, with average annual natural runoff, point up emerging long-run problems. Supporting these analyses are chapters concerning the availability of water and the various uses of water from a national viewpoint. These chapters have been prepared by the principally concerned Federal agencies.

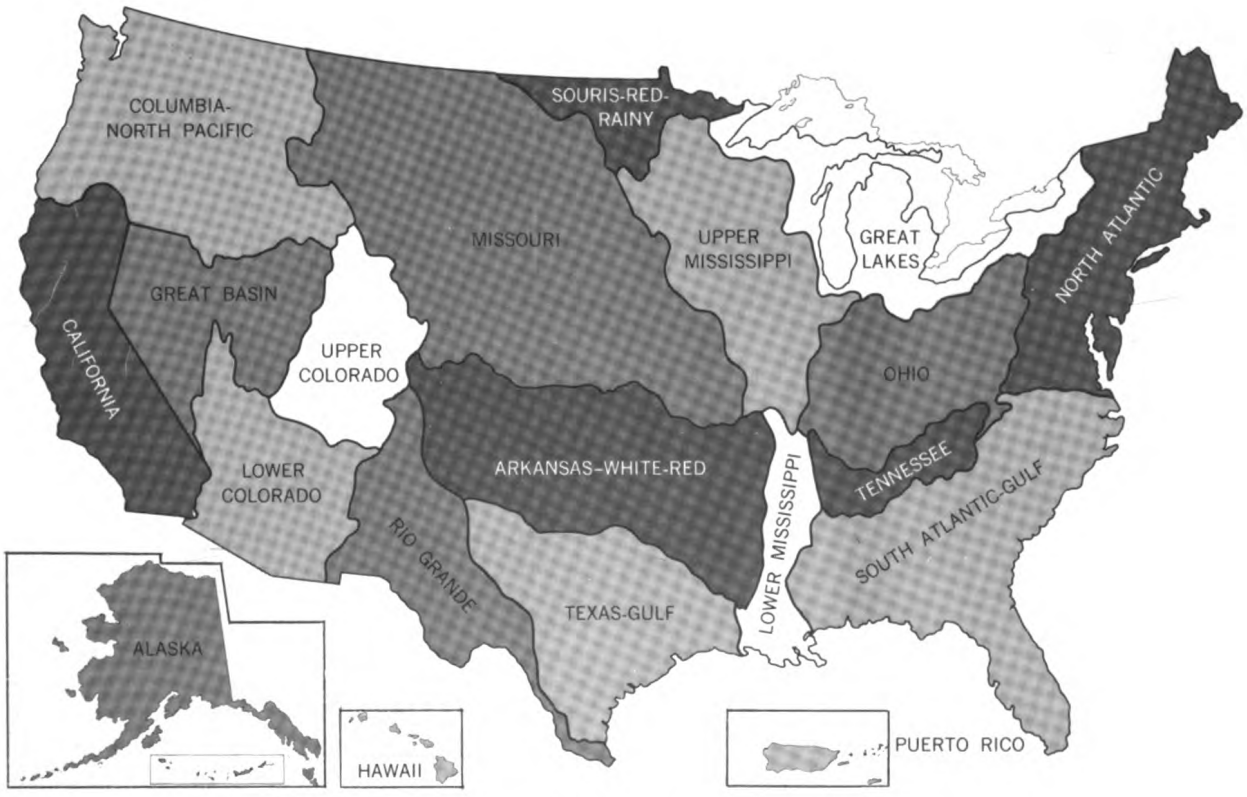

FIGURE 2–1.—*Water resources regions used in the first National Assessment.*

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To supplement the above method, and thus obtain a fuller picture of the entire water and related land resources situation in the United States, a second approach has been used. Regional committees composed of Federal, State, and other experts were asked to prepare chapters about current and emerging water problems in their regions. Thus, field personnel of the 20 regions, who are intimately involved in water resources activities, were asked what problems of water supply, excess water, water quality, and institutional problems they visualized in the near future.

FUTURE ASSESSMENTS

Phase I

The next National Assessment will be a continuation of phase I with refinements in geographic detail; improvements in the water supply and use data, including quantitative data on instream uses; and modified demographic, economic, and land use projections. It will be able to use the results of more of the comprehensive planning studies as they are completed.

Phase II

National assessments prepared under phase II will build on the approach taken in phase I. These assessments will be able to use the results of the completed comprehensive framework planning program. A computer simulation model will need to be developed to handle statistical elements of supply and demand and their spatial relationships within each of some 200-300 basins. The model would provide probabilities of deficiencies and excesses of water quality and quantity for each basin. These determinations would be made for existing and projected development conditions. Indexing systems of basin geometry for such things as inflow, outflow, withdrawals, returns, and imports of water and pollutants; and water resources structures would be used. Moreover, inventories of water development projects would be incorporated into the system to allow their rapid updating and processing.

Seasonal water supplies, demands, and qualities vary widely within basins as well as from basin to basin. In order to adequately represent these variations, the system inputs would be expressed in monthly units rather than the annual units used in phase I. Statistical parameters for all significant stream gages in each basin for natural flow conditions, perennial yields for known aquifers, and statistical parameters of quantity and quality for all withdrawals and consumptive uses in each basin would be used. These uses would include reservoir, phreatophyte, and other channel uses as well as municipal, agricultural, and industrial uses. In addition, parameters relating these uses to the quantity and quality of return flows would be incorporated into the analysis. Water quality standards; navigation, fish and wildlife, and hydroelectric power low-flow requirements; and high-flow limitations regarding critical channel capacities would be used.

Future water requirements for 1980, 2000, and 2020 will be based on population, economic, and land-use projections for some 200–300 basins. These projections will be translated on the basis of projected technology into future withdrawal, instream, and consumptive uses of water and pollution loadings in each basin.

The output from the computational model would provide a measure of existing and potential water supply; existing and projected water requirements, including water quality requirements; and probabilities of deficiencies and excesses in meeting these requirements. Measures of adequacy will be related to these probabilities. Phase II will identify current and future problem areas of water supply. In addition to identifying these areas, it will indicate the types and probable magnitudes of their problems.

Phase III

Phase III will incorporate additional information on productivity and cost into definition of supply and demand, allowing analyses of tradeoffs between various uses of water. In addition, it will provide an analytical tool for evaluating physical and economic consequences of alternative policy proposals, including such things as changes in pricing policy; allocation of research, planning, and construction funds; and economic development proposals.

The scope of the analysis will require inclusion of benefits and costs of existing water resource developments and such future programs as increased in-basin development, desalting facilities, weather modification, and exportable demands for water. The analysis will also require negative benefits or costs of deficiencies in the quantity or quality of water supplies. The model used is expected to evolve from phase II and may consist of several systems. These will allow the incorporation of and feedback from projection models or resource allocation models in the analysis. Full implementation of phase

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III will be highly dependent upon the development of new methodology.

Research

In the Council's plan for the National Assessment are provisions for the development of phase II and the identification of research requirements for both phases II and III. The Council staff has discussed these research needs with the Committee on Water Resources Research (COWRR) of the Federal Council for Science and Technology (FCST). Followup discussions were held with a group of Federal water resource research administrators concerning support of a long-range research program for the Assessment. This group agreed that research leading to the development of the central analytical system should proceed immediately and that the Office of Water Resources Research (OWRR) in the Department of the Interior was the appropriate agency to support such research. Subsequently, an agreement regarding needed research was reached between WRC and OWRR. A seminar on the research needs for the Assessment was jointly sponsored, and was attended by over 60 interested Federal and State agencies, universities, research organizations, and individuals. As funds are available under Title II of the Water Resources Research Act, it is expected that OWRR will support research related to the National Assessment.

Additionally, the Council has established a work group under the Planning Committee to explore the relationship of the National Assessment and comprehensive planning to the Planning-Programing-Budgeting System of its Member Agencies. As a result, it has been agreed to coordinate as much as possible such things as basin delineations; demographic, economic, and land use projections; target dates; and water supply and use data. The Council, through a different task force with membership from the Office of Water Data Coordination, the Bureau of the Census, the Bureau of the Budget, and other interested agencies, is also exploring ways to improve water use data for the National Assessment, the Planning-Programing-Budgeting System, and the comprehensive planning program.

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PART 3

Water and Related Land Resources

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Water and Related Land Resources

INTRODUCTION

For the Nation as a whole, water resources are statistically abundant. The average annual precipitation of 30 inches for the conterminous States provides usable streamflow in almost all rivers and creeks, with about 9 inches finally reaching the sea. The residual 21 inches evaporates in the process of nourishing forest and crops, cooling industrial plants, providing drinking water, and supplying the host of other uses for which we take water for granted.

The related land resource also has the appearance of bountiful abundance. Even with our burgeoning population and profligate use of land, we still have one-third of our land in forest much of which is relatively undisturbed and another third in permanent pasture.

But with a closer focus, the picture is not all that good. There are problems of distribution in both water and land resources. The strains in water distribution are both spatial and temporal. Some areas have a chronic deficiency, other areas have floods and periodic droughts. Not a single area is completely satisfied with its water resource. And poor water quality, usually caused by pollution, has become a concern of every region.

The strains on the land resource are largely socio-economic in origin. The urban proportion is increasing at a rapid rate along with population growth. Lands shifting into urban use are often farm lands of the highest capability. More and more land is demanded for recreation, and multiple-use proponents do their best to fulfill new demands. But competition for land resources is steadily increasing.

The impressive economic growth of the United States is certainly a reflection of the bountiful water and land resources at its disposal. Until recently, any constraints to economic growth have been local and there have been alternative locations available. Now, deficiencies are becoming regional in scope. The economy is growing more rapidly in the South and West than in the highly populated northeastern regions. As a result, many regions are looking elsewhere for additional water supplies.

The possibility of influencing population distribution and achieving a better balance of economic growth through water and land resources development is a serious concern of the Water Resources Council.

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CHAPTER 1

Economic Growth and Water Use

INTRODUCTION

Future rates and patterns of economic development are major considerations in the assessment of future water supplies and requirements and in the formulation of plans and policies for water resources development. Population growth is the most important factor in estimating future personal and household needs for water. Expansion of certain sectors of the economy is indicative of future needs for water for industrial processes. The demands for numerous products and services obtainable from water use and water development—electric power, transportation services, and recreation opportunities—are greatly affected by population growth, expansion of industrial output, and increasing national income. The effect of economic development on national demands for food and fiber and the resultant agricultural demands for natural resources have special significance for water use. Problems of water quality will intensify as metropolitan areas grow and key industries develop.

Economic growth imposes a variety of additional demands on the land base which impinge on the future availability and cost of land required for reservoir sites, canals, and related development. Added pressures on the land base will also create additional needs for a variety of measures to enhance the quality of environment. Thus, population growth and economic development are significant factors on both the supply and demand sides of the use of water and related land resources.

As a general guide to the assessment of emerging water problems, historical trends in economic development are examined in this chapter. Preliminary projections of future economic growth, developed by the Office of Business Economics and the Economic Research Service, are also included. These projections, along with discussions of trends in rates of water use, provide a general indication of the magnitude and location of future water problems.

Throughout the National Assessment, the concept of a dynamic growing economy is maintained. The long-term projections are based on this concept, as is the discussion of the demands for water, the influence of changing technology, and the opportunities for substitution among factors of production.

TRENDS AND PROSPECTS FOR FUTURE ECONOMIC GROWTH

Economic projections are necessary for the analysis of future water problems. Such projections are not predictions or prophecies of the future. They are attempts to view the future in the light of present knowledge of relationships of the past and foreseeable developments. The results are orders of magnitudes of probable economic changes that may take place during future time periods. They are based on certain basic underlying assumptions such as no major wars and the continuation of national policies which will ensure a high level of economic growth consistent with full employment of resources and reasonable price-wage stability. The further into the future one projects and the smaller area for which the projections are made, the less the reliability of the projections. The projections do, however, provide an essential tool in planning for water resources development and utilization.

Projections of both population and economic growth are constantly under review. It is unlikely, however, that the substantive rates of economic growth projected in this report will be altered by such reviews to significantly change the outlook for water requirements in the near term.

The most comprehensive measure of output is gross national product (GNP). This measure represents the total market value of all goods and services produced in the economy expressed in constant prices. Long-term growth potentials for physical output are examined and expressed in these terms.

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National Growth

The year 1965 is the mid-point of a 110-year period of national economic development stretching from 1910 to 2020. Economic growth, prior to 1965, provides the primary basis for visualizing the broad contours of future economic activity.

Growth of population and production in the national economy since 1910 and anticipated growth over the next half century is shown in figure 3–1–1. A straight line through the years 1910 and 1965 represents a growth rate of 3.0% per year in GNP. Projected growth of the economy to 2020, however, represents an annual increase in GNP of about 4.0% per year—a significant acceleration over that for the past 55 years. By moving from underutilization of the Nation's productive resources to near capacity, the Nation experienced a remarkable growth rate of 4.8% for the 1960-65 period. Rates of unemployment declined from 5.6% to 4.6% during the same period. A growth rate equal to that of the 1960-65 period seems unlikely, but a rate significantly higher than the 3% of the 1910-65 period seems attainable.

The high growth rate is due in part to accelerated population growth. The population growth rate for the period 1910-65 was 1.4% per year. The population growth rate for 1965-2020 used in this Assessment is 1.6%, resulting in a projected population of 468 million in the conterminous United States in 2020. This projection is patterned after the U. S. Census "B" level and approximates the population growth rates of the period 1960-65. Birth rates in recent years suggest that a lower population increase patterned after the U. S. Census "C" level should be used in the next Assessment. However, because of offsetting factors, net changes in rates of future economic growth will be minimal.

Recent experience and prevailing opinion suggest relatively full employment in the future. Rates of unemployment ranging from 1.2% to 24.9% have been experienced since 1929. Fiscal, monetary, and labor market policies are expected to be sufficiently effective to hold unemployment rates to an average no higher than 4%. With a decline in working hours per work week, the labor force is expected to attract increasing numbers of women and, possibly, older persons. Thus, rising labor force participation rates are expected for the future. The preliminary projections of population, employment, and income for the conterminous United States are given in table 3–1–1.

Despite an expected decline in annual hours of work per man, the increase in employment under a full employment assumption will assure a sizable annual growth in total hours worked. A continuous growth in output is foreseen. Educational levels will rise. The structure of employment is expected to move toward the higher skill end of the occupational spectrum. Moreover, "automation," which accompanies the shorter work week, takes the form of higher capital investments per worker. Employees in the future will have at their disposal more and better hardware and, in a computer age, more and better software. Management will require greater skills and will be correspondingly more productive.

A change in the composition of GNP has taken place. In 1910, 12.2% of the Nation's gross product originated on farms. By 1965, a decline to 3.9% had occurred. During the same period, gross product arising in government in-

TABLE 3–1–1.—*Projections of population, employment, and income, conterminous United States, 1960-2020*

Item	Unit	1960 [1]	1980	2000	2020
Population	Thousand	176,291	243,900	336,800	467,700
Population per worker		2.66	2.57	2.58	2.58
Employment	Thousand	66,372	94,800	130,600	181,200
Agriculture	Thousand	4,528	2,500	1,900	1,750
Manufacturing	Thousand	18,229	24,800	31,300	40,400
Other commodity producing	Thousand	6,457	8,500	10,970	14,630
Distributive industries	Thousand	16,915	23,500	31,300	41,280
Service industries	Thousand	20,243	35,500	55,130	83,140
Personal income [2]	Million dollars	351,582	785,000	1,680,000	3,630,000
Per capita	Dollars	1,994	3,220	4,990	7,760
Per worker	Dollars	5,297	8,280	12,860	20,030

[1] Some data for 1959.

[2] 1954 dollars.

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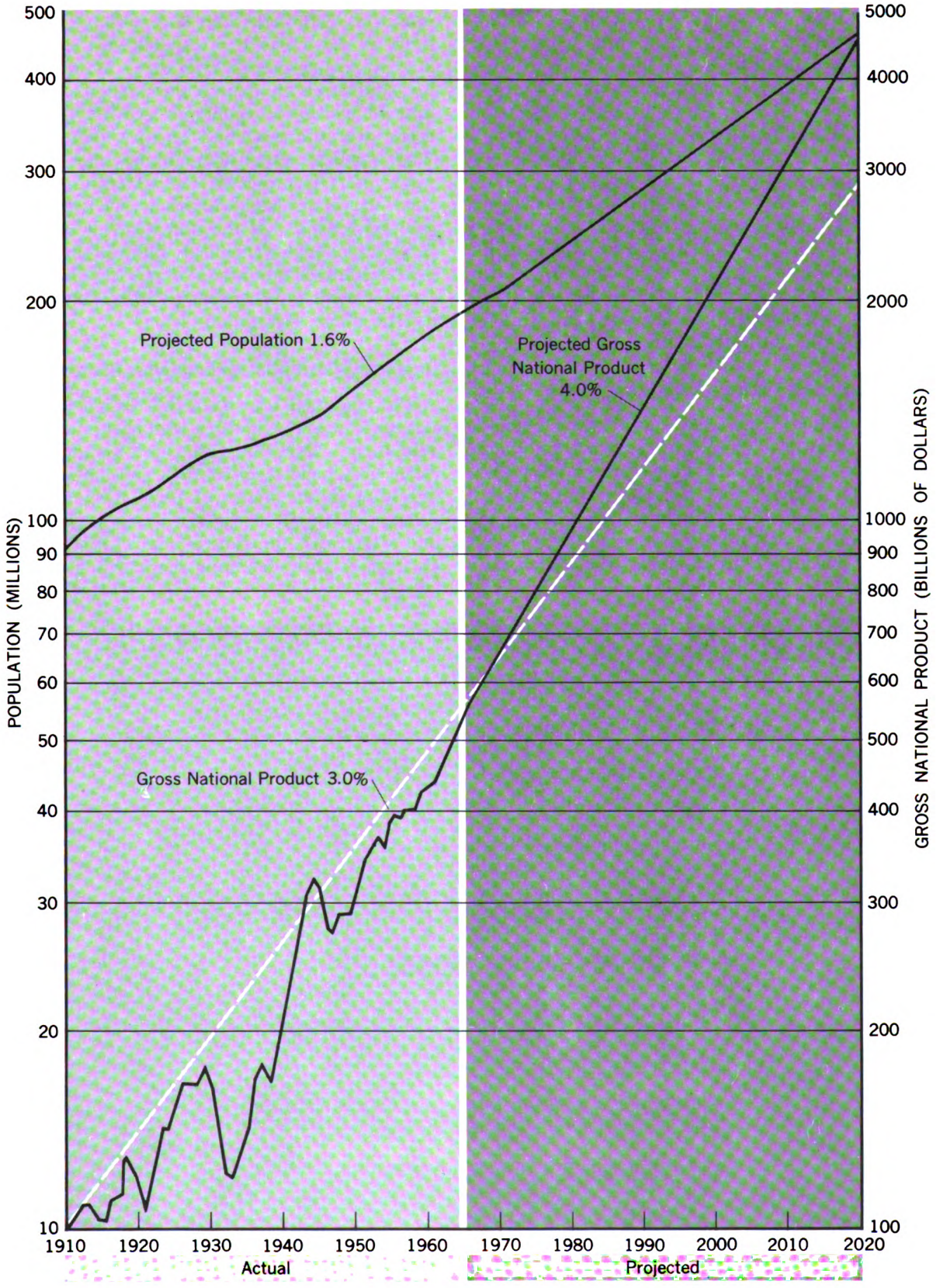

FIGURE 3–1–1. *Historical and projected population and gross national product (1954 dollars), 1910–2020.*

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creased from 5.4% to 8.3%. All other sectors contributed 82.4% of the gross product in 1910, but by 1965 this had increased to 87.8%. More changes of a similar nature are expected in the years ahead. The continued decline in the relative contribution of the farming sector is anticipated but, as in the past, there will be increasing activity in the agricultural supply, processing, and marketing activities off the farm. The relative importance of government in the GNP will reflect a moderate growth in government employment, mostly in the State and local sectors. The rise in importance of other industries will reflect both employment growth and rising output per worker.

Growth of Major Water-Using Industries

The major "water-using" industries (defined as industries that withdraw or consume large quantities of water or that add substantial pollution to streams) include agriculture, mining, and manufacturing. Within manufacturing, the major water users are primary metals, food products, chemicals, paper products, and petroleum products. Although there are substantial variations in anticipated rates of growth in production among major water-using industries, all such industries are expected to participate in the upward sweep of economic growth that will occur over the next half century (fig. 3–1–2). The smallest expansion among these major water users is projected for agriculture, where total output in 2020 will be nearly three times its 1965 volume. At the other end of the scale, production in the chemicals industry in 2020 is expected to be about 15 times its 1965 level. Large growth is also expected in recreation and electric power generation.

Regional Distribution of Economic Growth

The economic growth of the Nation is a composite of widely differing regional rates of development. Over the past three decades, these differences have resulted in a substantial redistribution in the shares of population and economic activity from the northeast to the south and west, with the central plains areas experiencing a slightly declining share (fig. 3–1–3).

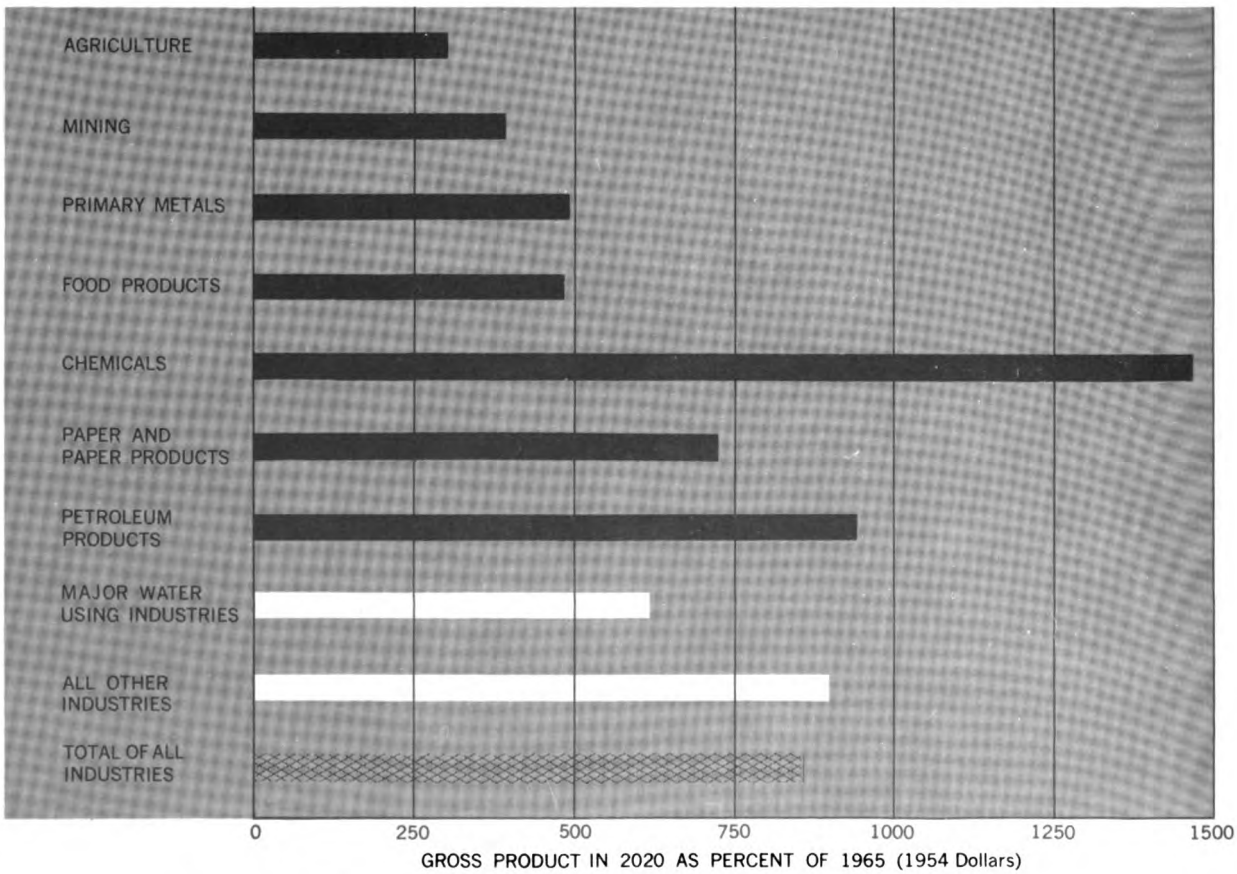

FIGURE 3–1–2.—*Projected changes in output of major water-using industries, 1965–2020.*

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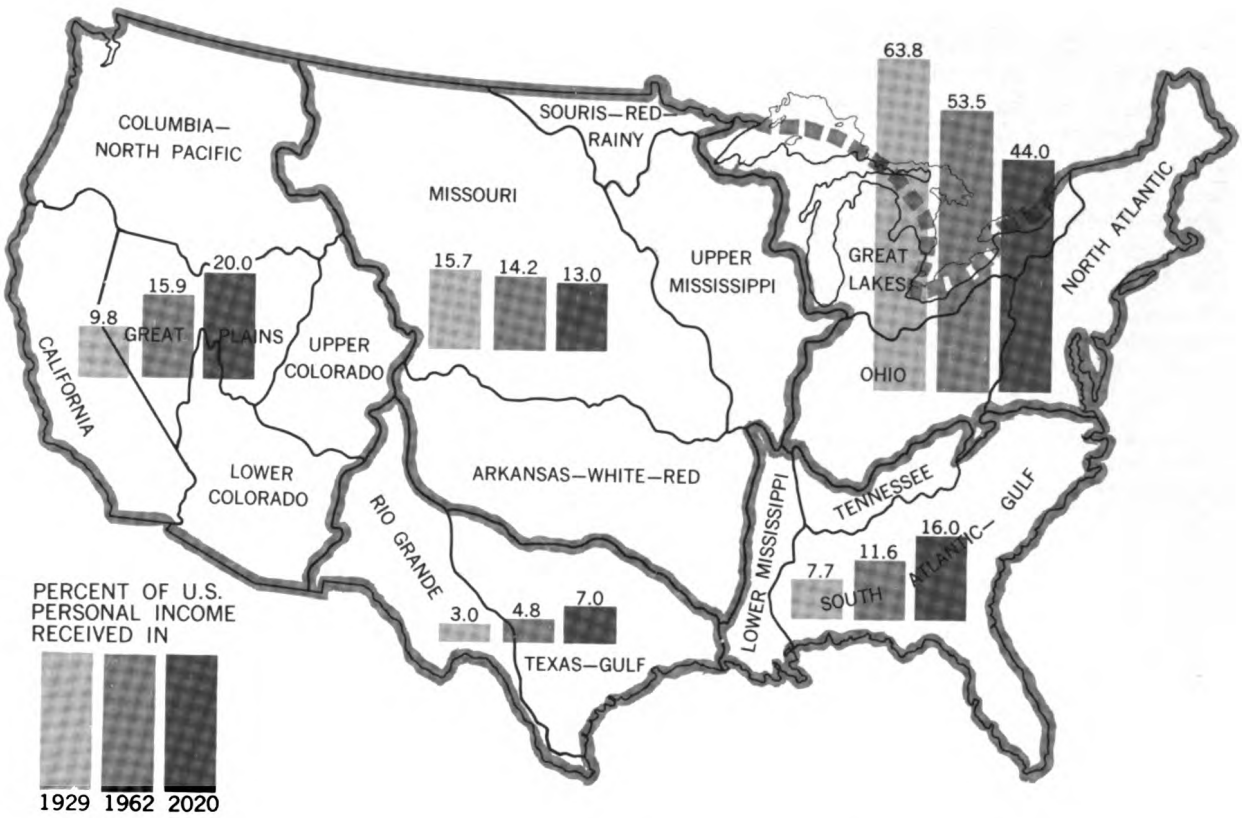

FIGURE 3–1–3.—*Changes in the geographic distribution of economic activity as measured by each area's share of total personal income, 1929, 1962, and 2020.*

From 1929 to 1962, the share of the Nation's total income received in the northeastern water resources regions (North Atlantic, Great Lakes, and Ohio) declined from 64% to 54%. In contrast, the share accounted for by the combined southern regions (South Atlantic-Gulf, Tennessee, Lower Mississippi, Texas-Gulf, and Rio Grande) increased from 11% to 16%. At the same time, the proportion in the western regions (Upper Colorado, Lower Colorado, Great Basin, Columbia-North Pacific, and California) rose from 10% to 16%. The share of the four central regions (Upper Mississippi, Souris-Red-Rainy, Missouri, and Arkansas-White-Red) declined from 16% to 14%.

The economic projections developed for the National Assessment (table 3–1–2) envisage a general continuation of past trends. The share of the northeastern regions is shown in figure 3–1–3 to decline a little more than 15% over the next 60 years, so that by 2020 these three regions will account for less than half (44%) of the Nation's economy. The share of the western regions, on the other hand, is expected to rise by one-fourth by 2020, while that of the two other areas will expand by one-third. The size of the shift may be illustrated by comparing the shares at the beginning and end of the span of almost a century. In 1929, the volume of economic activity in the northeastern regions was three times that in the southern and western regions combined. In 2020, the two areas are projected to be nearly equal in economic size.

The historical and projected declines noted are relative—not absolute. As shown in figure 3–1–4, income has risen substantially in every water resources region since 1929. In the large and economically mature North Atlantic Region, where the rate of economic growth was slowest, the volume of economic activity in 1962 was more than twice that in 1929, while the volume in 2020 is projected to be eight times the 1962 level. Thus, all major sections of the Nation are expected to share substantially in future economic growth.

The regional projections are based on the

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TABLE 3–1–2.—*Projections of population, income, and employment, by regions, 1960-2020*

Region	Population				Per capita income [1]				Employment			
	1960	1980	2000	2020	1960	1980	2000	2020	1960	1980	2000	2020
	Thousands				*Dollars*				*Thousands*			
North Atlantic	43,896	56,693	74,993	101,726	2,282	3,525	5,300	8,150	17,621	23,066	30,106	40,437
South Atlantic-Gulf	19,727	29,099	42,602	61,438	1,429	2,525	4,300	7,150	7,232	11,142	16,354	23,639
Great Lakes	25,474	33,171	43,293	57,640	2,218	3,450	5,325	8,075	9,664	12,944	16,836	22,379
Ohio	18,793	23,498	30,742	41,241	1,840	3,050	4,900	7,750	6,546	8,575	11,361	15,417
Tennessee	2,979	4,118	5,643	7,785	1,508	2,625	4,225	6,900	999	1,478	2,066	2,894
Upper Mississippi	11,759	15,180	20,004	26,766	1,986	3,175	4,950	7,700	4,407	5,869	7,725	10,338
Lower Mississippi	4,619	5,871	7,815	10,587	1,526	2,700	4,450	7,200	1,505	2,040	2,788	3,859
Souris-Red-Rainy	652	791	1,023	1,368	1,708	3,175	4,925	7,700	230	288	377	510
Missouri	7,845	10,337	14,260	20,079	1,800	3,075	4,850	7,550	3,003	4,063	5,575	7,824
Arkansas-White-Red	7,122	8,972	11,952	16,055	1,590	2,774	4,400	6,975	2,519	3,311	4,458	6,044
Texas-Gulf	8,109	12,491	18,230	25,901	1,713	2,925	4,675	7,375	3,006	4,823	7,038	10,004
Rio Grande	1,604	2,649	4,173	6,063	1,964	3,175	4,950	7,600	540	972	1,561	2,331
Upper Colorado	317	454	700	1,025	1,897	2,775	4,325	7,075	111	160	256	383
Lower Colorado	1,480	3,038	4,768	7,194	1,736	2,950	4,800	7,675	525	1,159	1,827	2,766
Great Basin	970	1,790	2,822	4,285	1,900	3,200	5,100	7,800	355	690	1,089	1,655
Columbia-North Pacific	5,359	7,581	10,463	14,444	2,045	3,250	4,975	7,725	1,990	2,921	4,032	5,570
California	15,584	28,167	43,317	64,003	2,410	3,750	5,450	8,175	6,120	11,296	17,148	25,050
Alaska	.....	.....	.....	.....	....	....	....	....	.....	.....	.....	.....
Hawaii	.....	.....	.....	.....	....	....	....	....	.....	.....	.....	.....
Puerto Rico	.....	.....	.....	.....	....	....	....	....	.....	.....	.....	.....
Total	176,289	243,900	336,800	467,600	1,994	3,220	4,990	7,760	66,373	94,797	130,597	181,100

[1] 1954 dollars.

premise that the primary motivation for geographic changes in employment and population is economic opportunity. Industries generally locate where economic advantages are greatest; and the population migrates to the resulting employment opportunities. The obverse of this principle is seen in agricultural areas, where rapid advances in technology and major substitutions of capital and other inputs for labor in the production process have resulted in major outmigration of population.

Geographic changes in manufacturing have played a major role in regional economic growth. Increased industrialization has been the largest factor in the shift of economic activity from the northeastern to southern and western regions. Changes in the geographic distributions of manufacturing activity between 1929 and 1960 and projected changes to 2020 are similar to the aggregate changes in total economic activity. Industrialization of the southern regions has more than offset a substantial decline in agriculture. In the western regions, manufacturing has expanded along with most other industrial sources of economic growth.

Locational shifts in agricultural production have contributed to changes in the geographic distribution of income over the past three decades and will contribute to further changes in the next half century. On balance, the shares of national agricultural production changed only a little in the northeastern and central areas, although shifts have occurred in individual water resources regions in these areas.

The relative contribution of the South Atlantic-Gulf, Tennessee, Lower Mississippi, and Texas-Gulf Regions to national agricultural output has declined. In contrast, agricultural production in the Rio Grande, Lower Colorado, Great Basin, Columbia-North Pacific, and California Regions has increased in relation to other regions.

Activities at Federal installations have stimulated economic growth in the southern and western regions. Major increases in personal income over the past 35 years in the metropolitan areas of these regions have resulted from the expansion of Federal activities.

ECONOMIC DEMANDS FOR WATER

Future growth of the economy is but one of several major forces shaping the requirements for water and the needs for development. Requirement for water, in a long-term sense, is a function of two major variables—demands for products and services obtainable from water, in-

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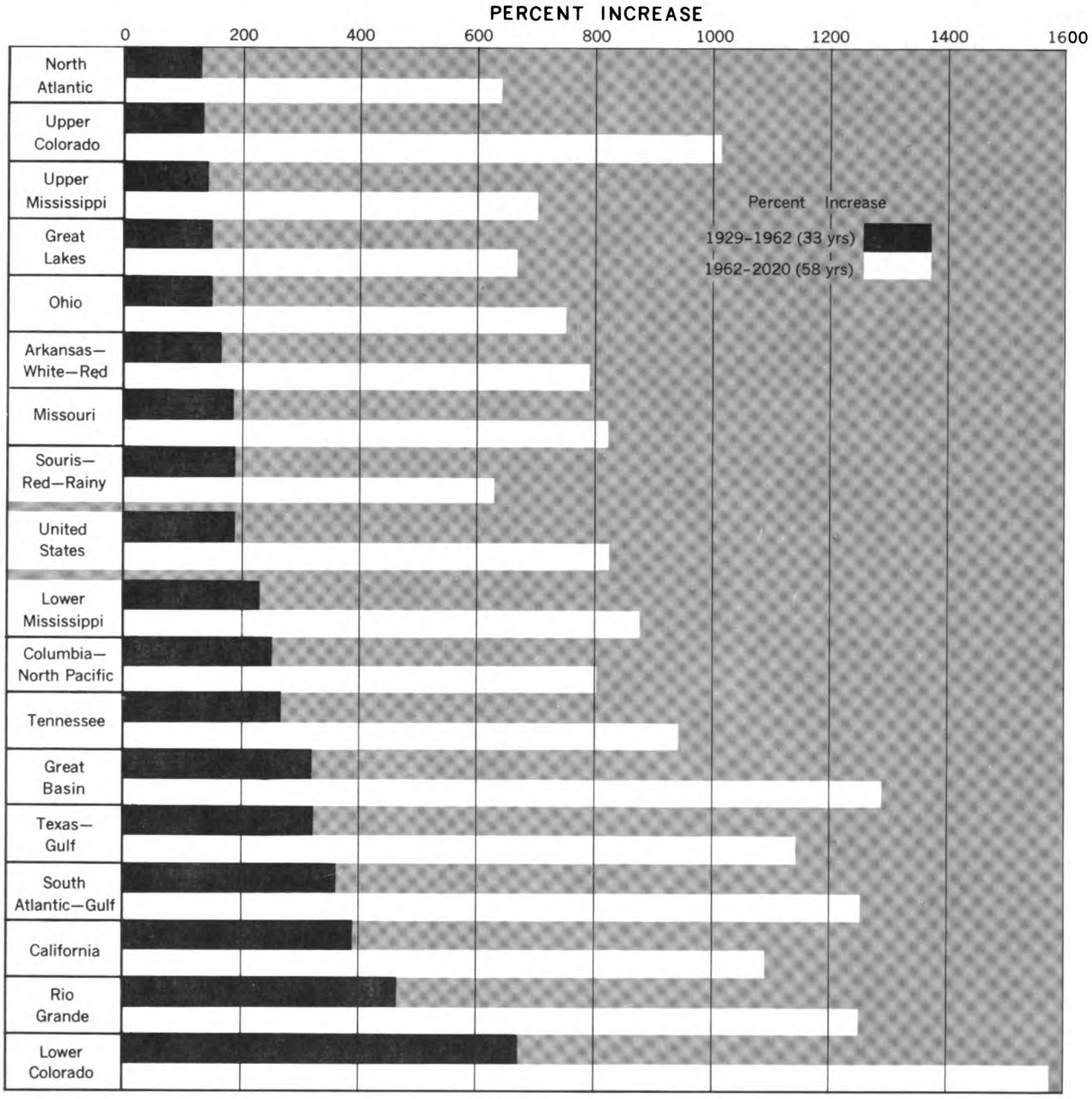

FIGURE 3–1–4.—*Historical and projected changes in personal income, by water resource regions, 1929–2020.*

cluding the broad social and economic impacts of water resource development not associated with marketable products, and the cost of alternative sources and processess for satisfying the demands for such products and services. In agricultural production, fertilizer and a variety of other inputs contribute to productivity and in this way may substitute in part for water insofar as the production of food and fiber is concerned. Transportation services can be obtained from several alternative modes of moving commodities, including navigation. All major means of producing power use water. The cost of these alternatives is influenced by the development and use of improved technology in the production process.

The term "water demand," in an economic sense, is the quantitative relationship of water use to water price. The relationship may apply to a single household, firm or a sector of the economy or may represent an aggregate of many uses. Since "demand" relationships are variable among uses, the term "aggregate demand" implies a shift in patterns of use in response to changes in water prices. "Water demand" may represent a price-use relationship for a "normal"

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year, month, or some other stated period. These relationships may shift rather sharply from one seasonal period to another.

"Water use," however, reflects not only the interaction of supply and demand but a variety of institutional constraints. For example, the transfer of water from one area to another is governed by State water laws and may be affected by interstate compacts. Even within a localized area, water usually cannot be transferred freely from one use to another in response to supply-demand forces. In some Western States, water can be transferred from agricultural to other uses only through the sale and purchase of land. Water quality standards may also affect the use of water. Such institutional controls usually change slowly, and economic forces operate within these institutional constraints.

The amount of water used by many industrial firms and in many industrial processes may be affected by its cost. If costs are low, there are lesser constraints on the amounts used. Since it is common practice for the large water-using industries to provide their own water supplies through groundwater sources or by direct withdrawal from surface sources, the costs are reflected in certain capital facilities and energy considerations. Once the capital investment has been made, the constraint on use is associated with operating and maintenance costs which usually are not closely regarded. If the industrial firms must make a payment to some agency to assure the continuance of the supply or if the firms must actually buy the water, the constraint on use depends on the level of the payment or price. It is expected that in the future there will be more such payments required and that they will be higher than at present, tending therefore to reduce the amounts of water used per unit of production.

However, a greater constraint on water use will be asserted through water pollution control requirements. The necessity of meeting water quality standards in the receiving waters will have the effect of reducing waste discharges and consequently may reduce intake volumes, for waste discharges are largely a function of operating practices and industrial processes. Both the practices and the processes should lead to conservative water use practices, including recirculation and waste water renovation for reuse, as the implementation of water quality standards takes hold. The net effect though difficult to estimate, will mean more careful use of water and less shifting of treatment costs to downstream users.

Use of water and related land resources in production is affected by the price of water in relation to the price of other input factors. Studies of price-quantity relationships over time and among diverse areas are needed in order to derive demand curves for a variety of industries and production processess. Demand relationships of this type would reveal the potentials for substituting other inputs for water and the marginal value of water among competitive uses.

Substitution possibilities for certain industries may be interregional in character. Water scarcities and intense competition between uses, together with high water costs in one region, may affect the competitive position of the region in relation to other regions. Shifts in the competitive positions of regions can be projected on the basis of complex analyses involving (1) an assessment of interregional competition for specific industries, and (2) interindustry competition for water—particularly in water-short regions. Studies of this type are not currently available. As they become available, more reliable projections of geographic patterns of economic growth may be possible. Thus, projections of economic activity for any region may be improved as information becomes available on water supply-demand relationships within either the given region or a competitive area.

Projections of water use involve all of the complexities and uncertainties of demand projections, and, in addition, require appropriate consideration of other factors. These include physical supplies and institutional arrangements for water allocation, including water pricing. Physical supplies are usually variable from year to year and season to season because of weather cycles and seasonal patterns of precipitation. Water uses, even with a given level of economic development, also fluctuate throughout the year. The supply-demand relationships for critical years and critical seasonal periods are of great relevance in water resources planning and public policy formulation. The seasonal and year-to-year, supply-demand relationships are also important elements in river basin planning. Development of projections of supply and demand in this context, however, is difficult and has not been undertaken for the first National Assessment.

Industrial Uses of Water

Levels of industrial output in heavy water-using industries are major determinants in water uses. Other important factors, such as fluctuating demands and supplies, water allocation, and

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water pricing, have frequently been disregarded in projecting future water requirements. As a result, estimates have often been based on fixed rates of water use depending on projected levels of industrial output.

The cost of water has been a small part of the total cost of production in most industries and in most parts of the Nation. As a result, little attention has been given to water-conserving practices. As the pressures on water and related land become greater, however, the cost of water may be expected to become more important. Production processes may be altered so as to use smaller quantities of water in relation to other inputs. Reliable estimates of future water uses must be derived from a procedure that considers water as an economic resource and treats it as a cost of production. An appropriate procedure would evaluate (1) the relationship of water cost to the cost of other input factors; (2) the substitution and reuse possibilities in the water utilization systems; and (3) the impact of technological changes on water use in industrial processes. Differing responses will occur among industries, but considerable change in the quantities of water used per unit of product may be expected.

An increase in water costs may result in the introduction of recirculating systems or in process modifications within the plant and a decrease of water withdrawal for cooling and washing purposes. When recirculated water is used for cooling purposes, cooling towers or ponds are usually needed. When recirculated water is used for washing, impurities may need to be removed. In either case, withdrawal of water may be related inversely to necessary capital investment.

The economy of using cooling towers in major industries, such as the steel industry, will be determined on an individual plant basis and the decision will be based on factors affecting total costs, including the cost of water withdrawals, the cost of any necessary water treatment, the cost of cooling towers or ponds, and the initial and operating cost of the recirculation system. According to the Census of Manufactures, Water Use in Manufacturing, 1964, 10.5 bgd of water was withdrawn by steel mills, but the within plant recirculation ratio was only 1.44. Thus, considerable possibility may exist for additional recirculation in the steel industry. Similar opportunities may exist in other industries.

Changes in water use come about not only through changes in the prices of water in relation to the prices of other factors but also through technological changes. The imposition of effluent controls may force a reduction in water intake even though the cost of water has not changed. The sugar beet processing industry, for example, has produced and discharged to streams large quantities of biologically degradable organic matter. Disposal of the waste to streams at no cost to the industry has been customary. If controls are imposed to eliminate or reduce the discharge of waste to water courses, other methods of disposing of the refuse will become the custom. With improved technology sugar beet refineries can reclaim from their waste water nearly all the sugar by-products which contribute to pollution. The cost of waste removal is reduced to the extent that the value of the product offsets the cost of its recovery.

The pulp and paper industry is one of the Nation's largest wet processors, with total water withdrawals in 1964 of about 5.7 bgd. In response to the increasing pressure for the control of water pollution and the associated water costs, the industry has made rapid progress in decreasing withdrawals of water per unit of production. As a result, the total water withdrawal of the industry rose by only one-fifth in the last decade and a half—although pulp and paper production nearly doubled. This has become about largely through recirculation of water at various points in the production process and through reclamation of valuable chemicals from the effluent.

Information is not available to appraise and quantify the potential effects on water use of changes in production costs and technology.

Agricultural Uses of Water

Consumptive use of water in agricultural production exceeds the total of all other uses. Rapid and far-reaching changes, including sharp increases in rates of production, have been taking place for several decades in the agricultural sector of the economy. As rates of production have increased in response to improved technology, the quantity of water has decreased per unit of output. Also, despite large increases in total agricultural output, smaller acreages of cropland have been required.

Increased agricultural production without corresponding increases in the net use of water has been possible because of the development and use of improved technology and the great potentials for substituting other inputs for water in the production process. Some increases in the usable supply of water on nonirrigated lands have become available through water conservation measures.

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The potential for further adjustments in agricultural use of land and water has not been fully evaluated. Projections of current trends, however, indicate a strong probability of achieving large increases in agricultural production with little, if any, increase in the use of land for crop and pasture purposes.

Should additional lands, most likely in humid areas, be utilized for agricultural purposes in the future, a comparable increase in the agricultural use of water may be expected. However, increases in agricultural use of water on such lands will be largely offset by reductions in the use of water by displaced natural vegetation. On the other hand, new irrigation and additional livestock use will result in net increases in consumptive use of water and additional withdrawals of surface and groundwater.

A few generalizations concerning future demands for irrigation water may be derived from the foregoing discussion. Improved opportunities for substitution between water and other productive factors are national and regional in character. Expanding national requirements for agricultural products may be satisfied, to some extent, by further intensification of production practices on existing agricultural lands without significant increase in net water use. Additional output, beyond these potentials, may be obtained from irrigation development or from the development of additional nonirrigated lands. The latter type of development will involve a shift of water from other kinds of vegetation to agricultural crops. And it may require the development of irrigation water sources to supplement natural rainfall. Choices among these alternatives will involve a number of considerations, including alternative uses of water required for irrigation development and the relative efficiency or cost of alternative sources of needed production.

Residential Uses of Water

Studies have shown that residential water use is not very responsive to changes in the price of water. However, it seems likely that rates of domestic water use would decrease when charges for water become prohibitively high. Some municipalities supply water below cost to induce new industries to locate in the area and thus improve its employment and tax bases. Water is provided to large domestic users at a discount in many cases. A change in water-pricing policies may or may not lead to lower rates of use depending on the overall pricing structure on labor, material, taxes, and other items.

It is certain, however, that water use increases as income rise. Since population and income are expected to increase in the future, the gross quantities of water for household and personal uses may increase substantially. In areas where water is not metered, considerable reductions in per capita water use or water wastage may result from imposition of a use-cost basis of water charges. The historical upward trend in per capita water use in many areas is indicative of the future.

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CHAPTER 2

The Water Resource

INTRODUCTION

As a whole the Nation has abundant water resources with average annual precipitation of 30 inches for the conterminous United States, average natural runoff of 1,200 billion gallons per day (bgd), and large reserves of water underground. However, the Nation is less fortunate in the distribution and timing of the water resources. Rainfall varies from the lush abundance of the Pacific Northwest to the scarcity of the parched Southwest. Furthermore, in any one region, streamflow can vary widely from season to season and from year to year. Thus, averages are a precarious base for broad conclusions.

This assessment presents a general picture of variations in precipitation, evapotranspiration, and runoff over the United States. The important surface water resources are also set forth for the various regions and subregions in terms of the mean annual natural runoff, and the annual flow available in 50%, 90%, and 95% of the years. The mean annual runoff can be considered as the theoretical upper limit of sustained development by regulation and storage.

The groundwater resources are more difficult to assess. Sufficient information is not available to determine quantitatively the total water supply that could be developed from this source. However, extensive aquifers where large water supplies could be developed are identified and the complexities of the groundwater system are discussed. Increased data on groundwater resources must be included in future National Assessments by the Council.

The quality of water may determine its ultimate use. Although low quality water can be made suitable for any purpose by treatment, it may be expensive to do so. An assessment of the natural quality of the water resource and the effects of society on water quality are presented.

PRECIPITATION

Origins

About 10% of the more than 40,000 bgd of atmospheric moisture moving over the United States reaches the ground as rain or snow. Evaporation from oceans provides over 80% of this precipitation. Less than 20% is supplied from inland evaporation and transpiration.

East of the Rocky Mountains, the main moisture sources are the Gulf of Mexico and the Atlantic Ocean; west of the Rockies, the main source is the Pacific Ocean. Large amounts of water are precipitated in local areas on the windward sides of high mountains as this atmospheric moisture is forced to rise as it moves inland. For example, the windward side of the Olympic Range in Washington receives 200 inches of rain a year compared with 20 inches on the leeward side.

Annual Precipitation

Normal annual precipitation over the conterminous 48 States is about 30 inches, ranging from less than 4 inches in parts of the Great Basin and Lower Colorado Regions to more than 200 inches in coastal areas of the Columbia-North Pacific Region. About 26 inches of the 30 is rain, and the remaining 4 inches is snow or other frozen forms. The area east of the Mississippi River averages about 44 inches, the area west of the Rocky Mountains about 18 inches, and the intervening area about 28 inches. The geographic distribution of precipitation is shown in figure 3–2–1.

In the Alaska Region the normal annual precipitation ranges from about 5 inches in the extreme north to more than 200 inches at places along the southern panhandle, and the regional average is about 20 inches.

The Hawaii and Puerto Rico Regions, which are in the zone of the easterly trade winds, experience great local variability in rainfall because of their mountains. In general, annual

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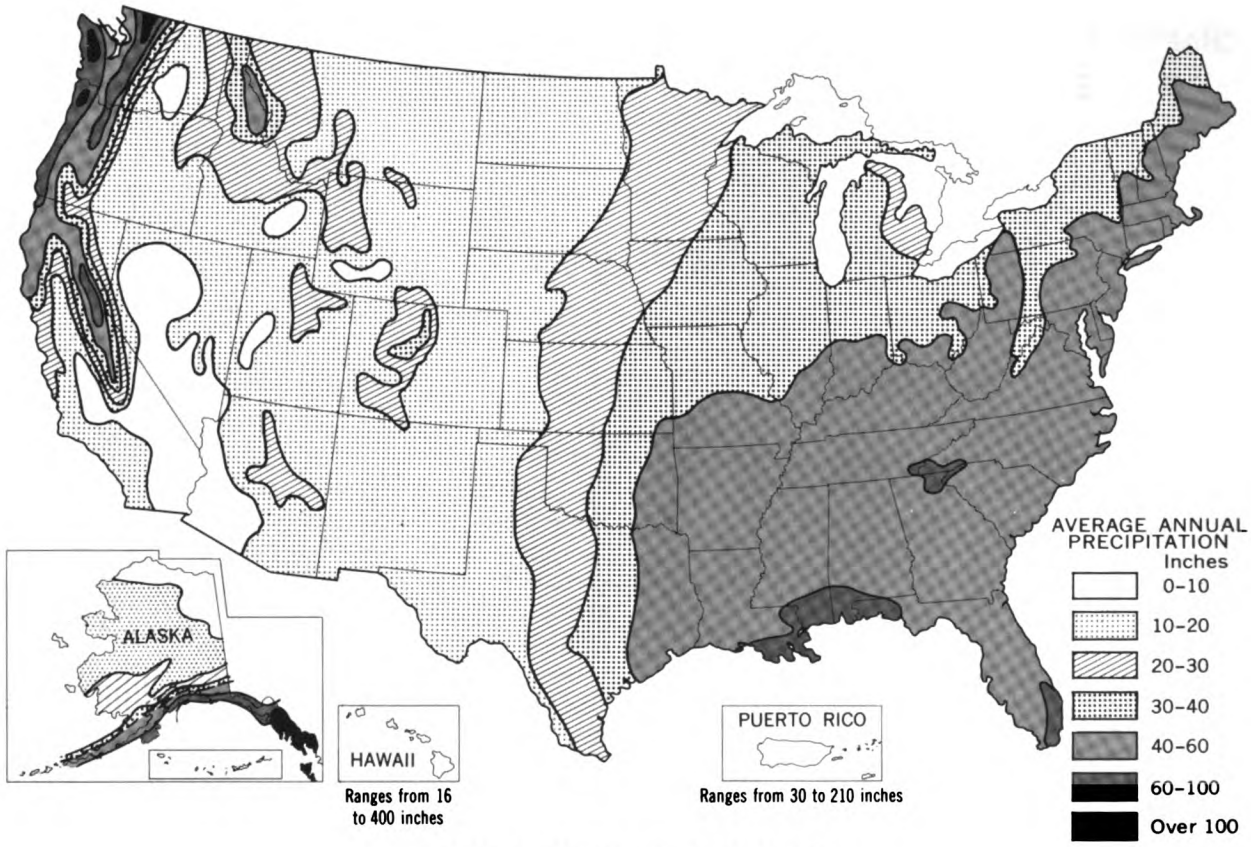

FIGURE 3–2–1.—*Average annual precipitation.*

rainfall is greatest on the windward slopes and at the highest elevations. Mt. Waialeale, Hawaii, has the world's record normal annual precipitation of 460 inches, but about 15 miles to the southwest, on the lee side of that mountain, the normal annual precipitation is less than 30 inches.

Yearly Variability

The area of the conterminous 48 States is so large that nearly every month heavy rains occur in some parts of the Nation and dry weather occurs in other parts. At representative stations in the East, the extremes of annual precipitation range from 50% to 150% of the station normal. In the West, precipitation is more variable and entire States may have annual totals ranging from 50% to 150% of the State normal. In general, the greatest yearly variability from the normal precipitation occurs where the normal amount is small.

Seasonal Variability

In the Northeast, there is relatively little seasonal variation in precipitation. In the Midwest, summer storms in the May-October period produce more than twice the precipitation that occurs in the rest of the year. In the South, where the seasonal trend is even more complicated, thunderstorms give some inland stations most of their rain in the summer, and hurricane rains give some coastal areas most in the fall. Cyclonic storms migrate far enough south in winter for some southern stations to have most of their rain at that time. In the intermountain areas, winter is the wettest season except at low altitudes in southern latitudes, where winter precipitation becomes less than summer rainfall. West of the Cascade Mountains and Sierra Nevada, the maximum precipitation is in winter and at some stations in California the summer months are virtually without rain.

In the northern and the mountainous areas of the United States, seasonal influences determine the type of precipitation. Snow is the prevalent form during the winter months in the Northern States and at high altitudes. Thus, in much of this area, water is stored over the winter months in a snowpack and is released to streams as temperatures increase through spring into summer.

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In Alaska, coastal stations tend to have most of their rain in the late fall; stations in the interior have most in the summer. In Hawaii, summer generally is dryer than winter. And in Puerto Rico, fall is the wettest season and early spring the driest.

EVAPORATION AND EVAPOTRANSPIRATION

Evaporation is the process by which water vapor escapes from a free-water surface or moist-soil surface. On land, in addition to water lost from soils, there is also a loss of water from plants; the combined loss is termed evapotranspiration. The basic factors influencing rates of evaporation and evapotranspiration are the same: short-wave and long-wave radiation, humidity, air temperature, wind movement, and albedo and temperature of evaporating surfaces. Potential evapotranspiration is defined as the evapotranspiration that would occur if an adequate supply of moisture were available at all times. For practical purposes, potential evapotranspiration may be assumed to be nearly equal to evaporation from a free-water surface. Actual evapotranspiration is usually less than the potential because soil moisture often falls below the level necessary for evapotranspiration at the potential rate.

Evaporation from lakes and reservoirs has an important effect on the amount of water available for use. Evaporation from a reservoir surface generally is greater than the evapotranspiration loss under prereservoir conditions. As a result the total outlow is reduced. This may be of little consequence in humid areas, but in arid areas the increased loss may be so great that it significantly diminishes the value of a reservoir used to regulate the water supply.

Mean annual evaporation from lakes in the United States varies from 20 inches to about 90 inches, as shown in figure 3–2–2. In defining the equal points of lake evaporation for this map, the effect of topography was taken into account in only a general way, because the effect of altitude on rate of evaporation is still not fully understood. Annual lake evaporation is less variable than annual precipitation or runoff.

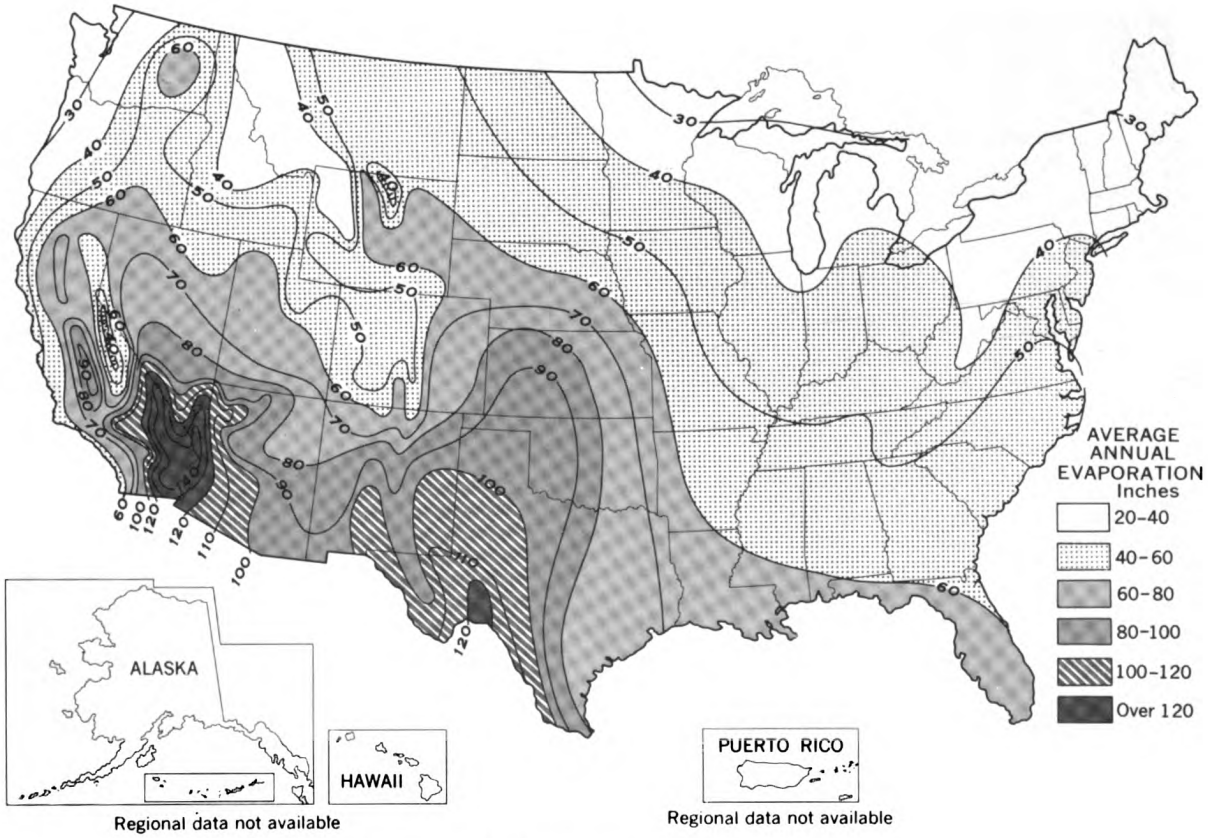

FIGURE 3–2–2.—*Average annual lake evaporation.*

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Evapotranspiration losses in areas of high water tables occupied by phreatophytic and riparian vegetation can reach phenomenal amounts. In parts of the southwest characterized by high temperatures, fertile soil and abundant subsurface moisture losses of 80 inches annually have been observed.

Areas in which natural water surplus or water deficiency commonly exist within the conterminous United States are shown in figure 3–2–3. The values shown have been computed by subtracting values of potential evapotranspiration from the average precipitation. However, even in areas having an annual water surplus, there are often seasonal or short-term periods of deficiency. The map shows a general natural water surplus in the eastern half of the country and a general natural water deficiency in the western half. The deficiency in southern Florida, of course, is the result of a very high evapotranspiration rate—not low precipitation.

SURFACE WATER

The flow of streams provides most of the Nation's usable fresh water resource. Streams supply about 67% of the withdrawal use of water, and water in stream channels is used for many purposes.

Streamflow is a highly variable resource. Within a normal year, the ratio of maximum flow to minimum flow may be 500 to 1. Year-to-year variations in the average flow are also substantial. Because streamflow is dependent on precipitation, evaporation potential, and basin characteristics, the amount of water available from streams varies greatly between different parts of the country.

Average annual runoff for the period 1931-60 is shown in figure 3–2–4. The lines show points of equal runoff at its place of origin where it first collects in the stream channel. In general, the yield of a basin is less than that indicated

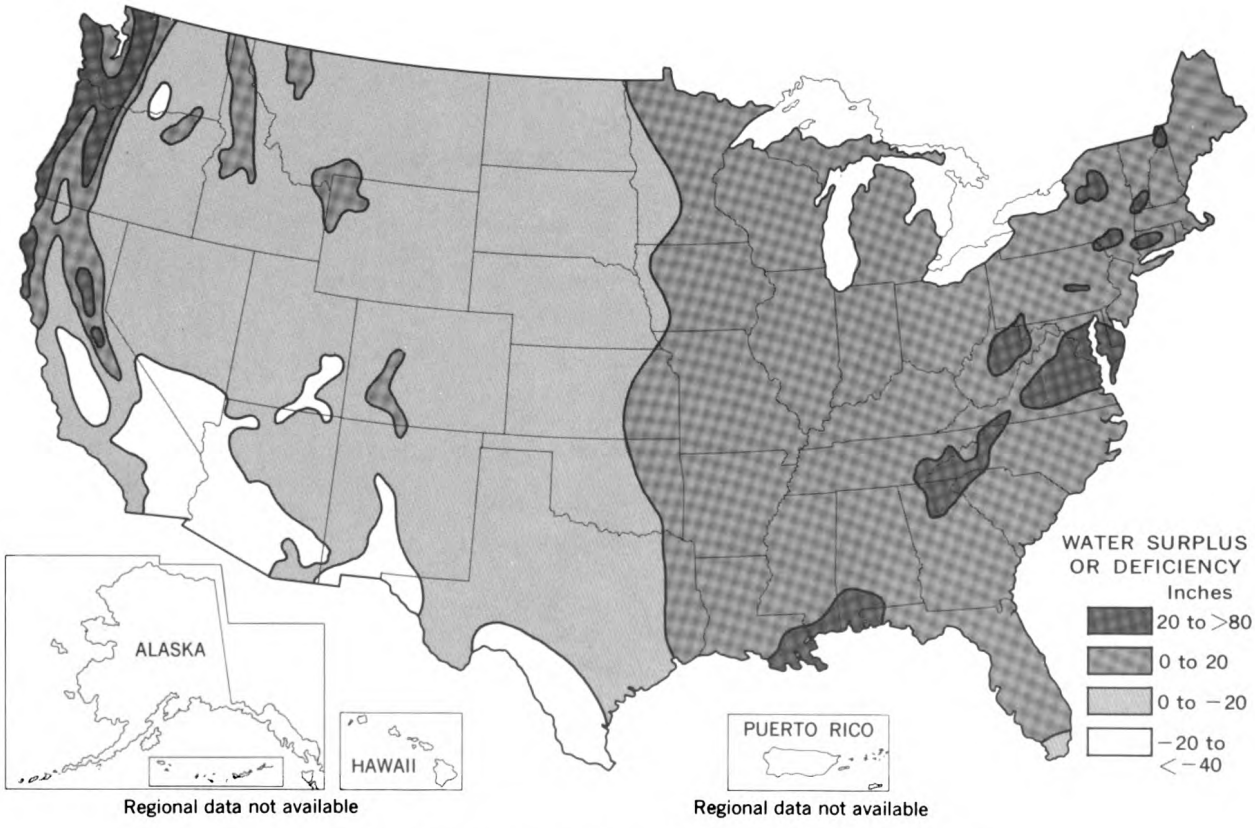

FIGURE 3–2–3.—*Areas of natural water surplus and natural water deficiency.*

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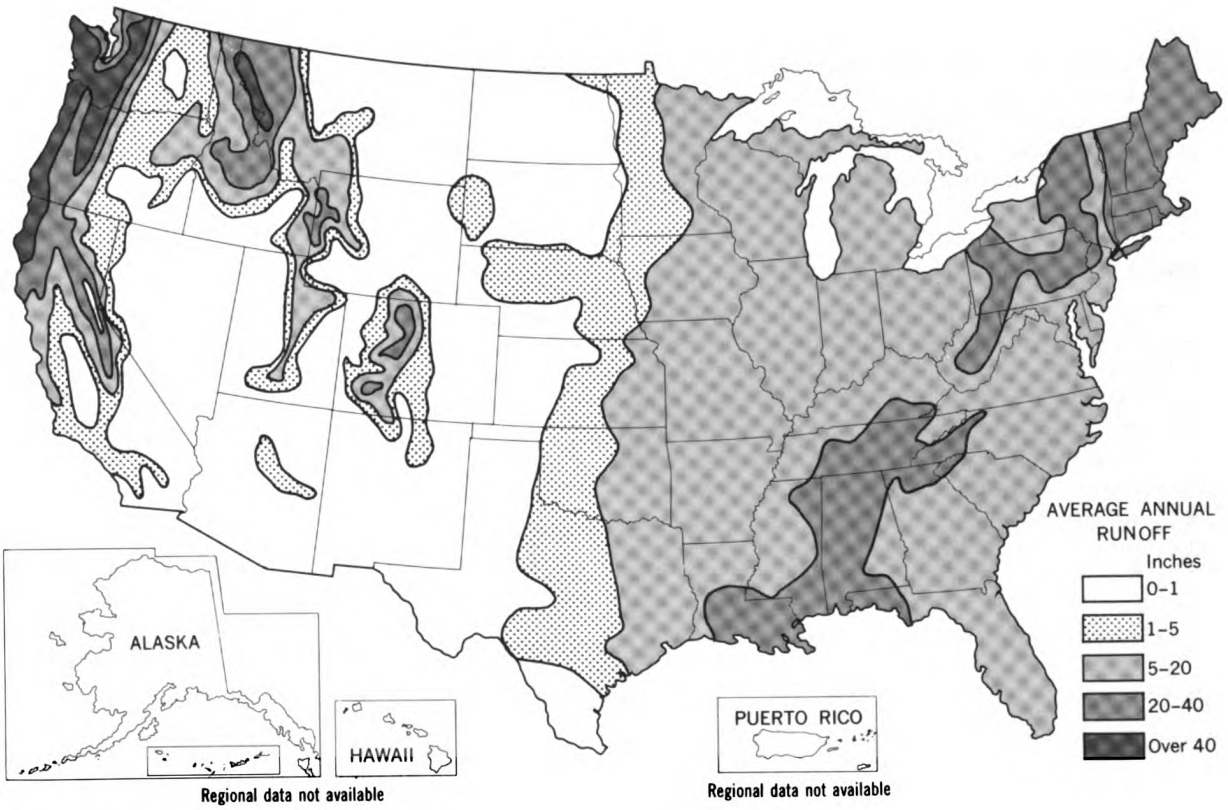

FIGURE 3–2–4.—*Average annual runoff.*

by the map because of evapotranspiration from channels and other losses.

Average annual runoff ranges from near zero in the Great Salt Lake Desert to more than 150 inches in the Olympic Peninsula. It exceeds 10 inches in the third of the country in which the climate is considered humid, and it is less than 1 inch in the third of the country considered arid.

Natural Runoff

Data in the National Assessment are based on natural runoff, which is the annual flow of water that would appear in surface streams if there were no upstream development. In some cases, natural flow is estimated from measurements made at key gaging stations with adjustments for upstream consumption, changes in reservoir storage, and evaporation from reservoirs and stream channels. In other cases, it is derived from precipitation-evapotranspiration-runoff relationships. In areas of surface water-groundwater continuity, the natural runoff includes the perennial recharge or yield of groundwater aquifers. Virgin flow, a term used in several regional chapters, is always measured at key gaging stations and adjusted for upstream effects of man. No adjustment is made for natural channel losses and therefore virgin flow tends to be less than natural runoff. Thus, natural runoff is a measure of water availability at and along streams and rivers where it first runs off and virgin flow is a measure of the same water availability at a specific point on a stream or river. Although natural runoff and virgin flow make the same adjustments for upstream effects of man in an attempt to indicate the total water supply available for development, neither measure, in this Assessment, incorporates atmospheric or watershed changes, caused naturally or by man, which may cyclicly or systematically change the average runoff.

The mean annual natural runoff of each of the 19 water resources regions in the United States is given in table 3–2–1. Mean annual runoff is an indication of the theoretical upper limit of sustained water supply from streams that could be developed by storage and regula-

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tion. The mean annual natural runoff of the conterminous United States is about 1,200 bgd. The mean natural runoff of the Alaska Region, 580 bgd, is almost 50% of the natural runoff of the conterminous 48 States. This Alaska resource represents the Nation's largest block of undeveloped water supply.

Variability of Annual Natural Runoff

Statistics of annual runoff other than the mean are useful in appraising the surface water resource. Annual runoff available 50%, 90%, and 95% of the years (table 3–2–1) was computed from statistical distributions of annual runoff at 700 gaging stations in the conterminous United States. In table 3–2–1, for example, the average annual runoff from the North Atlantic Region would be greater than 112 bgd in 95 years out of 100 years on the average.

The variability of annual runoff is seen by comparing the runoff exceeded in 95% of the years with the average. In the North Atlantic Region, for example, where the annual runoff tends to vary least from year to year, the annual runoff exceeded in 95% of the years is 69% of the mean. In the Lower Colorado Region, on the other hand, where the annual runoff varies widely from year to year, the annual runoff exceeded in 95% of the years is only about 25% of the mean. The variability of the annual runoff in the other regions lies between these extremes. In general, the areas of least variability in annual runoff are in the northwest, the northeast, and the southeast, whereas the areas of greatest variability are in the southwest and west-central parts of the United States.

The runoff shown as being exceeded in 95% of the years in each of the regions and subregions has an average recurrence interval of once in 20 years and that shown for 90% of the years occurs one year in ten. The runoff shown for 50% of the years is equaled or exceeded every other year on the average, but, due to chance alone, several successive years may all be above or all below this median value. Where the distribution of annual runoff does not conform to a statistically normal distribution, the runoff to be expected in half of the years is less than the average runoff.

TABLE 3–2–1.—*Annual natural runoff*

(Billions of gallons per day)

Region	Mean	50% [1]	90% [1]	95% [1]
North Atlantic [2]	163	163	123	112
South Atlantic-Gulf	197	188	131	116
Great Lakes [2 3]	63.2	61.4	46.3	42.4
Ohio [4]	125	125	80.0	67.5
Tennessee	41.5	41.5	28.2	24.4
Upper Mississippi [4]	64.6	64.6	36.4	28.5
Lower Mississippi [4]	48.4	48.4	29.7	24.6
Souris-Red-Rainy [2]	6.17	5.95	2.60	1.91
Missouri [2]	54.1	53.7	29.9	23.9
Arkansas-White-Red	95.8	93.4	44.3	33.4
Texas-Gulf	39.1	37.5	15.8	11.4
Rio Grande [5]	4.9	4.9	2.6	2.1
Upper Colorado [6]	13.45	13.45	8.82	7.50
Lower Colorado [4 5]	3.19	2.51	1.07	0.85
Great Basin [4]	5.89	5.82	3.12	2.46
Columbia-North Pacific [2]	210	210	154	138
California [5]	65.1	64.1	33.8	25.6
Conterminous U. S. [7]	1,201			
Alaska [2]	580	[8]	[8]	[8]
Hawaii	13.3	[8]	[8]	[8]
United States [7]	1,794			

[1] Flow exceeded in indicated percent of years.
[2] Does not include runoff from Canada.
[3] Does not include net precipitation on the Lakes.
[4] Does not include runoff from upstream regions.
[5] Does not include runoff from Mexico.
[6] Virgin flow. Mean annual natural runoff estimated to be 13.7 bgd.
[7] Rounded.
[8] Not available.

Seasonal Variability

Throughout most of the conterminous United States, the within-year cycle varies from the high flows during spring to low flows during late summer to early winter (table 3–2–2). There are sizable areas, however, that differ from the regional patterns. Thus, in southern Florida the high flow is in October and the low in May; and in southern Arizona the high is in midsummer and the low in November. Other local exceptions can also be found.

Effect of Variability on Development and Management

Even at levels of development such as those indicated by the annual runoff available in 90% and 95% of the years, storage would be required to make the indicated flow available. Although the average annual runoff is sometimes assumed to be the theoretical upper limit of supply, in some regions the storage that would be required to augment the runoff during below-average years would be so large that the resulting loss by evaporation from the required reservoirs would decrease the amount of water available for supply. Thus, the percentage of mean annual runoff that is available for development depends on the variability of the annual runoff, the storage and surface area of the reservoirs, and the evaporation potential, all of which vary from place to place. For this assessment, the

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TABLE 3–2–2.—*Seasonal variation of natural runoff*

Region	Months of high flow	Months of low flow
North Atlantic	March, April	August, September
South Atlantic-Gulf	February, March	September, October
Great Lakes	April	January, August, September
Ohio	March	September, October
Tennessee	March	October
Upper Mississippi	March, April	January, September, October
Lower Mississippi	March	October
Souris-Red-Rainy	April	January, February
Missouri	March, June	January
Arkansas-White-Red	April, May, June	January, September
Texas-Gulf	March, May	August, October
Rio Grande	May	June
Upper Colorado	June	January, February
Lower Colorado	March, April	June, November
Great Basin	June	September, January
Columbia-North Pacific	February, April, May	January, February, August, September
California	April, May	September, October, December

storage requirements have not been determined; instead, values of annual runoff representative of various frequencies have been presented as indices of the supply. Storage is required to regulate the flow within these dry years as well as to store part of the flow of wet years to increase the flow available in dry years.

GROUNDWATER

Groundwater aquifers presently supply about 22% of the Nation's withdrawal use of water. Groundwater also provides the base flow of streams, and in some regions it gives to the streams a continuity of discharge they would not otherwise possess. The magnitude and importance of the groundwater resources is shown by the annual national investment of over half a billion dollars to drill nearly half a million water wells. Further, groundwater aquifers may be expected to grow in importance as underground reservoirs and as regulators of water supply through techniques of artificial recharge, artificial storage, and induced infiltration.

Groundwater is difficult to inventory. Being invisible it can be expensive to locate. However, it has been estimated that the total storage greatly exceeds the volume of all five Great Lakes and that the usable portion is 150 times the amount of water used in this country in 1965. About one-half the country is underlain by rock material that could yield at least 50 gpm to wells. Water-bearing aquifers can be purely local or they may extend for hundreds of miles like those in the northern Great Plains.

Distribution of Groundwater

Spatial variations in geology and vagaries of climate complicate the distribution of the groundwater resource. Perhaps less than 10% of the rocks and soils economically accessible to water-well drilling rigs are of the types that yield water readily to wells—for example, gravel, sand, and certain sandstone, limestone, and basalts. These water-productive rocks are extensive and thick in some places, lenticular or thin in others, and absent in still others. Moreover, some of the groundwater reservoirs receive ample replenishment from rain and snow, even more than they can accommodate; but others, perhaps of equal water-yielding capacity, may receive small and even negligible replenishment. For instance, aquifers in the wet eastern United States are matched by comparable ones in the western arid alluvial basins, but differences in precipitation generate great disparity in opportunities for long-term withdrawals.

These irregularities in geology and climate, and the characteristically unsteady hydraulic conditions caused by pumping, add up to an intensely complex resource requiring detailed hydrologic analysis as a prerequisite to intelligent planning and management.

Large groundwater supplies are available in the United States, as seen in figure 3–2–5. The Atlantic and Gulf coastal plains contain the largest reserve of groundwater in the Nation. Present pumpage is but a small fraction of the supplies that could be developed. However, salt-water encroachment along the Gulf and Atlantic Coasts is a limiting factor in groundwater development.

Perhaps the next most significant area of potential groundwater development is the series of alluvial basins in the Far West. These are alluvium-filled valleys surrounded by mountains from which they receive runoff replenishment. The area is prevailingly dry, but the alluvial deposits are usually very thick and they now store water equivalent to centuries of recharge. In this area conjunctive development of streamflow and groundwater in storage is becoming a necessity, owing to water demands of large-scale irrigation and of population centers such as

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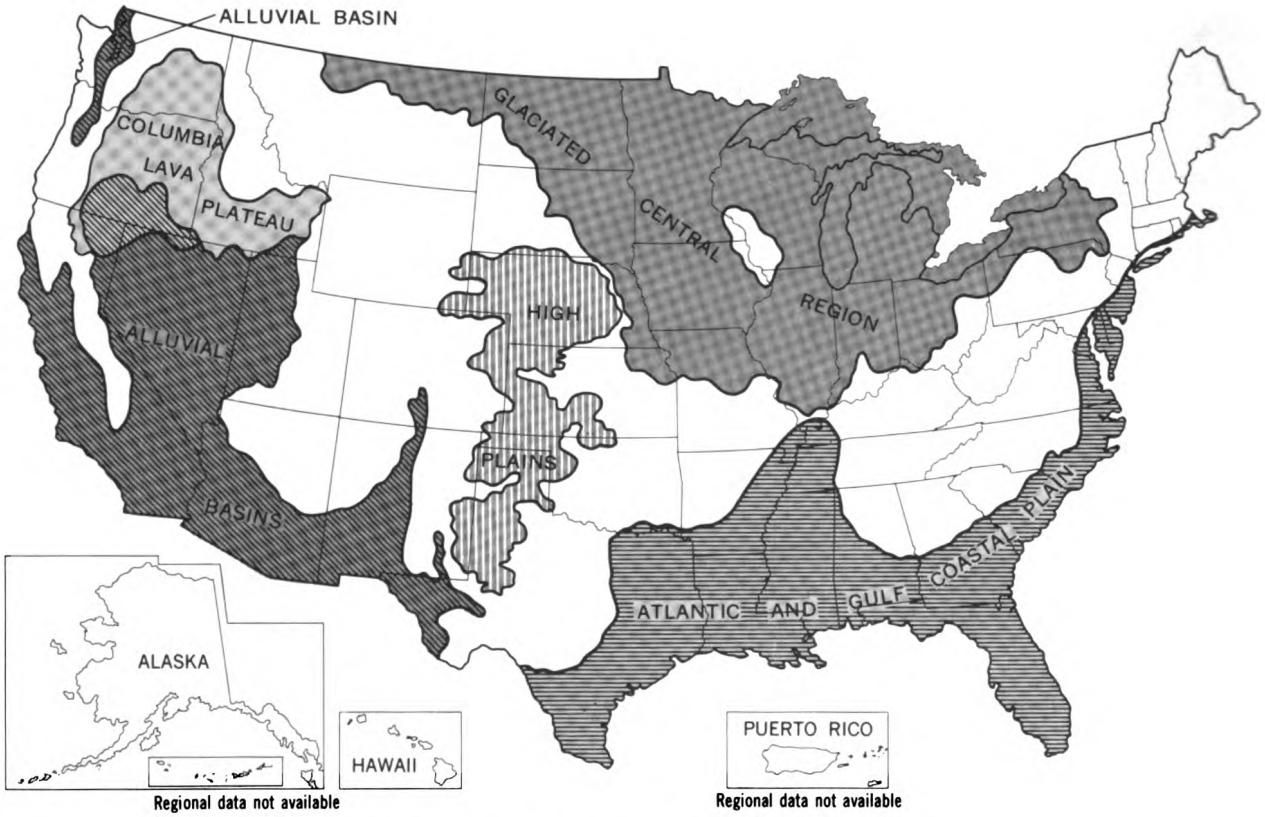

FIGURE 3–2–5.—*Major areas of potential groundwater development.*

metropolitan Los Angeles, Phoenix, and Albuquerque.

Still another area with important potential for large additional groundwater development is the northern part of the Nation encompassing the area of glacial deposits extending from the Rocky Mountains nearly to the Atlantic Coast, and southward as far as the Missouri and Ohio Rivers. The rock and soil debris left by the glaciers contain beds of water-sorted permeable sand and gravel that constitute an important source of water. Favorable prospects for additional large development are outwash deposits, particularly where these deposits coincide with existing streams, which provide opportunity for inducing infiltration of stream water by pumping the adjacent ground water.

The High Plains area, a large remnant of a vast alluvial apron, has large quantities of water in storage. This remnant extends northward east of the Rocky Mountains in a wide band from Texas to South Dakota. In the southern part of the Plains irrigation pumpage from wells amounts to 7 bgd. This is over 10% of the national total groundwater pumpage. The southern part of the High Plains is a classic example of groundwater mining with withdrawals greatly in excess of replenishment.

Development of groundwater in the Columbia Lava Plateau of northwestern United States has been relatively light, and a great reserve remains. Certain volcanic rocks, such as those in the Snake River plains area, are highly productive groundwater aquifers. The area also contains numerous productive alluvial basins.

Elsewhere in the Nation the groundwater potential is smaller, although locally there may be moderately large supplies.

Hydrologic Controls on Development and Management of Groundwater

Withdrawal from the groundwater reservoir must be balanced by recharge or by decreased storage in the reservoir. The reservoir may be a simple layer of sand or a complex of all water-bearing elements in a river basin. However, this simple concept has limited value in many practical problems of groundwater supply.

Dynamic equilibriums that occur in nature are upset when water is withdrawn from wells, and the resulting movement of groundwater in

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a given basin must be considered in development and management decisions. A new well necessarily upsets any previous equilibrium, because all water discharged from the well must be balanced by a loss of water somewhere. This loss is always to some extent, and in many instances largely, from storage in the aquifer, as evidenced by the deepening and expansion of the "cone of depression"—the form taken by the pressure surface around the well in response to the demands of the well for water. Over time, the cone may spread to a recharge area where, because of depressed groundwater levels, additional water from rain or a stream is induced to enter the aquifer, compensating at least in part for the withdrawal from the well. After sufficient pumping time has elapsed for the cone to reach an area of natural discharge, such as a spring or streambed, further discharge by the well will be compensated in part by reduction in flow in the surface stream.

Modern approaches to complex groundwater problems require construction of electric-analog, digital, and mathematical models. These computational and analytic techniques allow the whole system to be tested under assumed conditions in its different parts until the most desirable or equitable distribution of available water is determined.

FLOODS

Floods are natural events caused by excessive rainfall, melting snow, or ice jams. Large flows seeking their way to the sea have carved stream channels and flood plains according to the geology and topography, thus creating the stream system of the United States. Because of the encroachment of society on the flood plains, a flood can be a nuisance, a hazard, or a disaster. Damaging floods occur in all parts of the United States.

Floods can be controlled to some degree by reservoir storage, levees, and channel improvements. However, flood damage in the United States continues to increase despite flood control measures that have been instituted.

Seasonal Aspects

Because of prevailing rainfall and temperature patterns, winter and spring are the dominant flood seasons for much of the country. Moist air masses yield rainfall over large areas in excess of infiltration capacities of the soils. The resultant runoff, though moderate on small areas, concentrates in rivers and causes major flooding. Conversely, severe but areally small summer thunderstorms with intense rainfall cause major floods on small headwater streams, with moderate or no flooding on rivers.

Along the Gulf Coast and in Florida, the predominant flood season occurs from August through October when heavy rainfall and tropical hurricane rains influence the runoff pattern. Occasionally, as in 1955 with hurricanes Carol and Diane, tropical storms have traveled northward along the Atlantic Coast and caused major flooding on both small and large streams as far north as New England.

Regional Significance

Flood characteristics vary considerably over the United States. In the desert areas of the Southwest and in the Great Plains, thunderstorms cause severe floods on small areas. In the humid rain forest of the Olympic Peninsula, widespread storms moving inland from the Pacific Ocean result in moderate but sustained rains which cause flooding. In contrast, snow accumulation and melting is a major factor in the northern and northeastern United States; and ice jams frequently create backwaters that intensify the flooding. In the western part of the United States, climate and flood potential are closely associated with the physiography. Warm, moist air moving inland from the west drops most of its moisture as rain on the coast, or as rain or snow on the high mountains, creating a rain shadow over the eastern slopes of the mountains and the areas of lower altitude to the east. The generally rugged terrain from the Rocky Mountains westward causes a wide range in precipitation, resulting in a wide range in flood characteristics.

Recent Floods

Since 1960, major floods have occurred in most parts of the country, but the Upper Mississippi has been particularly affected. Areas in this region were inundated in 1961 and again in 1965. Record high flood stages were measured in both instances.

West Virginia was also subjected to two floods. Very intense rainfall in July 1961 struck a small area around Charleston, causing the death of 22 persons. The flood of March 1965 was much more widespread, extending from West Virginia and Ohio to Georgia.

The Western States were hit twice in 1964—the first, during June in northwestern Montana, where 34 lives were lost; the second flood was

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the extremely damaging Christmas flood in the Pacific Northwest, where the death toll reached 47.

The June 1965 flood in the South Platte and Arkansas River Basins in Colorado and Kansas caused 16 deaths; with heavy storm damage at Denver.

The estimated property damage from these seven events totaled about one billion dollars.

DROUGHT

Droughts are extended periods of subnormal precipitation and are caused by natural variation in the weather. The effect of a drought, however, depends on the climate and on how man has adapted to his environment. The effect on human activities is related directly to the concentration of human beings and to the normal pattern and intensity of human activity in the area. In arid areas where man customarily depends on surface or on groundwater for irrigation and municipal supply, the lack of rainfall for a few months may not be noticed; but in humid areas where man relies more on water from current rainfall, lack of rain for a few months could bring disaster to the farms and even to some towns and cities.

Agricultural drought occurs when the soil moisture is so depleted that the normal yields of crops, pastures, and forests are reduced enough to result in economic loss. In general, an agricultural drought is terminated either by rainfall or by the end of the growing season, but depleted soil moisture can have a carryover effect on ground-water storage.

A water-supply drought, on the other hand, may persist and intensify from one season to the next. Water-supply shortages during drought are more related to the facilities provided for collecting, storing, and delivering water than to natural availability of water. Gradual increases in demands by population and industry when coupled with a sudden drought often result in severe restrictions on water use.

A recent drought, major in terms of area extent and duration, began in the northeastern part of the United States in the early 1960's. Streamflow through the summer of 1961 was near normal for the area, but in September streamflow began to recede to below normal for much of the area from Maine southward into Pennsylvania. From September 1961 through the summer of 1966, the drought spread and intensified as precipitation in general remained considerably below normal.

The drought extended over an area from Massachusetts to southern New Jersey. Precipitation for parts of this area averaged 1 inch per month less than normal for the 51-month period of October 1961 through December 1965. Thus, precipitation was in the order of 30 to 35 inches per year, which is more typical of eastern Kansas than of the Northeast. A drought of this duration can be expected to occur on an average of once in about 160 years.

The effect of the drought on agriculture was a reduction in the yield of crop and pasture lands and an increase in the threat of forest fires during the summer of each year. These effects tended to become more severe as the drought continued but, in general, they varied with the weather in each growing season.

The effect on public water supply also increased with the duration and intensity of the drought. Unlike the effect on agriculture, the effect on public water supply tended to be cumulative as water stored in reservoirs was drawn down year by year while low streamflow and ground-water levels persisted. Although the great majority of public water supplies continued to meet the requirements placed upon them, more than 100—about 1 out of 8—had to adopt emergency conservation measures in 1965 after their reserves had reached critically low levels.

WATER QUALITY

The quality of water determines its suitability for an intended use. If the water is not suitable in its raw state, it can be made so by proper treatment at a price that may or may not be economically justifiable. Water-quality data provide the facts for assessing the economic value of water for specific beneficial uses.

Some of the more common problems associated with the use of water containing excessive amounts of dissolved solids are the deposits that accumulate on metal surfaces and the staining by the dissolved iron found in most ground water. Less common is the highly saline water found in some parts of the arid West that cannot be used for irrigation or domestic supply and the high color in waters of the Southeast that is difficult to remove.

The quality of a natural water source is determined by and is a product of the geologic and hydrologic influences present in a basin and

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also of such manmade influences as regulation of flow, discharge of wastes, and accelerated soil erosion.

Geologic Influences

Most dissolved and suspended material in natural water originates from weathering of soils and rocks. Generally, igneous rocks are only slightly soluble, and water running over and percolating through such rocks contains relatively small amounts of dissolved matter. Sedimentary rocks, on the other hand, usually are more soluble and impart larger amounts of dissolved matter to water in contact with them.

As sedimentary rocks are more prevalent and more porous than igneous rocks, their distribution and character have a major effect on water quality. Significant concentrations of dissolved materials, such as sodium, calcium, magnesium, chloride, and sulfate ions, are commonly associated with evaporite rocks and with other sedimentary rocks retaining brine from former marine environments.

Hydrologic Influences

Large floods generally decrease the dissolved chemical content of water in streams, lakes, and reservoirs, but may have the opposite effect on sediment loads and concentrations. As precipitation is almost completely free of dissolved matter, the surface runoff that results from heavy precipitation dilutes the ground water effluent that in drier periods maintains the streamflow.

On the other hand, large floods nearly always are accompanied by substantial and often very large increases in sediment loads carried by streams. Sediment concentrations as high as 50,000 ppm are fairly common in southwestern streams during floods. Some of this sediment comes from erosion of land surfaces and some from erosion of streambanks and channels in the steeper reaches of the stream. Most of it is deposited in overbank areas and on the streambeds of flatter slopes farther downstream. A particularly bad effect of floods is the movement of sediments into reservoirs where much of it is deposited, thereby reducing the reservoir's effective capacity.

Within-the-year variations in streamflow result in cyclic changes in the quality of surface water. When flow is high, concentrations of dissolved material generally are low, but when flow is low the concentration usually increases because much of the flow comes from the more mineralized groundwater. During droughts the low-flow concentration is intensified because practically all streamflow then consists of the more concentrated ground-water effluents. Groundwater usually is more mineralized than surface water owing to its longer and more intimate contact with weathered rocks and soils.

Droughts may also cause an increase in the growth of algae and in the undesirable tastes and odors that waters high in organic matter sometimes acquire when treated for potable supply.

Geographic Variations

Rivers and groundwater aquifers are natural drainage ways with an enormous capacity for transporting natural salts and particles dissolved from rocks and from weathering of soils. To a large extent, natural processes—precipitation through the atmosphere, streamflow across the land, and underground seepage and groundwater flow—set the base for the quality and composition of water, and produce the areal variation in quality of water shown in figures 3–2–6 and 3–2–7. The concentrations shown in these figures are those which are exceeded half the time.

Figure 3–2–6 shows that the concentrations of dissolved solids in streamflow tend to be lowest in areas of plentiful precipitation, such as east of the Mississippi River and in the Pacific northwest, and highest in areas of incompletely leached rock, such as the semiarid lands of the Southwest. The average concentration of dissolved solids in the water discharged to the oceans from the conterminous United States is about 130 ppm, or 225 million tons per year, which is equivalent to 82 tons from each square mile of the land area.

Figure 3–2–7 shows that the amount of sediment carried by stream-flow tends to follow the same geographic pattern as dissolved solids. The low concentration in areas of plentiful precipitation can be largely attributed to the dense vegetative cover in those areas. The high concentration of sediment load in the Southwest is due to the sparse vegetation and the infrequent but often intense rainfalls characteristic of semiarid regions.

Effects of Land Use and Management

The use and management of watershed lands have profound effects on water quality. Sediment resulting from erosion processes is not only the most abundant physical pollutant in streams and lakes, but also provides transport for other pollutants. Although sediment from some areas with fragile soils, scant cover, and subject to

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ppm. A stream draining agricultural land, however, may contain twice these amounts. Superimposed is the enriched effluent of sewage treatment plants in which the phosphorus content from an activated sludge plant may be from 10 to 25 ppm and the nitrogen content from 35 to 50 ppm. For example, the daily nutrient contribution to the Potomac River estuary from Washington, D. C., sewage effluent discharge is estimated to be more than 22,000 pounds of phosphorus and more than 68,000 pounds of nitrogen. The estuary cannot assimilate this quantity of nutrients without producing algae blooms, aquatic nuisance conditions, and environmental stresses on aquatic life. At times, algae population is more than 10 times that normally found in tidal systems.

METHODS OF INCREASING WATER SUPPLIES

The supply of water that can be made available for use depends upon the water supply potential and on the facilities that have been or are constructed to utilize the resource. The usable supply in most areas, however, can be further increased by improvements in water management practices, as well as by existing and emerging methods for increasing the potential supply.

Improved Water Management

There are many possibilities for using water-management methods to increase the supply of water available for use. Some of these methods provide for redistributing water in time and place while others provide for salvaging water that would otherwise be wasted.

Regulation by storage is the most widely used method of water management. The 1,400 reservoirs of more than 1.6 billion gallon (5,000 af) capacity now in use in the conterminous United States have a total usable capacity of 120,000 billion gallons (360 maf), which is used mostly to regulate streamflow for power production, flood control, and irrigation and municipal supply. Full development of the potential supply, however, would require three times as much storage capacity. As suitable reservoir sites for this much storage are probably not available, full development would require that part of the capacity be supplied by groundwater reservoirs that could be depleted during extended droughts and recharged during years of excess runoff. Improved hydrometeorological and snow-melt forecasting together with systems operation of surface water and groundwater supplies are needed to realize optimum water supply management.

Although interbasin diversion has long been used to equalize the supply and demand of water, the amount is small in comparison to that involved in some of the large-scale regional plans that are now being considered. If water that cannot be used in humid parts of the country is transported and used in arid parts, the usable supply of water is in effect increased.

Additional water can be made available for use by reducing conveyance losses and by suppressing evaporation from water surfaces. Conveyance losses of irrigation water amount to 22 bgd (25 maf/yr) and the leakage from municipal systems is unknown. Improved canal linings and better inventorying of water supplies will help to reduce and identify these losses. The water loss from lake and reservoir evaporation in the arid West is estimated to be over 10 bgd (11.2 maf/yr). Recent studies of Lake Hefner in Oklahoma indicated a reduction in evaporation of about 9% by the use of a monomolecular layer, although the potential for reduction is estimated at about 20%.

Land management, including vegetative manipulation, snowpack management, and phreatophyte control, can be utilized to increase water yields. Increases of as much as 16% in yield for several years have been measured in the humid East as a result of cutting riparian vegetation in the valleys of small streams. An intensive program of phreatophyte elimination, particularly in the Southwest, could conserve for some beneficial use about two-thirds of the estimated 22 bgd (25 maf/yr) of water transpired by these plants. Only a small portion of this would result in added streamflow.

Another method of effectively increasing the usable supply of water is through improved water quality management. By means of effective water quality standards, increased waste treatment, low-flow augmentation, and alternative waste disposal methods, water of otherwise unusable quality may be upgraded for further use and reuse.

Recycling and reuse of water do not increase the supply of water available for development, but rather reduce the demand imposed upon the supply. The use of water for process cooling in industry is by far the largest reuse application. Water use by industry now averages about two gallons for each gallon of new water that is withdrawn. The highest recirculation ratios are in the petroleum products, coal products, rubber, and plastic industries and in the pro-

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duction of papers and chemicals. Heat is the principal component that must be removed in reuse and recycling, but contaminants such as chemicals, organic wastes, and microorganisms must also be removed. Reuse and recycling of water will undoubtedly increase as new industrial plants provide for the necessary treatment and as steam-electric powerplants using fossil and nuclear fuel become more numerous.

The Ocean as a Water Resource

At present about 11% of the Nation's water withdrawals are from saline sources, most of which are from the ocean or other tidewater sources. The direct use of saline water is expected to grow to about 40% of withdrawals by 2020. Most of the saline water is used for cooling in industrial processes and in steam-electric power condensers.

In addition, saline water is being used to produce fresh water through desalting processes. Research and development programs in the past 15 years have advanced desalting technology to the point that economical conversion of saline water to fresh water is becoming more widespread. Currently, there are nearly 300 land-based desalting plants in operation or under construction in the United States or its possessions, each with a capacity of 25,000 gpd or more. Of the total combined capacity of 42 mgd, about 19 mgd is obtained from 11 plants of one mgd or greater capacity.

The range of desalting methods includes some which have existed conceptually for centuries and others which have been developed, in theory and in fact, only in recent years. In the United States, a number of processes are being studied and developed. Some of them are being used commercially while others are at the pilot-plant stage or at the laboratory stage. Each process has a potential effectiveness and application, and they vary widely among the processes depending on the relevant costs and associated rates of conversion.

Conversion processes can be conveniently divided into four broad groups or categories: (1) distillation, (2) membranes, (3) crystallization, and (4) other processes. The major costs are the capital investment, and the cost of energy used in the conversion plant.

The distillation or evaporation processes involve the conversion of salt water into sweet-water vapor and then its condensation. The major process types in this group are multiple-stage flash distillation, multiple-effect (LTV) distillation, vapor compression, and humidification (solar process). The major research emphasis is on development of materials which resist corrosion yet maintain their requisite heat transfer properties; and development of methods for minimizing or eliminating the compounds which increase corrosion and scale formation, such as calcium sulfate.

Membrane processes involve diffusion through a semipermeable membrane. While still in the liquid state, salt and water are separated. The major types are electrodialysis and reverse osmosis. In this area, major emphasis is being placed on the reverse osmosis process. Pressure in excess of the osmotic pressure of the saline feed is applied to a permselective membrane and as a result, water passes through. Another membrane process being studied is electrodialysis, which involves the selective passage of ionic salt species through alternating pairs of cation- and anion-selective membranes under the influence of an electrical potential. The process may be economical for brackish waters. Efforts are being directed toward the development of membranes which will be more resistant to pollutants.

One process of crystallization is freezing which involves separation of pure water solids (ice) from a salt solution. The two major types are direct or vacuum freezing and secondary refrigerant. A second process is that based on use of a hydrate-forming material to combine with water to form a solid clathrate. The parameters of heat and mass transfer which limit the various solidification, washing, and melting steps are being studied with particular emphasis on nucleation and growth of ice and hydrate crystals.

The quest for new processes has led to significant findings of potential promise in the area of electrode demineralizers, environmentally modulated ion absorption beds, new hydrate processes, electrogravitational separation techniques, and the transport depletion and electro-sorption processes.

Research and development have been and are centered on improvement of water conversion processes and on cost reduction. Sometime beyond 1975, the cost of desalting may become attractive for irrigation purposes in selective areas. These future decreases in desalting costs hinge on continued development and improvement of processes and technology for large-scale desalting, and on the attainment of low cost heat and power sources such as from advanced nuclear breeder reactors.

Engineering and economic feasibility studies are under way on possibilities for augmenting

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existing water supplies by desalting in many areas in the southwestern part of the United States. A major step in the development of desalting technology is a proposed nuclear power and desalting plant to be located near Los Angeles. This is a cooperative effort of the Metropolitan Water District of California, private and public utilities, and the Federal Government to design, construct, and operate a dual-purpose plant. Using sea water as feed, this plant will produce 150 mgd of fresh water and 1,500 megawatts of electricity. The first phase (50 mgd) is scheduled for completion in 1974, and full operation is planned for 1976. The Governments of Mexico and the United States are conducting preliminary joint studies of 1,000 mgd desalting plants to provide new water supplies for the portions of Mexico, California, and Arizona adjoining the Gulf of California. Reconnaissance studies also have been made of a preliminary plan for augmenting the flow of the Colorado River by about 1.8 bgd (2 maf/yr) by 2010 through desalting of sea water. Other significant desalting potentialities exist in meeting future water demands through desalting for a number of communities in coastal or inland brackish water areas.

Desalting of saline waters may also be of value in providing emergency water supplies and in drought proofing for large metropolitan areas in humid regions such as the Northeast. There is a further potential for desalting in the treatment of acid mine drainage and other polluted waters, and in improving highly saline irrigation return flows.

As water shortages develop, and as saline water conversion technology continues to advance, greater consideration will necessarily be given to desalting as a new water source. Ultimately, in all cases, the potential application of desalting in meeting new or supplemental water demands will depend on its associated costs and benefits considered within the framework of larger water and related land resources development programs.

The Atmosphere as a Water Resource

Atmospheric precipitation in the conterminous United States averages about 4,200 bgd of which about 1,200 bgd appears as natural runoff. However, these atmospheric precipitation processes are only about 10% efficient, and more than 37,000 bgd pass over the United States without falling to the earth. It is this vast potential source of water that atmospheric scientists hope to manage through weather modification.

Weather modification techniques for increasing water supplies are directed toward management of the atmosphere for optimum release of precipitation. To date, experiments with cloud seeding to increase precipitation suggest optimism for its potential. There is considerable evidence that under certain meteorological conditions a 10% to 20% increase in precipitation yield is possible over areas as large as 1,000 square miles. However, it must be understood that the possible increase for a given area is related to the characteristics of that area and that extensive research and development will be needed before these techniques can be used to substantially increase the available supply of water.

Research is being directed toward development of cloud seeding materials and instrumentation to measure effectiveness, the investigation of possible atmospheric side effects, and the accompanying legal, social, and environmental considerations. Three operational research projects are contemplated by 1970 in the southwestern, central mountain, and northwestern areas of the Nation. Limited operational programs can be initiated by 1972, and large-scale operational programs are contemplated in a selected area by 1975.

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CHAPTER 3

Related Land Resources

INTRODUCTION

Management of land and water are intimately interrelated. Many important relationships between land and water are direct, rather obvious and widely understood. Others, many of which are economic in character, are more indirect and obscure. The focus of this chapter is on the nature of these interrelationships.

Related land can be considered in two categories: that land which is affected by water resource development and that land, the use, treatment, and management of which affect the water resource and water resource developments. In the first case, lands irrigated, drained, protected from flooding or otherwise enhanced are included. Appropriate attention is given to these lands in parts 4 and 5 of this report. In addition, land involved in the storage, conveyance, and disposal of water is also included. This matter is considered further in this chapter.

The second category includes relationships which are not as clear-cut or perhaps as well understood. One relationship involves markets and prices for products and services of the land which require water as a production factor. Production of food, fiber and forest products is heavily dependent on both land and water. In terms of area and volume, agriculture is the dominant user of both. More importantly, agricultural demands for water in a given area or region are influenced greatly by the supply of both land and water for agricultural uses in other areas and regions. Hence, the pattern of water use in a given region or locale is influenced not only by available supplies within the area but by the demands and supplies in other regions. This relationship is given considerable attention in this chapter.

A second relationship involves the quantity and quality of water and the life of water resource developments as influenced by the land cover conditions and treatment practices. Without adequate conservation treatment, agricultural land adversely affects water quality principally through erosion. However, forest and grasslands providing good vegetative cover maintain water quality and with proper management can increase water yield. Patterns of urban and industrial growth cause a variety of problems, such as flooding, water pollution, and sedimentation, that are of concern in national and regional assessments of water problems. These relationships are considered in more detail in a following section of this chapter.

As a setting in which to view the relationship of land and water, the total land resource base—its control and use—is discussed. Land ownership, use and capability have an important bearing on the availability of land and its relationships to water.

THE LAND RESOURCE BASE—ITS CONTROL AND USE

Land Ownership

The land area of the United States and Puerto Rico is 2,274 million acres. The management of land varies with the type of ownership. The major types of ownership are shown in figure 3–3–1. The 766 million acres of Federally owned lands are concentrated in the Western States and Alaska. The Federal Government owns about 98% of the land area of Alaska; more than 50% of Idaho, Nevada, Oregon, and Utah; and from 20% to 50% of Arizona, California, Colorado, Montana, New Mexico, Washington, and Wyoming. Except for Alaska, no major change is expected in the amount of Federal land.

The area managed by Federal agencies is distributed as follows:

	Million Acres
Bureau of Land Management	482
Forest Service	186
National Park Service	28
Fish and Wildlife Service	27
Other	43
Total	766

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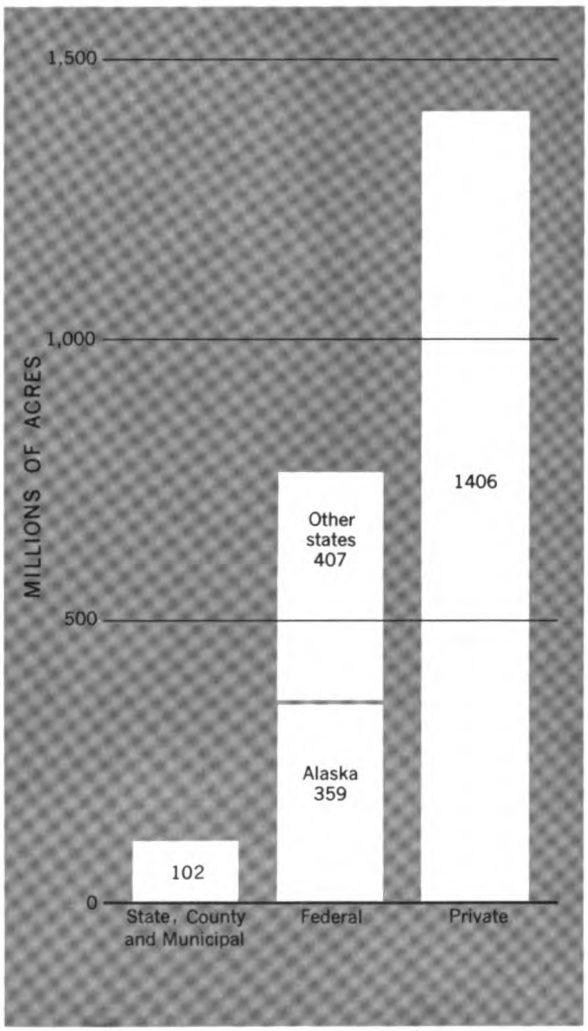

FIGURE 3–3–1—*Land ownership, 1965.*

Total non-Federal land amounts to 1,508 million acres, of which nearly 80% is in farms and ranches. These non-Federal lands embrace only 2% of Alaska, but 79% of the total land area of the 48 States, 91% of Hawaii, and 95% of Puerto Rico. In Alaska, the Statehood Act allows the State to select over 100 million acres from the unreserved public domain for its own use by 1984. This selection is under way and will ultimately transfer almost 30% of the land area of Alaska to State ownership.

The Land Resource

Physical classification of land is necessary to focus attention on proper land use and to point out the potential need and location of conservation practices to control erosion and overland flow of water. The system developed by the Department of Agriculture classifies soils in interpretive groupings according to their capabilities for agricultural uses. All non-Federal rural land is classified into eight capability classes with decreasing range of agricultural capabilities as the class number increases. This classification shows that 60% of the non-Federal rural lands is physically suitable for cultivation, and that 40% is suitable only for pasture and for forest, range, and other wild lands.

Urban land classification, on the other hand, is based on location as well as physical characteristics of the land. The proximity of seacoasts, waterways, transportation systems, and metropolitan areas all have a bearing on urban land classification. Thus, each case is unique to some extent.

Minor acreages of Federal rural lands are cultivated and additional small acreages are suitable for cultivation. But most Federal rural lands are suitable only for forest, range, and other wild land uses. They are usually managed for multiple uses and the sustained yield of products and services obtainable from them. The public lands have been classified into various designated use areas and management plans have been developed.

Classification systems for forest and related wild lands administered by public agencies are quite varied. The trend in land classification is toward more complex systems which portray the productive capability and management constraints under the various multiple uses. The factors to be recognized and evaluated in a rather complex system would include (1) physiographic, climatic, and soil characteristics; (2) hydrologic characteristics; (3) species composition; (4) stocking; (5) productivity, growth, and yield; (6) wildlife habitat characteristics and potential; (7) recreation opportunities and potential; and (8) management, protection, and development requirements.

The classification systems in use have not yet been standardized, and more developmental work needs to be done to provide a suitable capability classification system. However, the physical capabilities of the soil are basic considerations.

The land resource regions of conterminous United States are shown in figure 3–3–2. Because the land has a wide range of climatic, topographic, and soil and vegetative conditions, there is a wide range in land capabilities.

Land Use Trends

Most of the land area of the United States is available for agricultural purposes although the

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EXPLANATION

A Northwestern forest, forage, and specialty crop region

B Northwestern wheat and range region

C California subtropical fruit, truck, and specialty crop region

D Western range and irrigated region

E Rocky Mountain range and forest region

F Northern Great Plains spring wheat region

G Western Great Plains range and irrigated region

H Central Great Plains winter wheat and range region

I Southwestern plateaus and plains range and cotton region

J Southwestern prairies cotton and forage region

K Northern Lake States forest and forage region

L Lake States fruit, truck, and dairy region

M Central feed grains and livestock region

N East and Central general farming and forest region

O Mississippi Delta cotton and feed grains region

P South Atlantic and Gulf Slope cash crop, forest and livestock region

R Northeastern forage and forest region

S North Atlantic Slope truck, fruit and poultry region

T Atlantic and Gulf Coast Lowland forest and truck crop region

U Florida subtropical fruit, truck crop, and range region

FIGURE 3–3–2—*Land resource regions of the conterminous United States.*

intensity of use varies widely across the country. While the total acreage of agricultural land has fluctuated very little over the past 65 years, significant changes in major uses for agricultural purposes have taken place (table 3–3–1). Cropland has declined from a peak of 480 million acres in 1920 and 1930 to an estimated 444 million acres in 1965, an average decrease of about one million acres per year. Pasture and range have declined only moderately in recent years, whereas forest land and other land have increased steadily although the managed uses of these lands have changed. The steady increase in "other" lands reflects the expansion of urban acres.

TABLE 3–3–1.—*Trends in major land uses, conterminous United States, 1900–1965*

(Million acres)

Land use	1900	1920	1940	1960	1965
Cropland [1]	389	480	467	458	444
Pasture and range [2]	761	652	650	630	636
Forest [3]	610	614	630	637	638
Total agricultural land	1,760	1,746	1,747	1,725	1,718
Nonagricultural land [4]	142	156	155	177	184

[1] Cropland harvested, crop failure, cropland idle or fallow, and cropland used for pasture.

[2] Grassland pasture and other nonforested grazing land.

[3] Includes grazed forest land and reserved forest lands.

[4] Includes special land uses, such as urban areas, highways and roads, and parks and so on.

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About 23% of the land area is currently used as cropland, including cropland used as pasture. About 33% is used for open permanent pasture and range. Another 34% of the total area is forest land, some of which also provides grazing for livestock and wildlife. The remaining 10% is in other land uses, including about 3% for urban and related uses. About 4% is used primarily for public installations and facilities. The remaining 3% is mainly desert, bare rock, swamp, and land having esthetic and wildlife values or other uses. Estimates of land use in 1960 by water resource regions of the conterminous United States are shown in table 3–3–2.

THE INTERACTION OF LAND AND WATER

Water is both a catalyst and an active force in the formation of soils. Biotic activity, chemical changes, leaching, freezing and thawing, wetting and drying, erosion and deposition are some of the soil-forming processes involving water. Water resources play an important role in determining land use potentials and values. Soil and cover are the first modifiers of the rainfall runoff relationship and land management is a prime determinant. Land and vegetative cover management affects volume and distribution of water yields through its influence upon interception, snow packs, infiltration, and evapotranspiration.

In urban areas the use of land has major impacts on the water resources. Solid waste disposal and septic tanks may have adverse effects on water quality, especially in inland lakes. Also, flood peaks are increased as a result of paving and roof construction. On the other hand, urban areas yield a greater proportion of precipitation to downstream flow. If reservoir capacity is available, the increased yield will be useful.

Soil conservation and watershed management programs designed on a sound hydro-ecologic basis specify a variety of land treatment measures to be installed along with structures on upland watersheds to give the soil greater absorptive capacity and to decrease overland flow and sediment production. Such measures may be employed to improve the timing of yield and the quality of water. Since rainfall impact and the energy of flowing water are causal factors in soil erosion, the quality of runoff water

TABLE 3–3–2.—*Land use, conterminous United States 1960* [1]

(Millions of acres)

Region	Total land base	Cropland			Pasture and range	Forest	Non-agricultural land
		Total	Used for crops [2]	Idle and fallow [3]			
North Atlantic	106.3	17.6	15.4	2.2	8.0	66.7	13.9
South Atlantic-Gulf	167.2	29.6	24.3	5.3	16.7	108.9	12.0
Great Lakes	82.3	26.8	22.6	4.2	4.8	39.6	11.2
Ohio	102.2	39.3	34.8	4.5	12.5	40.2	10.2
Tennessee	27.3	6.5	5.4	1.1	2.7	16.4	1.7
Upper Mississippi	112.0	65.3	61.5	3.7	12.4	24.3	10.1
Lower Mississippi	41.7	14.8	13.1	1.7	3.5	17.7	5.6
Souris-Red-Rainy	33.5	20.5	15.0	5.5	4.1	6.1	2.9
Missouri	329.4	115.1	88.0	27.1	166.8	31.4	16.1
Arkansas-White-Red	170.4	51.0	38.8	12.1	59.4	45.0	15.1
Texas-Gulf	117.6	28.5	24.1	4.4	55.6	25.1	8.4
Rio Grande	87.5	2.8	2.2	0.6	59.7	14.1	10.9
Upper Colorado	65.0	2.0	1.7	0.3	32.2	22.3	8.5
Lower Colorado	98.8	1.8	1.4	0.4	57.8	28.6	10.6
Great Basin	87.2	2.9	2.1	0.7	57.0	20.9	6.4
Columbia-North Pacific	169.3	19.5	13.8	5.7	54.1	84.5	11.3
California	104.0	13.6	11.3	2.3	22.9	45.4	22.1
Conterminous United States	1901.8	457.5	375.5	82.0	630.1	637.3	176.9

[1] Values rounded.
[2] Includes cropland harvested and cropland used for pasture.
[3] Includes soil improvement crops and crop failure.

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is determined to a significant degree by land and cover management.

Soil erosion decreases the capabilities of land to support plant growth and thus destroys its value for agriculture and other uses. Eroded lands mar the beauty of the landscape and degrade the quality of our environment.

Return flows from irrigation in arid regions often cause salinity problems downstream. Runoff from agricultural areas can carry wastes which degrade the water quality. Acid mine drainage is a problem in many areas. Runoff from urban areas also degrades the quality of streamflow. The quality and to a lesser degree the quantity of streamflow is a reflection of land use in the watershed area.

Over 60% of the annual natural runoff originates on forest land, even though it represents only about one-third of the area of the 48 conterminous States. In the 11 Western States over 90% of the usable water originates in high altitude watersheds which are largely forested and predominantly in National Forest ownership. Therefore, the condition, use, treatment, and management of forest lands are matters of importance and concern in water resource planning and development.

Although fully stocked forests require water in their growth processes in quantities comparable to those used by field crops—probably an average of 25 inches per year—the values of the products together with the soil stabilizing and infiltration benefits more than compensate for the value of water used.

AGRICULTURAL PRODUCTION— ITS EFFECT ON LAND AND WATER

The Complementary Nature of Land and Water in Agricultural Production

Historically, agricultural economies have flourished in areas and regions with favorable conditions for plant growth. The locational influence of population centers, while still important in agricultural production, has declined as transportation services and marketing technology have improved. Thus, environmental considerations—soil, water, and climate—are increasingly important in the location of agricultural production and related economic activity.

The special importance of water management in agricultural production stems from two major factors. First, the full response from other components of plant growth—light and nutrients—cannot ordinarily be obtained when there are water surpluses or water deficiencies. Second, agricultural firms are reluctant to invest heavily in other production inputs when such investments are threatened by drought, poor drainage, or flooding. Thus, the elimination of a water problem results in more intensive use of the other growth components, higher levels of production, and lower costs per unit of output on lands thus affected.

It appears that high-quality lands have shown greater response to new production technology than have poorer quality lands. This would suggest a trend toward more intensive use of lands essentially free of water problems, or those high-quality lands on which water developments can be applied reasonably. Water disposal or water conservation programs on high-quality lands can lead to significantly greater efficiency in agriculture.

Irrigation, land drainage, and flood protection are increasingly developed in combination and are frequently associated with other forms of land development such as land clearing and leveling. The composite response, both physically and economically, is often greater than would be suggested by a simple summation of the individual responses.

Competitive Aspects of Land and Water Use

The demand for land and water for agricultural production reflects two major forces: (a) national demands for products derived from the land, and (b) substitution possibilities between land and water and other factors inputs. Demands for food and fiber have grown over time and continue to expand. The adoption of new technology has resulted in increased production without corresponding increases in land and water use. Patterns of resource use do not respond quickly to these forces, however, because of long-term capital commitments in established areas and the stabilizing influence of certain public programs. The influence of the indicated changes, however, is clearly evident.

Agricultural demands for irrigation, drainage and flood control are associated with the supply and productivity of all other lands available for agricultural production. Such demands are dependent not only on the productivity of other lands now available for agricultural use but on the potential productivity of lands improved by water resource developments. Agricultural use of water for irrigation is also dependent on the total supply available and its cost to agricultural firms. Agricultural use of lands improved by drainage or flood control are similarly affected

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by the value of other potential uses of such lands.

Growth of Agricultural Markets

The projections of population, employment, gross national product, and personal income provide a framework for projections of agricultural and forestry output. Population growth, however, is the most important single factor in determining the future demands. Requirements for agricultural products are also affected by changes in consumer income and other factors influencing the level and composition of diets such as the age distributions of the population, price levels and relationships, the development of both new uses and of synthetic substitutes for farm products, and levels of exports and imports.

Estimates of projected crop and livestock requirements, shown in table 3–3–3, are based primarily on analyses of demand and supply relationships since World War II. Crop yields, land uses, and other factors affecting estimated resource requirements are based largely on projections of levels and trends during the last decade or two.

Projections of timber production are based to a large extent on prospective timber supplies. These are based on projections of timber growth in the Eastern regions and projections of allowable cut in Western regions.

TABLE 3–3–3.—*Projections of agricultural and forestry output by major product groups*

Product group	Base [1]	Projections		
		1980	2000	2020
		Index numbers		
Feed crops	100	140	182	234
Food crops	100	150	196	261
Oil and fiber crops	100	144	182	235
Livestock and livestock products	100	142	196	273
Industrial timber products	100	124	150	165
Pulpwood	100	188	308	341

[1] For agricultural products, 1959–61=100, and for forest products 1962=100.

Production Technology

Improvements in production technology and practices in recent decades have been such as to increase agricultural output with smaller acreages of land. Expanded use of fertilizer, improvements of land, drainage, erosion control, factor and product prices, and control of plant and animal pests are prime examples. Levels of production have also been influenced by the quality of land resources utilized.

The continued substitution of capital and other inputs for labor and land as well as other shifts in the organization and use of resources will result in substantial gains in productivity in agriculture in the future. Particular developments that could result in increased productivity beyond 1980 are largely speculative. However, new scientific developments will continue in agricultural research. Accordingly, crop yields were projected to increase from 1980 through 2020. Projected rates of increase for most of the major crops, however, are greater to 1980 than for later periods.

Projected Land Requirements for Agricultural Production

The projected land use for major crop groups reflects the expected increases in productivity. In 1965, about 235 million acres of cropland were used to produce feed for livestock. By 1980, the acreage of cropland devoted to feed crops is projected to decline to about 200 million acres. Projected acreage of feed crops in 2000 and 2020, although larger than 1980, are less than acreage used for livestock feed in 1965.

Food crops, oil crops, cotton, and tobacco production will require larger acreages of cropland through the projection period. About 117 million acres of cropland were devoted to production of these crops in 1965. By 1980, a projected increase of 12 million acres will be needed. Similar increases have been projected for 2000 and 2020.

LAND AVAILABILITY AND PROJECTED USE

Projected Land Use

Projections of major land uses to 2020 are shown in figure 3–3–3. The greatest change will occur in nonagricultural land use, which is expected to increase over 50%. Agricultural land, with a much larger base, will decline almost 6%. Although permanent pasture and range acreage is expected to increase slightly, cropland harvested will decrease to 1980 and then increase, and forest land is predicted to decrease almost 12%.

Projected changes in land use within the various water resource regions are also substantial. The greatest decreases in total crop-

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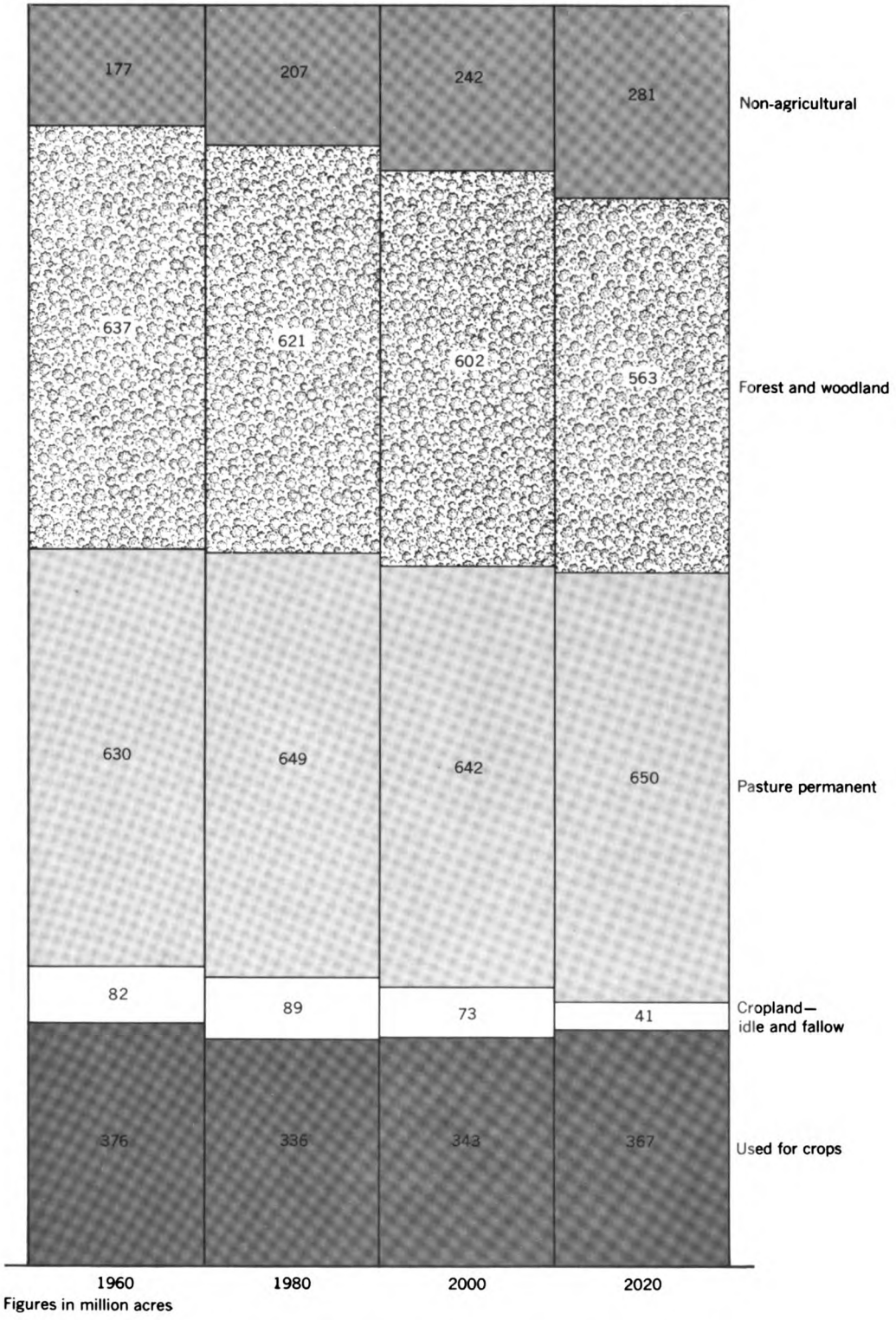

FIGURE 3–3–3.—*Projected land use, conterminous United States, 1960-2020.*

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land are expected in the North Atlantic, Ohio, and Great Lakes Regions; and the only Region with a projected increase is the Columbia-North Pacific. Substantial increases in permanent pasture acreage are projected for the Great Lakes, Lower Mississippi, and Arkansas-White-Red Regions; and California is the only Region in which a significant decrease is expected. Forest and woodland acreage, projected to decrease in all regions, will decrease most in the North Atlantic, Great Lakes, and Texas-Gulf Regions. Nonagricultural land use, expected to increase in all regions, will increase most in the North Atlantic, South Atlantic, Great Lakes, Ohio, and California Regions.

Trends in the nonagricultural uses of land are greatly affected by socioeconomic factors as well as by increases in population and technology. The metropolitan area has become the dominant feature of urban growth. Over 60% of the population resides in metropolitan areas. Twenty-six States had at least 50% of their people living in metropolitan areas, and California, with over 86% had the highest share of its people in metropolitan areas.

Increasing population combined with more leisure time, greater income, and mobility have resulted in increased recreation demand. Land for recreation areas is needed most in densely populated areas. Lands that are severely limited for agricultural or urban purposes because of flood hazards or slope and soil limitations can serve as recreation areas. But satisfaction of public needs for outdoor recreation, quality environment, and wildlife values cannot be fully met in this way. Lands readily accessible to users must be provided for these uses.

Land Resources to Meet Projected Demands

Although the pressure on land to meet future demands will increase with time, the total land base remains unchanged. This raises a question as to the capability of the land area to meet increasing agricultural food, fiber and forage needs and still satisfy the other demands that appear to be increasing even more rapidly. Comparing table 3–3–3 with figure 3–3–3, it is evident that more agricultural and forest projects output will be required from smaller acreages of land. Improved technology will have a most important role in solving this problem, as noted earlier, but there will also have to be shifts in crop production to areas of high soil capability that are not now in production. Generally, these areas are not in production because of water problems, either deficiencies or surpluses. They may be brought into production when irrigation water is provided, when drainage is applied, or when flood protection is achieved.

Table 3–3–4 shows the suitability for cultivation of non-Federal rural lands by regions. In addition, some public domain lands in the West could be cultivated if a water supply were available for irrigation. About 25 million acres now in crop production are on land not suitable for cultivation. Located chiefly in the Ohio, Upper Mississippi, and Missouri Regions, these areas present a serious land use problem. If they cannot be shifted to other uses, extraordinary measures will have to be taken to avoid soil deterioration and heavy sediment production.

LAND REQUIRED FOR WATER RESOURCE DEVELOPMENT

Land is almost always a major element in developing facilities for the storage, conveyance, and disposal of water. Lands required for these purposes usually have economic value in alternative uses. In extreme cases, the alternative uses represent a major part of the production base for local communities and economies.

As a practical matter, the economic activities displaced by such developments must be weighed against the benefits to be derived from prospective water developments. The economic impacts of land acquisition and the restrictions in use caused by the acquisition frequently have adverse effects on communities that are not directly benefited. Such adverse effects may reduce the tax base without correspondingly reducing the demand for public services. Displacement of business firms causes temporary underutilization of capital and underemployment of the labor force.

These adverse effects naturally constrain water resource development. If the development is not precluded entirely, often an inferior site is chosen as an alternative to the one in contention. In the course of future economic development, and as high-quality sites diminish in number, the land acquisition problem will become increasingly acute. Preservation of high-quality sites for future water development should be a major objective in our water and land use policy.

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TABLE 3–3–4.—*Land suitable for cultivation, non-Federal rural land*

(Millions of acres)

Region	Suitable for regular cultivation [1]	Suitable for limited cultivation [2]	Suitable for cultivation with major reclamation projects only [3]	Total potentially suitable for cultivation	Total non-Federal rural land
North Atlantic	34.4	9.7	0.5	44.6	96.6
South Atlantic-Gulf	77.4	29.9	13.3	120.6	152.3
Great Lakes	44.4	10.3	0.9	55.6	65.7
Ohio	48.8	9.6	0.3	58.7	94.6
Tennessee	9.0	3.3	—	12.3	23.7
Upper Mississippi	74.9	12.7	3.3	90.9	105.3
Lower Mississippi	22.5	3.7	3.5	29.7	37.9
Souris-Red-Rainy	25.4	4.4	2.2	32.0	36.0
Missouri	119.0	34.5	3.1	156.6	278.1
Arkansas-White-Red	72.8	17.3	6.6	96.7	156.4
Texas-Gulf	62.6	11.4	6.1	80.1	112.7
Rio Grande	4.8	2.7	7.6	15.1	64.0
Upper Colorado	1.5	1.8	1.6	4.9	21.6
Lower Colorado	1.7	0.3	19.3	21.3	46.6
Great Basin	3.2	0.9	1.7	5.8	21.0
Columbia-North Pacific	21.7	9.8	1.9	33.4	80.4
California	14.0	6.3	3.1	23.4	54.7
Alaska	0.6	0.2	n.a.	0.8	1.3
Hawaii	0.3	0.3	0.4	1.0	3.5
Puerto Rico	0.4	0.3	n.a.	0.7	2.0
Total	639.4	169.4	75.4	884.2	1454.4

[1] USDA capability classes I, II and III
[2] USDA capability class IV
[3] USDA capability classes Vw, VIc and VIIc

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CHAPTER 4

The Role of Water in the Economy

INTRODUCTION

Historically, economic development has been a major policy objective of all types of resource development. Despite a growing concern with income distribution and environmental goals in public policy formulation, economic development continues to be a central objective of water resource policies and programs. The patterns and projected rates of economic development raise two important questions for water resources planning. What does economic growth imply with respect to future requirements for water? And what will be the influence of water resource development on achieving economic growth in various regions?

The first question is concerned with current and projected demands for goods and services; its solution requires an exploration of potential developments that will attempt to satisfy the water needs for these goods and services. The second question goes deeper and seeks a pattern of development that will optimize the growth of national, regional, and local economies.

Water problems influence local and regional development and in some instances have significant effects on the functioning of local communities and economies. Such problems may impose severe constraints on economic development in specific areas or regions, but the relationship of such constraints to national growth is not clearly understood. Adverse effects of seasonal or year-to-year shortages, flooding, or water quality deficiencies on established communities and economies may be reflected in the national economy. The evaluation of these problems is of vital importance to the difficult task of shaping public policies and programs.

Great deficiencies exist in available knowledge on the many relationships between water supplies and water problems on the one hand and between water supplies and the regional and national economies on the other hand. Because of gaps in data and the lack of fully developed analytical tools, the influence of water supplies or water development cannot, at this time, be traced in precise quantitative terms through our complex economic system.

WATER PROBLEMS IN THE ECONOMY

Water shortages, water surplus problems, and water quality deficiencies may influence economic activity in a variety of ways. Shortages of water with suitable quality characteristics may render an area unattractive for industrial development. Flood hazards, in a similar manner, may restrict industrial development in an area lacking in potential flood-free plant sites. Too much or too little water may interfere with the development of a viable economy and may contribute to resource underemployment. Economic activity in an area or region is frequently disrupted by drought or water surplus leading to temporary underutilization of plant capacity, underemployment of the labor force, and reduced purchasing power. The impact of these problems on an existing economy have not been fully evaluated. Little attempt has been made to assess their future effect in a dynamic growing economy at the national or regional level.

Water supply and water quality problems and the exposure of an area to floods or drought constitute important elements in industrial location decisions. But supplies of material used in the industry, markets, transportation facilities, labor supply, and other factors may be even more vital in these decisions. In agricultural development, natural productivity of the land and other environmental factors are primary considerations. The past influence of water availability on agricultural production is generally known, and the influence of water on the geographic distribution of agricultural production in the future may be assessed. Water as a means of transportation similarly may be evaluated. Although the effect of water supplies or water problems on the overall geographic pattern of development cannot be defined readily,

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high water prices or water supply deficiencies in a specified area tend to restrict the growth of heavy water-using industries.

Water supply or disposal problems are less likely to interfere with the growth of a region as a whole than a localized area within the region. A water constraint cannot exist for the region as a whole unless the constraining problems prevail throughout the region. Situations of this type have not been experienced to date in the United States except for a few areas and a limited number of heavy water-using industries —primarily agriculture and related service industries. Requirements and costs of pollution control may become more important constraints in nonagricultural water uses in the foreseeable future. However, the absence or elimination of water supply constraints may result in locational advantages for economic activity within a region and thereby favorably affect economic efficiency and influence regional growth. Analytical systems are not as yet adequately developed for measuring the magnitude or value of these locational advantages or their effect on regional income. The relationship of water supply problems to growth of the national economy is even more indirect and obscure than at the regional level.

A somewhat different set of economic problems and considerations stems from the impact of year-to-year or seasonal variations in water availability on economic activity. How do floods or droughts affect an existing economy and in what manner are these phenomena related to capital investment, creations of employment opportunities, and regional or national income?

In a long-term context, the Nation's capital and labor resources are mobile. Capital investments, both public and private, are made at locations deemed by the decision-maker to be advantageous. Employment opportunities and, hence, the labor force and population follow these investments. At a given level of economic development and over a shorter span of time, however, a more static situation exists. The labor force and capital resources are relatively immobile in such periods. The economic impact of floods and drought are viewed in this context. Underutilization of existing plant capacity and underemployment of the labor force are of special importance in assessing the effects of year-to-year or seasonal variations in the quantity and quality of available water or the short-term effects of flooding. These effects are in addition to the physical destruction of capital assets.

The first and most basic question to be resolved in assessing the effects of short-term water shortages or surpluses in an economy is the response of households, firms, and public institutions to drought or flood conditions. Adverse impacts on output and employment are, to some degree, minimized by adjustments in water use. Households may restrict the use of water to the most essential purposes. Limited water supplies in agricultural areas are usually applied in the production of high value crops. Public institutions usually, to the extent permitted by their authorities, attempt to allocate scarce supplies to the most essential uses. Comparable adjustments in response to flooding are more limited. In agricultural areas, however, replanting of crops and other operational adjustments may soften the impacts of flooding on employment, output, and income.

Despite such adjustments to reduce the impact of short water supplies or flooding, output and employment of affected firms are reduced. The purchase and use of other production inputs may be curtailed accordingly. Since output of basic industries is reduced, facilities for processing, storing, and marketing may be temporarily underutilized. Loss of employment and income of the affected labor force results in a temporary reduction in the demand for goods and services in the trade and service industries. Thus, unless offset by counterbalancing factors in the local economy, the adverse economic impacts of temporary water problems will extend well beyond the firms and households affected physically.

Secondary effects in other parts of the region and the Nation are mixed. Demands within the affected area for goods and services produced elsewhere are obviously reduced. Competitive firms outside the area on the other hand may gain a temporary price or market advantage.

IMPLICATIONS FOR WATER MANAGEMENT

Previous discussion has indicated that water supply may be a significant factor in the economic growth of an area especially for agriculture and other heavy water-using industries. This potential exists in areas and industries where local economies are damaged by year-to-year or seasonal shortages of water. In these water-short areas, even with optimal use rates, economic activity may be curtailed in the absence of new supplies.

Supplies for a specific industry or use can be augmented in several ways: (1) development of new supplies not otherwise utilized, (2) the

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transfer of water from other uses or other areas, and (3) treatment, reuse, or more efficient use of existing supplies. Adjustments in use frequently take place within individual firms in response to price changes, new technology, or other factors. However, the economic implication of a specific adjustment in alternative patterns of water use within a firm or industry is generally not known. Neither is information readily available on the interindustry effects of reallocation of water among areas or substitution of other production factors for water.

Substitution possibilities for certain industries may be interregional. Water scarcities and intense competition among uses, together with high water costs in one region, may affect its competitive position in relation to other regions. This is particularly true in agriculture.

Irrigation farmers frequently adjust their water allocation among crops, or between one farm and another where State and local institutions permit. Interfarm transfers are also effected through established water markets or through purchase and sale of land. In some areas, year-to-year adjustments are made through water rental arrangements. Major transfers of water from one area to another are usually severely limited, however, because of physical and institutional factors.

Studies carried out in conjunction with comprehensive river basin planning efforts should include information on which to base improved projections of economic growth in each region. To be fully effective, these studies should give coordinated and balanced consideration to the following: (1) development of cost-price-use relationships for water in each sector of the economy which uses large quantities of water, indicating the substitution relationships between water and other input factors; (2) determination of the resultant effects on the cost structure of industry and the consequent disadvantages imposed on each sector in relation to competing regions or areas; (3) appraisal of the dislocations and the adverse consequences on established industries and areas that would result from specified transfers of water to alternative uses; (4) an evaluation of prospective increases in economic activity to be derived in the benefiting areas and sectors; and (5) estimation of aggregate net economic gains associated with alternative patterns of water distribution and use.

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PART 4

Water Use

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Water Use

INTRODUCTION

Water is used for many purposes—domestic and municipal, industrial and power, irrigation and livestock, navigation, recreation, fish and wildlife habitat, and waste disposal. Water used for these purposes may be withdrawn from its native course or may be used instream—free flowing, regulated, or ponded. It may be supplied by public or publicly regulated distributors or it may be self-supplied; its source may be from surface water, groundwater, tidewater, or wastewater; and its quality may range from distilled water to sewage and it may even be saltier than the ocean.

Because of varying sources, as well as lack of complete coverage, the data in part 4 do not necessarily agree with the regional data, which represent regional goals as well as national and regional requirements, or with the Council's projections of national water requirements (table 4–1).

The Council's projections indicate that the major withdrawal uses are expected to increase their withdrawals over 400% by 2020 and consumption by about 100%. Rural domestic withdrawals per capita are expected to increase from 51 gcd to 83, but the population served will decrease from 46 million to 40 million. On the other hand, domestic withdrawals per capita from municipal facilities are expected only to increase from 73 gcd to 83; however the population served will increase from 149 million to 428 million. Total municipal withdrawals are projected to increase from 157 gcd to 170 gcd.

Self-supplied industry is expected to increase its withdrawals by over 350% and steam-electric power utilities by almost 1,000%. This is particularly dramatic when projected increases in recirculation are considered. For example, recirculation in manufacturing is projected to increase from 2.25 times in 1965 to 6.3 in 2020, in mineral industries from 3.43 to 10 and in steam-electric power (fresh water) from 1.2 to 1.9. Whereas the withdrawals of fresh water by the steam-electric power industry are projected to increase 550%, consumption will increase 1,100%. This is due to the increasing use of cooling towers which, although reducing withdrawals per kwh, increases consumption.

TABLE 4–1.—*Estimated water use and projected requirements, United States*

(Million gallons daily)

Type of use	Used 1965	Projected requirements			Used 1965	Projected requirements		
		1980	2000	2020		1980	2000	2020
	Withdrawals				*Consumptive use*			
Rural domestic	2,351	2,474	2,852	3,334	1,636	1,792	2,102	2,481
Municipal (public-supplied)	23,745	33,596	50,724	74,256	5,244	10,581	16,478	24,643
Industrial (self-supplied)	46,405	75,026	127,365	210,767	3,764	6,126	10,011	15,619
Steam-electric power:								
Fresh	62,738	133,963	259,208	410,553	659	1,685	4,552	8,002
Saline	21,800	59,340	211,240	503,540	157	498	2,022	5,183
Agriculture:								
Irrigation	110,852	135,852	149,824	160,978	64,696	81,559	89,964	96,919
Livestock	1,726	2,375	3,397	4,660	1,626	2,177	3,077	4,238
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

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Irrigation withdrawals are projected to increase by only 45% and irrigated land by 49%, representing a slight increase in water efficiency per acre of 3%. Withdrawals for livestock uses will increase slightly faster than the population rate as the Nation's per capita consumption of meat products continues to increase.

In this first Assessment the Council has been unable to adequately quantify requirements for instream uses of water. Measures of future requirements for hydroelectric power, navigation, recreation, and fish and wildlife habitat are presented in the following chapters; however the translation of these requirements into water requirements is beyond the capability of this limited Assessment and will have to wait until future Assessments. The instream use of water for waste disposal has been considered a special case and is not covered in this part, but rather in part 5—Water Quality Management.

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CHAPTER 1

Domestic and Municipal Uses

INTRODUCTION

The Nation has adequate water supplies to meet foreseeable domestic and municipal needs. In 1965, total municipal and rural domestic withdrawals in the United States were about 26 bgd, or about 2% of the average annual natural runoff. Projected municipal and rural domestic withdrawals for 2020 are 78 bgd—or only 6.5% of the average annual natural runoff. Nevertheless, both urban and rural areas experience water shortages. In some cities, this "shortage" is due to a lack of planning, to poor water storage and distribution systems, or to a lack of economic incentives to conserve water.

This chapter considers present and projected domestic and municipal water requirements, including factors affecting these requirements, examines per capita use, presents data on costs of municipal water, and discusses problems of urban areas confronted with increasing demands for adequate water supplies.

PRESENT WATER USE AND FACTORS AFFECTING DEMAND

Municipal and domestic water use in 1965 is shown in table 4–1–1. Water used by municipalities includes all water pumped into the system or delivered through irrigation facilities. In addition to meeting domestic demands, municipalities use water for fire protection, street flushing, irrigation of lawns and gardens, and for industry and commerce. These municipalities and communities were served water by both publicly and privately owned distribution systems. Water for rural domestic purposes is not served by public or community facilities and is used primarily for household use and lawn and garden irrigation.

Various data sources for municipal and rural domestic water use are available; however, they are not consistent with each other. The municipal water use data presented in this chapter are a composite of data from the Public Health Service, the Geological Survey, and the regional chapters of this Assessment, and the rural domestic water use figures have been prepared from data from the Economic Research Service, the Geological Survey, and, again, the regional chapters. Future Assessments will have to resolve these differences.

TABLE 4–1–1.—*Municipal and domestic water use, 1965*

(Million gallons per day)

Region	Public distribution systems		Individual systems	
	Withdrawals	*Consumption*	*Withdrawals*	*Consumption*
North Atlantic	5,446	905	390	186
South Atlantic-Gulf	1,980	363	504	472
Great Lakes	3,622	502	274	100
Ohio	1,791	230	300	200
Tennessee	253	46	64	61
Upper Mississippi	1,103	162	203	101
Lower Mississippi	470	175	58	52
Souris-Red-Rainy	36	11	14	14
Missouri	969	221	106	85
Arkansas-White-Red	687	241	103	94
Texas-Gulf	1,055	400	40	40
Rio Grande	254	108	10	7
Upper Colorado	60	14	6	3
Lower Colorado	342	203	6	5
Great Basin	274	94	15	9
Columbia-North Pacific	1,105	182	148	134
California	4,010	1,320	90	60
Alaska	32	7	8	1
Hawaii	115	39	7	7
Puerto Rico	141	21	5	5
Total	23,745	5,244	2,351	1,636

In 1965, the North Atlantic, California, and Great Lakes Regions accounted for 55% (13.1 bgd) of the 23.7 bgd of water withdrawn for public supply in the 50 States and Puerto Rico. In contrast, Alaska, Souris-Red-Rainy, and Upper Colorado Regions withdrew a total of about 0.1 bgd. Extremes in rural domestic use are

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shown by the South Atlantic-Gulf and Puerto Rico Regions. The South Atlantic-Gulf Region withdrew about 21% (504 bgd) of the national total and Puerto Rico on the other hand, withdrew about 0.2% (5 mgd).

Consumption of water in municipal systems varies from less than 20% in the more humid regions to about 60% in the Lower Colorado Region. A major factor in the amount of consumption is the degree to which lawn irrigation is practiced. Another factor, not considered here, is the practice of discharging municipal wastewater into the ocean. About 70% of the water withdrawn for rural domestic use is consumed. This high percentage is due primarily to the fact that most of the wastewater from individual systems is evaporated or transpired after being discharged on or immediately below the surface of the ground.

In 1965 about 46.6 million people in the conterminous United States were supplied with water from wells or other individual systems. The Farmers Home Administration authorizes grants and loans for water development in rural areas to public or quasi-public bodies and corporations not operated for profit, which serve residents of open country and rural towns and villages up to 5,500 population not part of an urban area. During 1965-67, the FHA made loans or grants to 2,009 associations for domestic water systems which serve more than 1.5 million people. Increasing FHA applications will result in gradual decline of the number of people now obtaining water from other than public supply systems.

Water withdrawals may differ markedly among cities having about the same size populations. For example, Wheeling, West Virginia, and Everett, Washington, each serves a population of about 65,000. Wheeling withdraws an average of 10 mgd, whereas Everett uses 100 mgd —10 times as much as Wheeling. Everett's high use of water is explained by its pulp and paper industry. Two pulp plants use city water exclusively, and a third plant, manufacturing paper, uses the public supply part of the time. Enormous volumes of water are used in this one industry. Many other factors, such as climate, local economy, urbanization, water distribution facilities, costs to consumer, availability and variability of the water source, and kinds of commercial and industrial establishments supplied from the municipal system determine quantities of water withdrawn.

PER CAPITA USE AND CONSUMER COSTS

Total water withdrawn by a public supply—domestic, industrial, commercial, and public use—divided by population served is a measure of average water use, commonly expressed as gallons per capita per day (gcd). The national average within the conterminous United States in 1965 was about 157 gcd. In large cities of the United States the per capita withdrawal is higher than the national average. Philadelphia, for instance, had a per capita withdrawal of 169 gallons per day in 1966, and Chicago during 1960 produced enough water each day on the average to provide individual residents with about 255 gallons. Projections of per capita withdrawal are shown in table 4–1–2.

TABLE 4–1–2.—*Present and projected water withdrawals per capita for public and individual water supply systems.*

(Gallons per capita per day)

Year	Public systems					Individual systems
	Domestic	*Public*	*Commercial*	*Industrial*	*Total*	
1965	73	20	28	36	157	51
1980	77	18	28	40	163	58
2000	81	16	28	43	168	71
2020	83	14	28	45	170	83

Costs per million gallons of municipal water range from $218 in the Great Lakes Region to $431 in the Rio Grande Region, and average $292, or 29.2 cents per thousand gallons in the conterminous United States. These costs to consumer, shown in table 4–1–3, include operation, maintenance, and amortization of investment, and have been adjusted to 1965 price levels. No reliable data are available on detailed breakdown of total investment costs, but there is some evidence that these costs average about $190 per person for the provision of complete water supply systems. Apportionment of the overall cost per person is estimated as $36 for development of the source, $42 for treatment, and $112 for distribution.

Although local governments provide by far the most funds for planning, constructing, operating, and maintaining municipal and other public water supply systems, the Federal Government is providing increasing support. Federal activities embrace planning and development grants and loans and construction of mul-

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TABLE 4–1–3.—*Cost to consumer per million gallons of water supplied by municipal systems, conterminous United States, 1965*

Region	Dollars
North Atlantic	288
South Atlantic-Gulf	318
Great Lakes	218
Ohio	315
Tennessee	298
Upper Mississippi	224
Lower Mississippi	312
Souris-Red-Rainy	309
Missouri	297
Arkansas-White-Red	385
Texas-Gulf	361
Rio Grande	431
Upper Colorado	230
Lower Colorado	232
Great Basin	235
Columbia-North Pacific	357
California	308
Conterminous United States	292

tipurpose water resources projects on a reimbursable basis. Some nonreimbursable construction is authorized for Indian communities and government installations.

PROJECTED WATER REQUIREMENTS

Projections of water requirements for domestic use are based primarily upon projections of population and per capita domestic water use, which in turn are based upon many of the factors mentioned in the two preceding sections. In addition, municipal water use requires projections of the population served by municipal facilities and rates of water use by industry, commerce, and public facilities. Projections of rural domestic water use are based upon that portion of the population not served by municipal or community facilities. These projections are shown in tables 4–1–4 and 4–1–5.

For the most part these projections assume that the Nation's population growth will occur in areas served by public distribution systems. This assumption is based upon the continuing expansion of municipal systems and the establishment of new public systems. As a result, the projections of self-supplied domestic water use are based on a fairly constant rural population of from 40 to 50 million. Shifts in population, Federally assisted rural community water developments, and expanding urban growth are factors that may decrease use of individual water systems. Many small, rural communities are taking advantage of Federally assisted upstream

TABLE 4–1–4.—*Projections of municipal water requirements*

(Millions of gallons per day)

Region	*Withdrawal*				*Consumption*			
	1965	1980	2000	2020	1965	1980	2000	2020
North Atlantic	5,446	7,100	10,000	14,200	905	1,210	1,750	2,550
South Atlantic-Gulf	1,980	3,300	5,400	8,300	363	600	1,000	1,500
Great Lakes	3,622	5,030	6,900	9,500	502	702	953	1,304
Ohio	1,791	2,330	3,320	4,900	230	300	430	620
Tennessee	253	358	560	872	46	64	95	140
Upper Mississippi	1,103	1,770	2,760	4,000	162	258	403	580
Lower Mississippi	470	647	921	1,334	175	238	343	497
Souris-Red-Rainy	36	49	82	124	11	16	26	35
Missouri	969	1,225	1,481	1,738	221	280	339	397
Arkansas-White-Red	687	1,418	2,375	3,438	241	496	832	1,205
Texas-Gulf	1,055	1,890	3,110	4,540	400	740	1,200	1,750
Rio Grande	254	430	720	1,090	108	220	400	670
Upper Colorado	60	120	160	240	14	30	35	50
Lower Colorado	342	520	860	1,400	203	310	515	840
Great Basin	274	450	745	1,005	94	154	255	345
Columbia-North Pacific	1,105	1,304	2,100	3,240	182	219	350	537
California	4,010	5,090	8,280	12,690	1,320	4,620	7,350	11,300
Alaska	32	120	230	375	7	24	46	75
Hawaii	115	195	320	520	39	65	106	173
Puerto Rico	141	250	400	750	21	35	50	75
Total	23,745	33,596	50,724	74,256	5,244	10,581	16,478	24,643

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TABLE 4–1–5.—*Projections of rural domestic water requirements*

(Millions of gallons per day)

Region	*Withdrawal*				*Consumption*			
	1965	1980	2000	2020	1965	1980	2000	2020
North Atlantic	390	400	400	400	186	200	200	200
South Atlantic-Gulf	504	380	340	310	472	355	320	290
Great Lakes	274	257	292	347	100	85	103	125
Ohio	300	350	415	490	200	250	290	340
Tennessee	64	128	167	212	61	122	158	202
Upper Mississippi	203	143	132	130	101	94	85	76
Lower Mississippi	58	80	147	254	52	72	133	229
Souris-Red-Rainy	14	16	17	21	14	16	17	21
Missouri	106	134	162	190	85	108	130	153
Arkansas-White-Red	103	213	336	515	94	194	325	470
Texas-Gulf	40	70	120	160	40	65	110	145
Rio Grande	10	10	10	10	7	7	7	7
Upper Colorado	6	10	10	10	3	4	5	5
Lower Colorado	6	7	8	9	5	5	5	5
Great Basin	15	15	15	15	9	9	9	9
Columbia-North Pacific	148	148	148	148	134	134	134	134
California	90	90	90	90	60	60	60	60
Alaska	8	11	12	13	1	2	2	2
Hawaii	7	5	4	3	7	5	4	3
Puerto Rico	5	7	7	7	5	5	5	5
Total	2,351	2,474	2,852	3,334	1,636	1,792	2,102	2,481

watershed management programs to provide storage and dependable flow to meet local needs. Under this program, by 1980, about 600 headwater reservoirs will provide 326 billion gallons (1 maf) of storage to serve approximately 2.5 million people. Nevertheless, lack of running water in rural establishments is by no means an exception to the rule even today. The United States Census of Housing reported 17.6 million houses in rural areas in 1960. Of this number, 3.7 million accommodating an estimated 11.3 million people did not have piped water. Rural domestic withdrawals are expected to increase very modestly from 2.35 bgd in 1965 to 3.33 bgd in 2020, only 42% over a period of 55 years, whereas municipal withdrawals are expected to increase from 23.7 bgd in 1965 to 74.3 bgd in 2020—an increase of 213%.

PROBLEMS OF URBAN WATER SUPPLY

Water is unevenly distributed in nature and often must be transported long distances from the source to the point of use. An example is Los Angeles, which obtains its water not only from local sources but also from the Owens River on the east side of the Sierra Nevada, 240 miles away; from Mono basin, 350 miles distant; and from the Colorado River, 250 miles east. To supplement these sources plans are under way to tap rivers in the northern part of the State, which is better watered and less populated. In most of the United States, however, ample water is usually available for municipal development within reasonable distances. Even in semiarid regions, additional supplies are often physically available for development and may be economically available when combined with other purposes. Many examples exist of multipurpose water developments which have benefited municipal needs. The availability of water for municipal use is limited less by its source and more by underestimating long-range requirements and inability or unwillingness to finance the planning and provision for waterworks.

Projections for 2020 of withdrawals of 74.3 bgd of water does not mean that new water sources must provide this total quantity. Municipal water, like water for other purposes, can be and is used over and over again. Reuse will be practiced to an even greater extent in the future. Water quality, a critical factor in the reuse of water, is an important problem to urban areas maintaining public water supply systems and is discussed in part 5.

A vexing problem in providing urban water supply is the rigidity of legal or political struc-

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tures and organizations. Conflicting demands of adjacent States for water flowing in interstate rivers, and the multiplicity of independent governments in large metropolitan areas are examples of institutional problems that handicap orderly development of areal water supplies. Individual governmental agencies often compete with each other, as well as with other interests, to supply water to the numerous segments of metropolitan areas. These local governmental units must be coordinated more effectively to permit efficient, less costly planning and provision for the benefit of all interests concerned.

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CHAPTER 2

Industrial Uses

SUMMARY

Industrial needs for water in the United States in 2020 will require the withdrawals of about 130 bgd from fresh and saline water sources. Water conservation practices, including water and waste treatment and in-plant recirculation, will make that withdrawal requirement equivalent to a gross industrial water use of more than 850 bgd. In their production, industries will consume about 23 bgd. Over 100 bgd will be discharged after treatment and become available to other users. To provide this water supply and to meet the water quality requirements dictated by industry needs and local environments, it is estimated that capital investment of about $135 billion will occur between now and 2020.

GENERAL

In this chapter, industry includes the activities of the four following standard industrial classification (SIC) groups: Manufacturing, Mining and Mineral Processing, Ordnance, and Construction.

Their combined industrial activities in 1965 accounted for about 37% of the total national income and provided employment for some 29% of the total civilian labor force. Water has long been recognized as a large and necessary input to these economic sectors, but only in recent years have assessments of the input been attempted.

In the 1954 Census of Manufactures, establishments were asked to report for the first time water withdrawal, in-plant recirculation or reuse, and water discharge. That canvass was repeated in the 1959 and 1964 Census of Manufactures and will be repeated in subsequent quinquennial manufacturing censuses.

Two canvasses have been made of water use by the mineral industry, covering 1958 and 1962. It is expected that a third canvass will be made by the Bureau of Census in 1969 to cover activities of 1968.

Water use by government facilities producing ordnance materials has not been reported, but the water used by privately owned establishments producing those items is reported under unsorted SIC categories in the Census of Manufactures and is included, therefore, in the data for manufacturing industries. Withdrawals for all military installations in 1960 were 600 mgd. Government-owned ordnance facilities are estimated to be only a small part of total military withdrawals and have been ignored in this Assessment.

Neither measurements nor canvasses have been made of water use in construction, but estimates can be made by relating water use to concrete put-in-place, miles of highways completed, and housing starts. Total water use for construction in 1965 is estimated to have been less than 40 mgd. Because of the minor quantity of water involved and because public systems usually supply that need, water use for construction will not be reported here.

Water withdrawals for power generation by industrial establishments for their own use are included in this chapter and are also reported in chapter 3. About 10% of total water withdrawals for manufacturing and about 2% of total water withdrawals of the mineral industry are obtained from public systems. These quantities are also reported in chapter 1. Chapter 3 in part 5 contains additional material concerning water quality control and industrial wastes.

PRESENT WATER USE

Manufacturing

The manufacturing sector of the Nation's economy comprises about 315,000 establishments whose output, measured by "value added in manufacture," exceeded $225 billion in 1965. Over 200,000 of the plants employ fewer than 20 persons each and together account for only

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6.5% of value added, and less than 8% of persons employed in manufacturing. It is the relatively few large establishments, less than 10%, that account for the greatest share of manufacturing production, more than 75%.

The concentration of output is paralleled by concentration of water use in relatively few establishments. According to the 1964 Census of Manufactures—Water Use in Manufacturing, 8,925 establishments, each reporting an average withdrawal of 55,000 gpd or more, accounted for nearly 98% of total water withdrawals for manufacturing; and 5,154 establishments in five major industry groups (food and kindred products; pulp and paper; chemicals; petroleum and coal products; and primary metals) accounted for 88% of total water withdrawals. Efforts toward water conservation must be addressed to this small number of plants, mills, and factories in particular.

In 1965, manufacturers required a withdrawal of 40 bgd of water which was recirculated 2.25 times (table 4–2–1). The processing of materials and products of manufacturing required 10.6 bgd, and about 2.9 bgd was used for boiler feed, sanitary service, and other purposes. The remainder of the withdrawal was used for cooling either in company-owned steam-electric powerplants, 8.0 bgd; or in process equipment, 18.5 bgd. About 20% of the withdrawal was from saline sources and was used mostly as a coolant. Some saline water was withdrawn, however, as a raw material for extraction of basic chemicals and metals, and for processing and washing. About 12% of the fresh water was purchased from public water systems, about 76% was self-supplied from surface-water sources, and 12% self-supplied from ground water.

Manufacturing consumed about 2.6 bgd in 1965 through incorporation of water into product, evaporation, and unaccounted losses. The remaining 37.4 bgd of wastes were discharged to surface-water bodies, 89.4%; to public sewers, 7.5%; to the ground, 1.5%; and to other users, 1.6%. About 29% received some degree of treatment before discharge, but the effectiveness of the treatment is varied and unknown.

Although water used for cooling and discharged into surface waters by manufacturers poses the problem of thermal pollution, it is a problem shared with the steam-electric powerplants of public and private utilities which use and discharge 3 times as much cooling water. The process and sanitary service waste waters are, however, a major pollution hazard if discharged without adequate treatment for removal of their pollutants. The quantities of pollutants discharged are undoubtedly great, but when considering the problems they present to the conservation of the Nation's water resources, the overall solutions will appear less difficult if it is kept in mind that fewer than 9,000 establishments discharge about 10.5 bgd of process and other wastes, as compared to about 0.7 bgd from all other manufacturing establishments numbering more than 300,000.

Mineral Industry

The mineral industry is a smaller economic sector than manufacturing, comprising about 22,000 establishments with a total output in

TABLE 4–2–1.—*Industrial water use in the United States—1965* [1]

Type of use	Withdrawal	Gross use	Recirculation ratio	Consumption	Discharge
	bgd	*bgd*		*bgd*	*bgd*
Manufacturing:					
Processing	10.6	—	—	2.0	8.6
Process cooling	18.5	—	—	0.2	18.3
Power cooling	8.0	—	—	0.1	7.9
Other	2.9	—	—	0.3	2.6
Total	40.0	90	2.25	2.6	37.4
Mineral industries:					
Mining operations	0.19	—	—	—	—
Processing	2.07	—	—	—	—
Cooling	0.87	—	—	—	—
Other	0.11	—	—	—	—
Total	3.24	11.1	3.43	0.76	2.48

[1] Both publicly and self-supplied.

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1965 valued at about $21 billion. Nevertheless, the industry requires significant quantities of water. Water use in the mineral industry, as in manufacturing, is concentrated in the production of a few commodities. More than 65% of the water withdrawn is used in the following five major operations: sand and gravel, petroleum and natural gas drilling and secondary recovery, phosphate rock, iron ore, and natural gas processing.

In 1965, the mineral industry withdrew an estimated 3.2 bgd (table 4–2–1), 97% of which was fresh water. The mineral industry used 64% of the water for processing and 27% for cooling. About 6% was used in mining operations and the remainder for boiler feed and sanitary service.

Water consumption in 1965 was about 0.8 bgd —almost 25% of the total intake. The relatively high consumption rate is due to the temperature and humidities of the arid areas in which much of the mineral industry is located. The industry practice of multiple recirculation of process and cooling waters through ponds and cooling towers, however, causes large losses through evaporation even in humid climates.

About 20% of the waste water discharged at the present time receives some type of treatment—pH control, precipitation, or settling. The overall effectiveness of these processes, however, is not known.

Except in some arid areas in the West, water supplies for the withdrawals of the mineral industry (comprising only 1% of the total withdrawals in the Nation) are not a major problem. However, the industry wastes, including drainage and seepage from mines and pits, contribute to water pollution. The most notorious pollutant is the acid mine wastes from coal fields.

TRENDS IN INDUSTRIAL WATER USE

Two factors, expanding population and the growth in real personal income, will exert the greatest influence on water use patterns in the United States. The industrial sector, as it increases output to meet the demands of a growing market, will continue rapid construction and expansion of facilities and will require more water to support the growth in production. The new water demand will be met in part by increased withdrawals, but in larger part by improved methods of water management.

Except for a few of the primary product industries (mines, forest products, oil and gas processes, and primary metals) whose plant locations are determined by source of raw product or similar factors, most industries will continue to locate in the urban areas that constitute their major markets or points of transfer. In urban areas, the cost and availability of water supplies for industry and the public and legislative requirements for maintaining the quality of the environment will exert pressures that will improve water management.

Efficient management of water use includes recirculation or multiple use of water within a plant or industry and even among industries. An example of the latter is found in the integration of woodpulp and paper mills. Industry will continue to increase its substitution of municipal waste water for fresh withdrawals. Industrial parks or districts will collect, treat, and recycle the waste waters from a combination of establishments. Mechanical or pneumatic conveyance of materials and products will be substituted for hydraulic conveyance. Processes employed in the manufacture of existing and new products will be selected or modified for small water requirements.

Ultimately, the degree to which the alternatives in water conservation are employed by industry will depend upon the relative costs of the quantity and quality of available water, the degree of treatment required for wastes discharged, and available management practices.

PROJECTED INDUSTRIAL WATER REQUIREMENTS

Manufacturing

The three censuses which obtained data on water use covered only 11 years of manufacturing activity, 1954 through 1964. Projections for water requirements based on this limited amount of historical data, however, are justified by the proven accuracy of similar type predictions and by institutional changes in industry during the same period, which are expected to continue. The rate of economic growth (GNP) achieved during that period was similar to the growth rate projected for purposes of the Assessment. Also, water use data for the 11-year period reflected changes in patterns of industrial water use in response to expressed public concern for the deterioration of the Nation's water resources.

In the huge and changing product mix of the Nation's industry, attempts to relate water use to physical output by weight or units of production are difficult because individual estab-

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lishment data are not available. The search for parameters by which projections of future water requirements could be made revealed only one which has persisted through the three censuses —manufacturing activity measured by value added in constant dollars retained a relationship to gross water use that varied less than 2% during the 11-year period. Projections for gross water requirements for manufacturing are based on that parameter.

Water withdrawals are a function of the recirculation rates that are employed. Recirculation rates are, in turn, influenced by the availability of water, water quality requirements for manufacturing, water costs, treatment costs, and effluent requirements. However, the complex product mix and the lack of data preclude analysis of these factors and, thus, preclude projections of withdrawals based on them. Again relationships were established between value added in constant dollars and water withdrawals as reported in the three censuses. The actual water withdrawal increased at a decreasing rate between succeeding censuses indicating that water withdrawals per unit of production were decreasing.

The data suggest that consumption of water is related primarily to production; that is, water consumption will be relatively unchanged whether water requirements for production are met with or without recirculation. Projections for water consumption are based on this assumption.

Projections of industrial water use, including both manufacturing and mineral industry uses, for the conterminous United States are given in table 4–2–2. Projections of water use in manufacturing for the 17 conterminous water resources regions are given in table 4–2–3.

TABLE 4–2–2.—*Projected industrial water requirements in the conterminous United States* [1]

Type of use	Unit	1965	1980	2000	2020
Manufacturing:					
Gross	bgd	90.0	164.3	349	763
Recirculation ratio	—	2.25	3.0	4.4	6.3
Withdrawal	bgd	40.0	54.8	80	121
Discharge	bgd	37.4	50.2	70	100
Consumption	bgd	2.6	4.6	10	21
Mineral industry:					
Gross	bgd	11.1	20.0	33.0	88.0
Recirculation ratio	—	3.43	4.9	7	10
Withdrawal	bgd	3.24	4.1	4.7	8.8
Discharge	bgd	2.48	2.9	3.3	7.0
Consumption	bgd	0.76	1.2	1.4	1.8

[1] Both publicly and self-supplied.

Mineral Industry

Projections of water use by the mineral industry (table 4–2–2) are based on data obtained in past industry canvasses and forecasts of requirements for the industry's products. Water use by regions cannot be reliably projected at this time.

The projections have been derived using an equation from the regression analysis between gross water and crude material processed. Recirculated water requirements are based on recirculation rates required to process the increased crude materials inputs. Consumption estimates employ a multiple regression analysis of the relationship between consumption, recirculation, temperature, and humidity. Withdrawal has been estimated as the residual between gross water and recirculated water.

CAPITAL EXPENDITURES

In 1965, total capital investments for new construction of industrial water supplies and industrial waste treatment facilities are estimated at $750 million. This sum was derived from data on sales of specific equipment and materials, and studies pertaining to the distribution of capital expenditures for water and waste water.

Estimates for future annual capital expenditures for water supplies are based on the rate of increase of intake water and the upward trend

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TABLE 4–2–3—*Projected water requirements for manufacturing, conterminous United States*[1]

(Million gallons per day)

Region	1960			1980			2000			2020		
	Total use[2]	With-drawal	Consump-tion	Total use[2]	With-drawal	Consump-tion	Total use[2]	With-drawal	Consump-tion	Total use[2]	With-drawal	Consump-tion
North Atlantic	21,950	10,670	610	42,130	14,040	1,170	80,920	18,650	2,248	167,180	26,470	4,644
South Atlantic-Gulf	6,870	3,340	191	17,150	5,720	476	40,360	9,310	1,121	92,910	14,710	2,581
Great Lakes	14,530	7,060	404	30,880	10,300	858	59,110	13,630	1,642	122,220	19,350	3,395
Ohio	8,130	3,950	225	17,740	5,910	493	36,460	8,410	1,013	75,110	11,890	2,086
Tennessee	1,220	600	34	3,270	1,090	91	6,950	1,600	193	14,480	2,290	402
Upper Mississippi	4,500	2,190	125	10,430	3,480	290	22,250	5,150	621	49,130	7,780	1,365
Lower Mississippi	970	470	27	2,410	800	68	5,620	1,300	156	13,310	2,100	370
Souris-Red-Rainy	60	30	2	130	40	4	290	70	8	680	110	19
Missouri	1,600	780	44	4,330	1,440	120	9,800	2,260	272	22,690	3,590	630
Arkansas-White-Red	1,630	790	45	4,330	1,470	123	10,110	2,330	281	22,910	3,630	637
Texas-Gulf	2,000	970	56	6,100	2,030	169	15,710	3,620	436	39,170	6,200	1,088
Rio Grande	180	90	5	730	240	20	2,230	520	62	6,210	1,070	173
Upper Colorado	20	10	1	50	20	2	110	20	3	220	40	6
Lower Colorado	240	120	7	1,140	380	32	3,450	800	96	9,440	1,490	262
Great Basin	210	100	6	770	250	21	1,980	460	55	4,960	790	138
Columbia-No. Pacific	1,760	850	49	4,490	1,500	125	10,080	2,320	280	22,610	3,580	628
California	5,740	2,790	159	18,210	6,070	508	43,370	10,000	1,205	99,320	15,730	2,759
Total	71,610	34,810	1,990	164,290	54,780	4,570	348,800	80,450	9,692	762,550	120,820	21,183

[1] Both publicly and self-supplied.
[2] Represents the withdrawal required if recirculation were not practiced.

in water reuse, both of which were explained earlier in relation to gross water requirements. The projected annual capital expenditures for industrial waste treatment facilities are based on 1965 prices and the assumption that all new waste discharges and those discharges not presently receiving adequate treatment for pollution abatement will be receiving secondary or equivalent treatment by 1985. Beyond 1985, capital expenditures are estimated only for the new waste treatment requirements. Table 4–2–4 gives capital expenditures according to four sources of capital—Federal, State, local, and private.

The total capital investment in industrial water supplies and waste treatment between the base year 1965 and the year 2020 is estimated to be about $135 billion.

TABLE 4–2–4—*Estimated annual capital expenditures for industrial uses*

(Millions of dollars in 1965 prices)

Source	1965	1970	1975	1980	1985	2000	2020
				Water supply facilities			
Federal	32	40	50	66	88	111	149
State	20	25	31	41	54	69	92
Local	50	62	79	104	137	174	232
Private	198	248	315	414	546	696	927
Total	300	375	475	625	825	1,050	1,400
				Waste water treatment facilities			
Federal	81	117	162	216	279	351	441
State	54	78	108	144	186	234	294
Local	100	143	198	264	341	429	539
Private	215	312	432	576	744	936	1,176
Total	450	650	900	1,200	1,550	1,950	2,450

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CHAPTER 3

Electric Power Uses

Water is a factor in the production of all electric power now generated. The bulk of the Nation's power supply is produced in steam-electric and hydroelectric plants. Relatively small amounts are produced in plants utilizing internal combustion engines or gas turbines. Hydroelectric plants convert the energy of falling water to electricity. Steam-electric plants require relatively small amounts of extremely pure water for boiler use and larger amounts of untreated water for condenser cooling purposes. Internal combustion reciprocating engines and gas turbines require little or no water in the power production process. All plants, however, do require small amounts of water for station services, including fire protection and sanitary requirements.

WATER USE

Conventional Hydroelectric Plants

The power produced in a hydroelectric plant is directly proportional to the quantity of water flowing through the plant and the head, or distance, through which the water falls. The design flow through the plant depends upon the natural and regulated streamflows available at the site and upon the characteristics of the power load to which the individual plant contributes its output. In general, a plant is designed to fit the topographic and geologic features of the site and utilizes the streamflows that are available or can be made available through regulation.

Most new hydroelectric plants operate at low plant factors to serve the peak portions of the load, because they have the ability to start quickly and to make rapid changes in the rate of plant output. For the same reasons, hydroelectric plants are used to provide spinning reserve capacity, and may be used to provide constantly changing outputs needed for load regulation. Moreover, when streamflows are reduced by additional consumptive uses, hydroelectric plants generally are capable of shifting to a lower plant factor, since other power sources in integrated power systems can usually supply the energy deficiency.

Except for the initial filling of the reservoir, hydroelectric power production usually does not involve the permanent withdrawal of water from rivers and streams; and except for the evaporation that may be associated with the reservoirs, they do not use water consumptively. When a reservoir is located downstream from a significant waste source, it may increase the effects of the wastes by decreasing the rate of reaeration. Also significant water quality effects may be associated with hydroelectric power generation as a result of density stratification within the reservoirs. Releases of cold water from the lower levels of deep reservoirs may lower summer temperatures in the stream, and such stored water may be deficient in dissolved oxygen. In order to control the effects of hydropower releases on the downstream water resources, some plants use multiple-level intake structures. In other instances, varying plant releases are evened in downstream reregulating reservoirs. Both these control measures tend to sustain, if not enhance, fish and wildlife values. In addition, such reregulating reservoirs may provide additional water-oriented recreation opportunities. However, many plants operate without reregulating reservoirs causing the reaches immediately downstream to be dewatered during weekends.

Pumped Storage Hydroelectric Plants

Pumped storage developments produce power using recirculated water. Water is released from an upper reservoir, passed through a power plant to a lower reservoir, and, during offpeak load periods, is pumped back into the upper reservoir. Most developments use reversible pumping-generating equipment. Pumped storage developments are divided into two broad categories. In the combined type development, reversible pump-generating units are installed

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in a hydroelectric project consisting of a reservoir on a stream with a downstream reregulating reservoir, or afterbay. In the pure pumped storage developments, water is recirculated between an off-channel upper reservoir on a nearby hilltop and a lower pool which may be a reservoir or another body of water, or a pond on a small stream. In all pumped storage projects, only small amounts of make-up water are needed to cover losses which are limited essentially to evaporation and leakage.

By utilizing high heads, pumped storage installations are capable of providing large amounts of power with relatively small amounts of water. Pumped storage developments require a supply of inexpensive off-peak energy for pumping, however, and it is usually obtained from steam-electric plants. Although site conditions and pump-back energy requirements affect widespread development of pumped storage projects, potential sites exist in most areas of the United States.

The optimal use of pumped storage projects is for the provision of peaking power and reserve capacity. The large steam-electric powerplants, which are now being constructed, operate most efficiently and economically at high plant factors in the base portion of the load. Conventional and pumped storage hydroelectric projects which would operate at low plant factors complement the operation of such steam-electric plants.

Steam-electric Plants

The principal use of water in steam-electric generating plants is for condenser cooling purposes. Water introduced into the boilers is converted into steam to drive the turbo-generator units. Steam leaving the turbines at less than atmospheric pressure is passed through the condensers where it is cooled and condensed. The condensate is pumped back into the boilers in a closed-circuit system. The only consumptive use in the boiler circuit is the feedwater make-up required to replace water losses. Losses are small. The requirement for a 1 million kilowatt plant operating at full load, for example, is estimated to be only about 0.3 mgd. However, a large separate flow through the condensers is required to carry away the waste heat of condensation. Although essentially no water is used consumptively in the condensers, losses occur when the condenser flows are either returned to the source bodies of water at higher temperatures, or passed through cooling towers.

The amount of water required for condenser flows depends upon the type of plant, its efficiency, and the designed permissible temperature rise within the condensers. The temperature rise of cooling water condensers is usually in the range of 10° to 20° F, and the average rise is about 15° F. Currently, large nuclear steam-electric plants require about 50% more condenser water for a given temperature rise than fossil-fueled steam-electric plants of equal size, due to lower throttle steam temperatures and consequent lower plant efficiencies. By 1980, this added requirement is expected to decrease by half to about 25%.

Research on nuclear breeder reactors is progressing; and as a result, they may be commercially available some time in the 1980's. These reactors will probably produce steam at temperatures approximating those now utilized in fossil-fuel fired boilers, so that the amount of waste heat to be dissipated by cooling systems of nuclear breeder plants will more nearly approach that of fossil-fueled plants. Research is also under way to develop materials for nuclear fuel systems which will permit steam temperatures of nonbreeder reactors to be raised. Some further improvements in the efficiencies of fossil-fueled plants can also be expected as unit sizes continue to increase.

Both fresh and saline water are used for cooling; and, in some cases, sewage effluents are used. Water for condenser uses may be withdrawn from rivers, lakes, reservoirs, canals, tidewater, or groundwater. When adequate supplies are available and allowable discharge temperatures permit, the water is usually passed through the condensers once and returned to the source body of water. When supplies are limited or there are thermal restrictions, the water may be recirculated in reservoirs or spray ponds, or passed through cooling towers. Evaporative cooling towers require smaller amounts of water withdrawals than the once-through systems, but the consumptive use is substantially higher. Although nonevaporative cooling towers have been considered for use in the United States, there have been no major installations. Such cooling towers would minimize the consumptive water use, but they are relatively expensive, they tend to reduce the thermal efficiencies of the steam-electric plants, and they involve very large structures.

Table 4–3–1 gives estimates of the average condenser water requirement and consumptive use per kilowatt hour for fossil-fueled plants from 1965 to 2020. The decreasing requirements over time reflect expected increases in average efficiencies of plants operating in the future.

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TABLE 4–3–1.—*Average condenser water requirement and consumptive use for fossil-fueled, steam-electric power-plants, 1965–2020*

(Gallons per kilowatt-hour)

Year	Condenser requirement [1]	Consumptive use		
		Once through	Cooling ponds	Cooling towers
1965	40	0.3	0.4	0.5
1980	35	0.2	0.3	0.4
2000	30	0.15	0.25	0.35
2020	25	0.1	0.2	0.3

[1] Based on a design temperature rise of 15° F. in the condenser.

Other Types of Plants

At present, sources of generation other than hydroelectric and steam-electric plants produce relatively small amounts of electric power. Internal combustion plants require small amounts of water to be circulated through engines for cooling purposes. Combustion turbines do not require water for power production.

New methods of generating power are being investigated. Among the more promising methods which eliminate the conventional steam cycle and may reduce the need for cooling water are magneto-hydrodynamic (MHD), electrogas-dynamic (EGD) and thermionic power generation, and generation by fuel cells. Although none of these methods can be used commercially at present, some of them may be developed for use well before 2020. It must be realized that the development and adoption of technologic innovations and improvements may substantially alter future cooling water requirements.

FUTURE ELECTRIC POWER REQUIREMENTS

Projecting future power requirements is complicated by many factors. Among these are the effects of power costs to the consumer on power demand and the effects of power costs to the producer on the types of plants and transmission facilities that will be utilized in the future. The electric power industry is one of the most dynamic industries in the United States, and it has had a growth rate which has exceeded that of the gross national product for a number of years. The technology of electric power generation and distribution is changing rapidly. More economical, larger sized units become feasible because of load growth, and the increasing interconnection and coordination of power systems via extra high voltage transmission facilities. Lower costs of generation are being realized in some cases through economies afforded by the use of unit-type coal trains, and the construction of mine-mouth plants. Furthermore, in the last 2 years there has been a large increase in the number of scheduled nuclear-fueled plants.

Despite the many uncertainties associated with long-range projections of power requirements, estimates have been made in order that approximate magnitudes of future water requirements for power purposes could be projected. Table 4–3–2 gives the projected generating capacity and the annual energy requirements for electric power to 2020. These requirements include both electric utility requirements and the relatively smaller requirements of self-supplied industries. Figure 4–3–1 is a graphic breakdown of table 4–3–2 giving projected generation according to the different types of prime movers. Of the 255 million kilowatts in operation in 1965, 18%, or 44½ million kilowatts, was in conventional and pumped storage by hydroelectric plants and

TABLE 4–3–2.—*Projected total electric power requirements, 1965–2020*

Year	Installed capacity	Annual generation
	Million kw	*Trillion kwh*
1965	255	1.2
1980	620	3.1
2000	1,800	9.2
2020	3,700	20.0

82%, or 210½ million kilowatts, was in thermal plants. By 2020, the portion of total supply in hydroelectric plants is expected to decrease to about 5% despite a projected quadrupling of the total hydroelectric capacity.

PROJECTED CONDENSER WATER REQUIREMENTS

Water withdrawals for cooling purposes at steam-electric plants currently constitute the largest nonagricultural diversion of water, and

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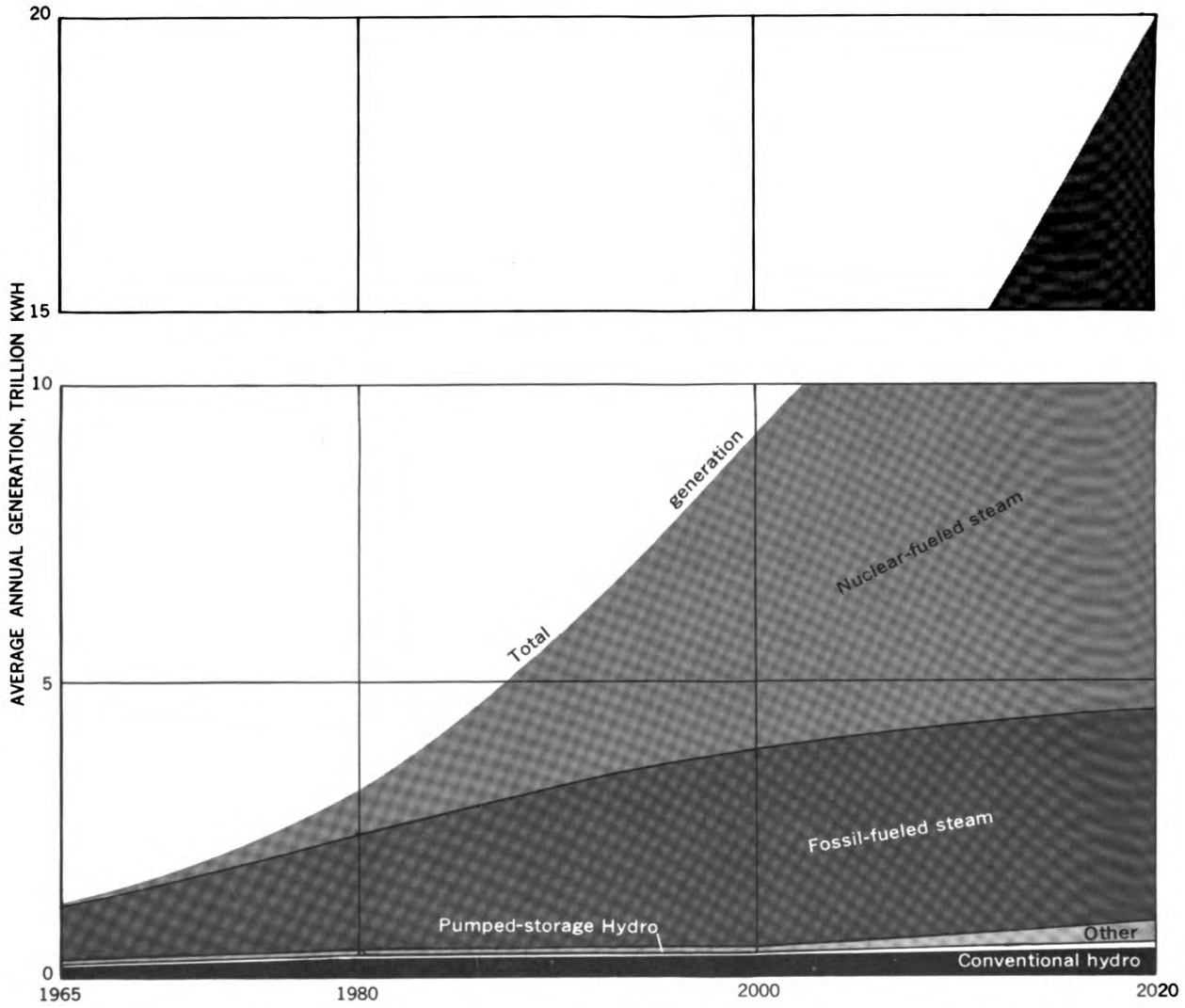

FIGURE 4–3–1.—*Projected electric generation by types of prime mover, 1965–2020.*

by 1980 these withdrawals are expected to surpass even those for agriculture.

In order to project the condenser water requirements, water withdrawals, and consumptive uses of steam-electric plants, several assumptions must be made. After projecting power generation according to type of plant, it is necessary to estimate the type of cooling likely to be used and the likely source of cooling water, a fresh or a saline water supply. Then, by applying unit water-use factors, projections of water requirements can be made. The estimated average water requirements (for condenser flow, withdrawal, and consumptive uses) for steam-electric plants owned by electric utilities for the water resources regions of the Nation are shown in table 4–3–3. The table also gives the total national water requirements for industry-owned plants which are also covered in chapter 2.

The estimated investment needed by 2020 to provide cooling water requirements for steam-electric plants is approximately $20 billion. A large part of the needed investment will be for cooling towers.

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TABLE 4–3–3.—*Projected water requirements for steam-electric power generation, 1965–2020*

(Millions of gallons per day)

Region	Fresh or saline	1965			1980			2000			2020		
		Condenser requirement	Withdrawn	Consumptive use	Condenser requirement	Withdrawn	Consumptive use	Condenser requirement	Withdrawn	Consumptive use	Condenser requirement	Withdrawn	Consumptive use
Utility owned plants:													
North Atlantic	F	10,500	10,500	75	14,800	10,900	120	28,600	11,300	320	42,300	14,700	580
	S	11,400	11,400	83	22,100	22,100	180	68,900	68,900	750	169,200	169,200	2,000
South Atlantic-Gulf	F	7,600	7,600	42	28,500	28,500	190	72,200	39,800	765	123,100	56,000	1,440
	S	3,700	3,700	19	12,000	12,000	80	27,600	27,600	215	44,800	44,800	385
Great Lakes	F	12,000	12,000	95	25,800	25,700	184	58,200	56,100	467	116,000	114,700	898
Ohio	F	17,400	17,400	138	41,000	27,300	350	73,600	45,200	775	119,500	61,200	1,190
Tennessee	F	[1] 3,700	[1] 3,700	[1] 24	10,100	10,100	65	14,600	10,700	115	21,300	13,800	175
Upper Mississippi	F	6,800	4,800	61	17,400	9,500	166	34,000	21,500	373	55,100	25,900	607
Lower Mississippi	F	1,600	1,600	16	8,900	5,900	60	24,600	16,700	175	42,200	19,500	295
	S	200	200	3	600	600	4	2,300	2,300	7	7,500	7,500	40
Souris-Red-Rainy	F	200	200	2	500	500	4	1,100	1,100	10	2,100	1,700	20
Missouri	F	1,700	1,400	24	6,500	1,500	80	16,200	3,200	200	24,900	4,800	320
Arkansas-White-Red	F	3,600	600	41	10,800	4,100	95	21,200	8,400	205	29,100	11,100	310
	S	—	—	—	40	40	—	40	40	—	40	40	—
Texas-Gulf	F	6,700	2,100	57	24,100	5,500	180	61,400	22,000	495	87,000	41,000	590
	S	200	200	2	2,700	2,700	20	7,300	7,300	55	15,900	15,900	145
Rio Grande	F	700	70	9	1,900	70	20	5,000	70	65	7,200	100	100
Upper Colorado	F	800	20	13	1,600	30	17	2,000	35	20	2,500	50	35
Lower Colorado	F	700	10	8	2,900	40	35	14,800	250	210	32,200	600	470
Great Basin	F	200	10	2	1,700	30	25	5,200	100	75	11,100	200	160
Columbia-No. Pacific	F	8	8	—	4,000	4,000	13	22,300	22,200	180	54,600	44,600	630
	S	—	—	—	—	—	—	19,200	19,200	180	52,600	52,600	740
California	F	1,400	70	70	5,000	90	80	10,900	300	100	18,900	300	180
	S	5,600	5,600	44	18,300	18,300	185	77,400	77,400	740	194,900	194,900	1,730
Alaska	F	20	20	—	200	200	1	250	250	2	300	300	2
	S	—	—	—	—	—	—	—	—	—	2,700	2,700	13
Hawaii	S	300	300	3	900	900	9	2,300	2,300	20	5,300	5,300	30
Puerto Rico	F	1	1	—	3	3	—	3	3	—	3	3	—
	S	400	400	3	2,700	2,700	20	6,200	6,200	55	10,600	10,600	100
Sub-totals [2]	F	75,600	62,100	677	205,700	134,000	1,680	466,200	259,200	4,550	789,400	410,600	8,000
	S	21,800	21,800	157	59,300	59,300	500	211,200	211,200	2,020	503,500	503,500	5,180
Total [2]		97,400	83,950	834	265,000	193,300	2,180	677,400	470,400	6,570	1,292,900	914,100	13,180
Industry owned plants:													
Sub-totals	F	9,200	6,400	81	10,700	7,500	80	11,500	8,000	95	13,000	9,000	110
	S	1,600	1,600	11	1,700	1,700	12	2,200	2,200	15	2,700	2,700	15
Total		10,800	8,000	92	12,400	9,200	92	13,700	10,200	110	15,700	11,700	125

[1] Tennessee Valley Authority data differs.
[2] Rounded.

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EMERGING WATER PROBLEMS

Thermal Pollution

As the amount of waste heat from steam-electric powerplants discharged to water bodies has increased, concern for thermal pollution and its effects has increased. As usually defined, thermal pollution means the addition of heat to natural waters to such an extent that it creates adverse conditions for the survival of aquatic life; accelerates biological processes in the streams, resulting in the reduction of the dissolved oxygen content of the water; contributes to taste and odor problems by increasing the growth of aquatic plants; or otherwise makes the water less suitable for domestic, industrial, and recreation uses. Not the least important of the effects of waste heat disposal is the reduction in the utility of the water for further cooling.

All of the States have proposed or adopted standards for water temperature control, having recognized the adverse effects of temperature increases on other stream uses. In the process of establishing water quality standards for interstate waters as required by the Water Quality Control Act of 1965, guidelines for control of cooling water discharges have been considered. Many of the proposed temperature standards would permit maximum water temperatures between 87° and 93° in warm water streams under summer conditions, and lower maximum temperatures in normally cooler streams. As knowledge of the effects of heat additions on streams and their ecology increases, concern heightens. There is still much to be learned, however, with regard to the ways in which large and small, and temporary and sustained changes in temperature can affect the life cycles of aquatic plants and animals.

The use of once-through cooling has proved to be an economic and effective means of dissipating waste heat from thermal powerplants. As a result, plant sites have usually been selected where large quantities of water were available for cooling at all times. Such sites in inland areas, however, are limited in number, and the increasing density of powerplants on rivers and estuaries will ultimately require utilities and industries to find other effective means of thermal control. The electric power industry has long been concerned with the thermal effects of cooling water discharges and has sought measures for their control.

In areas of short water supply, as in the southwest, cooling ponds, spray ponds, and cooling towers have been utilized to extend the capabilities of the water available for power generation purposes. While such practices can limit the amount of heat dissipated to the natural water environment, they increase the consumptive use of water and they may contribute to fog and ice problems in their immediate vicinities. In addition, cooling towers are very large and may be aesthetically unpleasing. Submerged intakes, which make use of the cooler water available in the lower levels of large reservoirs, have been effectively used to reduce water temperature problems in some areas. The increasing concern for thermal pollution will undoubtedly result in the wider application of available treatment methods. Further consideration needs to be given to means of making beneficial use of the waste heat from thermal powerplants.

Provisions of the Water Quality Control Act relative to the establishment of water quality standards on interstate streams, as well as other provisions of that Act, indicate the concern for thermal pollution that exists at the Federal level. A proposed amendment to the Federal Power Act would require licenses for cooling water withdrawals for steam-electric powerplants. Such a licensing system might provide an effective and equitable means of assessing potential thermal pollution loads and of controlling adverse temperature rises in receiving bodies of water. Further discussion of the effects of thermal pollution on water quality is provided in chapter 3, part 5.

Problems Related to Hydroelectric Power

Except for Alaska, the sites available for conventional hydroelectric projects are relatively scarce, and there are increasingly difficult problems involved in their development. Conflicts with other water uses, including municipal and industrial water supply, recreation, and fish and wildlife, are increasing. Many rivers are being proposed for preservation in their natural state for recreation purposes. In some cases, hydroelectric power development is being inhibited by difficulties associated with maintenance of anadromous fish runs over high dams.

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CHAPTER 4

Agricultural Uses

CURRENT STATUS

Agriculture uses more water than any other single industry in the United States. Most of the water is obtained from precipitation; and it is used for crops, pastures, livestock, and woodlands. It is estimated that an average of 30 inches of water in the form of rain or snow fall annually on the United States, but only about 30%, or 9 inches, reaches surface streams or underground aquifers. The remaining 70% consists of a complex relationship between evaporation, transpiration, and incorporation of water into plants which does not permit accurate measurement of water use by plants. Some of the rain falling on plants is intercepted by them; however, most plant water requirements are withdrawn from soil moisture.

While precipitation, particularly rainfall, directly supplies most of the water required by agriculture, it frequently needs to be supplemented from water diverted from streams or stored in surface impoundments or underground aquifers. Irrigation is practiced on 10% of the farms in the Nation. This small proportion of irrigated land is deceiving because nearly 20% of the value of farm crops is produced on this acreage. In the arid and semiarid parts of the country, irrigation makes the difference between unproductive range or waste lands and highly productive crop and pasture lands. In the humid areas, average rainfall may appear adequate for production of the major crops; but supplemental irrigation can prevent crop failures in drought years and increase yields and improve product quality even in average years. Irrigation is also used, both for frost protection and control of high temperatures, on some specialty crops.

The Assessment has been hampered by inconsistent data on irrigated land. The Census of Agriculture defines irrigated land as land in farms receiving water in a given year while the inventory of the Geological Survey does not define irrigated land. For this Assessment, irrigated land is defined as land developed for irrigation which regularly receives water for the production of agricultural products. Thus, this productive land definition of irrigated land includes lands which are temporarily idle for water supply or other reasons but does not include lands which do not regularly produce agricultural products. Using this definition, it is estimated that there were about 42 million acres of irrigated land in the United States in 1965 (table 4–4–1).

Water withdrawals for irrigation are shown in table 4–4–1 and amount to 111 bgd (125 maf/yr). About two-thirds of total irrigation

TABLE 4–4–1.—*Present irrigated land and water use, 1965*

Region	Irrigated land	Withdrawal	Consumption
	1,000 acres	*mgd*	*mgd*
North Atlantic	310	151	150
South Atlantic-Gulf	1,500	3,270	1,400
Great Lakes	140	75	68
Ohio	55	24	24
Tennessee	20	8	8
Upper Mississippi	140	95	83
Lower Mississippi	900	1,320	890
Souris-Red-Rainy	15	24	24
Missouri	7,400	16,039	9,798
Arkansas-White-Red	3,800	6,960	5,030
Texas-Gulf	5,500	7,450	5,810
Rio Grande	2,000	6,671	4,165
Upper Colorado	1,440	3,880	1,934
Lower Colorado	1,660	6,400	3,170
Great Basin	1,860	4,575	2,100
Columbia-North Pacific	6,250	26,400	10,050
California	8,850	26,200	19,290
Subtotal	41,840	109,542	63,994
Alaska	0.2	[1]	[1]
Hawaii	150	1,060	477
Puerto Rico	90	250	225
Total	42,080	110,852	64,696

[1] Insignificant.

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withdrawal is surface water (from lakes, streams, and reservoirs); and the remainder is groundwater. Large conveyance losses occur in the process of transferring irrigation water from the source to the fields where it is used. These losses amount to about 22 bgd (25 maf/yr), representing 20% of total withdrawals, and are comprised of seepage, evaporation, and phreatophyte growth. Irrigation uses consume about 65 bgd (73 maf/yr), or almost 60% of total withdrawals.

Western regions account for about 95% of total water withdrawals and consumption for irrigation in the Nation. Moreover, most of the total water withdrawn in these western regions is used for irrigation. The source of irrigation water and the amounts applied per irrigated acre vary among the western regions. In the Upper Colorado Region, practically all the water comes from surface sources, while the chief source in the Texas-Gulf Region is ground water. Average withdrawals for irrigation range from less than 1 af per irrigated acre in several eastern regions to more than 5 af per irrigated acre in the southwest. In the Texas-Gulf Region, about 78% of the water withdrawn is consumed; but in the Columbia-North Pacific Region, only 38% is consumed.

Water withdrawn for livestock uses is about 1.7 bgd. Almost 60% comes from wells, and the remainder from streams, lakes, and impoundments such as stock ponds. About 94% of this withdrawal is lost for further use. The Missouri Region uses the most water for livestock purposes, accounting for over 20% of the national total. Most of the water is consumed as drinking water. Lesser amounts are used for sanitary purposes—cleaning and disinfecting barns, washing livestock, and manure disposal. Livestock water development and irrigation enhance livestock production in some areas by supplementing water naturally available for drinking, pasture, and forage crops. Livestock production can cause water quality problems where animal wastes come into contact with streams, underground aquifers, or wells. The need for more economical means of manure disposal has intensified in recent years as the number of livestock per farm has increased.

Although irrigation as well as livestock production affect water quality adversely in some areas, perhaps more serious are the unknown pollution hazards posed by the use of fertilizers and pesticides on farmlands. The increasing utilization of these substances emphasizes the need for expanded research as to their effects on water quality.

MANAGEMENT PROBLEMS

Perhaps no other natural resource is the subject for as many institutional arrangements as water for agricultural use. Federal, State, and local government laws, policies, and administrative regulations all influence water use. The multiplicity of small districts and agencies with jurisdiction over water resources development also poses a management problem because each has its own area of jurisdiction, regulations, and programs, many of which overlap (see part 5, chapter 9).

Water laws and regulations are intended to facilitate beneficial use of available water supplies; but in many cases they actually obstruct optimum utilization of the resource by preventing the orderly transferral of water from one use to another, or from one agricultural use (or farm) to another. In Eastern States, the riparian doctrine is the basis for water law; and in the strict sense, the owner of lands contiguous to the stream is generally entitled to waterflow undiminished in quality or quantity. In general, Western States adhere to the appropriation doctrine; and the earliest water claim (quantitative and qualitative) establishes a water right in law which takes precedence over later claims.

At the district level, problems of water allocation among farm users and between farm and nonfarm uses arises. In some cases, farmers are unable to obtain water needed for crops during periods of shortage; and in others, irrigation projects are designed to bring supplemental water to marginal water users. Conflict between farm and nonfarm water uses are emerging as urban centers in the West continue to grow. Nonfarm uses of water generally bring higher economic returns than farm uses, and in some areas, nonfarm interests buy farmland at high prices in order to obtain control of water for current and future needs.

Even if legal and administrative regulations presented no problems in water management for agricultural production, problems would occur at the farm level. Farmers frequently have less than adequate water supply or uncertain supply. In humid areas, considerable uncertainty exists concerning the best combination of rainfall and irrigation—a heavy rainstorm following an irrigation may result in crop yield losses rather than gains; and in areas where groundwater resources are being exhausted, farmers generally have inadequate bases for determining both short-run and long-run optimum combinations of water and other resources.

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TRENDS IN USE AND CONTROL

Agricultural use of water, particularly for irrigation, has grown steadily. This long-term upward trend is related to a wide variety of factors including changes in population and technology, and socioeconomic conditions. The growth of total population, both at national and world levels, has created an overall increasing demand for farm products. Population shifts also affect agricultural production and water use. In the United States, population movement to the southwest has increased demand for regional production, and increased irrigation has enabled farmers to meet local demands as well as to export products to other parts of the Nation. Rural to urban shifts within regions, with their concomitant increases in per capita income, have tended to increase the demand for fruits and vegetables. In some areas, however, these shifts have diverted water from agricultural to nonagricultural uses.

Technical changes in irrigation development include changes in water storage, conveyance, and application methods for the conservation of existing water supplies. Experimental use of evaporation-retarding films on reservoirs has been successful in reducing water losses. Control of phreatophytes makes additional water available for irrigation use in some areas. Seepage losses during conveyance have been drastically reduced by lining irrigation canals with concrete and other impervious materials. The amount of water applied per acre has been reduced by sprinkler irrigation in some areas. Adoption of these measures has decreased conveyance and on-farm water losses, enabling some farmers to irrigate more acreage with the same withdrawal and others to maintain the same acreage with smaller withdrawals. On-farm irrigation efficiency is estimated to be about 50% at present. It is further estimated that with the adoption of recommended conservation practices, the efficiency level could be raised to 70%.

Development of new water sources has been an important factor in the upward trend in irrigation in the past quarter century. Development and use of groundwater in California, Arizona, New Mexico, Texas, Oklahoma, Kansas, Nebraska, and Idaho has been especially important in the irrigation development of these areas. Multiple-use reservoirs constructed by Federal agencies, particularly the Bureau of Reclamation, have provided a substantial portion of the water used for irrigation in the West. The 113 projects of the Bureau served some 8 million acres of irrigated land in 1965. Reclaimed sewage is being used increasingly for irrigation, although only 530 mgd (0.6 maf/yr) (less than 1% of the total irrigation withdrawal) currently comes from this source. More than two-thirds of this total amount of reclaimed sewage is used for irrigation in California.

Some technological changes in agriculture affect both irrigated and nonirrigated land. Use of larger amounts of fertilizer, increased plant population, improved crop varieties, pest control, and improved water management have produced spectacular gains in productivity of irrigated land. Some of these same technological changes have enabled many farmers to obtain satisfactory yields without irrigation. There is evidence, however, that these technological changes have been adopted more rapidly on irrigated than on nonirrigated farms.

The importance of irrigation even in humid areas has also increased as a result of technological change. Irrigation is an important quality control device in the production of many crops. Specialty crops are often produced under contract with processors who require farmers to use irrigation as a production and quality control practice.

Farm production costs have influenced irrigation development. Farmers have generally been interested in irrigation as a means of reducing unit costs of production by increasing yields. Moreover, the high yields per acre obtainable with irrigation are especially attractive where Federal acreage restrictions exist.

In some local areas, the level of economic activity has been related to irrigation development. Both the construction expenditures for irrigation reservoirs and canals and the increased returns from irrigated crops have stimulated the economies of these agriculturally dependent communities. Conversely, declining levels of economic activity have resulted where water deficiency has forced cutbacks in acreage irrigated.

On the basis of the projected increases in population, growth in the economy, and expansion of exports, agricultural production is projected to increase more than 40% from the 1959-61 level by 1980 (chapter 3, part 3). Further increases are expected to occur by 2000 and 2020. Part of the increase in agricultural productivity will come from increases in the acreage and productivity of irrigated lands.

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PROJECTED AGRICULTURAL WATER REQUIREMENTS

Future use of water for irrigation will depend upon several factors—primarily climate, cropping pattern, acreage irrigated, and the level of efficiency attained by irrigators in the use of water. In tables 4–4–2, 3, and 4 projections of irrigated land and irrigation water requirements are shown.

The acreages assumed to be irrigated should be regarded neither as predictions nor as goals for development. They are based largely on trends during the past quarter-century (1940–65) as modified by expectations of available water supply and increased use of irrigation on high-profit crops. In the eastern regions, the trend factor is given more weight, while in the western regions, water supplies are becoming more important as groundwater levels recede.

Plans for Federal development of irrigation water supplies are especially important in the western regions. The acreages in table 4–2–2 include projects already developed by the Bureau of Reclamation and Bureau of Indian Affairs, those under construction or authorized for construction, and those which studies show to be economically feasible under present criteria.

Water used in livestock production is projected to increase in all of the water resources regions (table 4–4–5). The projections are based on 1965 relationships between water use and quantity of product produced. While some changes in these relationships are likely to occur during the projection period, they are not expected to change livestock water needs significantly. Lack of water is not expected to limit livestock production in any of the regions, although local areas may be limited by periodic water shortages. In some areas, structures for supplying livestock water could affect downstream flows, but the aggregate effect of these structures is expected to be small, especially in the more humid eastern regions.

CURRENT AND PROJECTED CAPITAL INVESTMENT

It is impossible to obtain complete and accurate data on capital investment in water resources used for agricultural production, because of the number and variety of facilities involved in the process. Little is known of the aggregate investment in wells, springs, and ponds for livestock on individual farms. The Department of Agriculture shares with cooperators a small proportion of the development costs of these livestock watering facilities. Future investments will probably continue to come from private rather than public sources.

Information on irrigation investment is more

TABLE 4–4–2.—*Regional projections of irrigated land in the conterminous United States*

(Thousands of acres)

Region	1960	1965	1980	2000	2020
North Atlantic	240	310	380	550	700
South Atlantic-Gulf	850	1,500	1,800	2,750	3,750
Great Lakes	100	140	230	350	470
Ohio	35	55	90	180	260
Tennessee	15	20	30	40	50
Upper Mississippi	80	140	210	390	550
Lower Mississippi	700	900	2,100	3,050	4,150
Souris-Red-Rainy	10	15	90	240	250
Missouri	6,600	7,400	8,050	9,000	9,600
Arkansas-White-Red	3,100	3,800	5,600	6,400	6,850
Texas-Gulf	5,100	5,500	5,500	5,500	5,500
Rio Grande	1,950	2,000	2,050	2,050	2,050
Upper Colorado	1,370	1,440	1,800	2,000	2,000
Lower Colorado	1,520	1,660	1,750	1,800	1,800
Great Basin	1,700	1,860	1,950	2,000	2,000
Columbia-North Pacific	5,450	6,250	7,700	9,500	11,200
California	8,420	8,850	10,150	10,750	11,100
Total	37,240	41,840	49,480	56,550	62,280

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TABLE 4–4–3.—*Regional projections of irrigation withdrawals*

(Million gallons daily)

Region	1965	1980	2000	2020
North Atlantic	151	230	330	420
South Atlantic-Gulf	3,270	3,900	6,000	8,200
Great Lakes	75	110	170	230
Ohio	24	40	80	115
Tennessee	8	18	23	29
Upper Mississippi	95	110	200	280
Lower Mississippi	1,320	3,030	4,400	6,000
Souris-Red-Rainy	24	200	562	576
Missouri	16,039	19,300	21,600	23,000
Arkansas-White-Red	6,960	9,400	10,700	11,500
Texas-Gulf	7,450	9,400	9,000	8,500
Rio Grande	6,671	6,840	6,840	6,840
Upper Colorado	3,880	5,300	5,350	4,900
Lower Colorado	6,400	7,700	7,000	6,500
Great Basin	4,575	6,200	6,100	5,800
Columbia-North Pacific	26,400	31,400	37,500	42,500
California	26,200	30,950	31,700	32,600
Subtotal	109,542	134,128	147,555	157,990
Alaska	[1]	4	9	18
Hawaii	1,060	1,420	1,910	2,570
Puerto Rico	250	300	350	400
Total	110,852	135,852	149,824	160,978

[1] Insignificant

TABLE 4–4–4.—*Regional projections of irrigation consumption*

(Million gallons daily)

Region	1965	1980	2000	2020
North Atlantic	150	230	330	420
South Atlantic-Gulf	1,400	1,600	2,450	3,350
Great Lakes	68	95	140	190
Ohio	24	40	80	115
Tennessee	8	16	21	26
Upper Mississippi	83	95	170	240
Lower Mississippi	890	2,180	3,170	4,320
Souris-Red-Rainy	24	150	402	416
Missouri	9,798	12,100	13,500	14,400
Arkansas-White-Red	5,030	6,800	7,800	8,300
Texas-Gulf	5,810	7,100	7,100	7,100
Rio Grande	4,165	4,270	4,270	4,270
Upper Colorado	1,934	2,600	2,880	2,880
Lower Colorado	3,170	3,630	3,760	3,760
Great Basin	2,100	3,040	3,110	3,110
Columbia-North Pacific	10,050	12,900	15,900	18,700
California	19,290	23,800	23,700	23,800
Subtotal	63,994	80,646	88,783	95,397
Alaska	[1]	3	6	12
Hawaii	477	640	860	1,150
Puerto Rico	225	270	315	360
Total	64,696	81,559	89,964	96,919

[1] Insignificant

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TABLE 4–4–5.—*Present and projected water requirements for livestock*

(Million gallons daily)

Region	Withdrawal				Consumption			
	1965	1980	2000	2020	1965	1980	2000	2020
North Atlantic	81	90	130	170	69	80	110	140
South Atlantic-Gulf	146	200	300	380	139	190	285	360
Great Lakes	79	96	132	183	72	87	120	167
Ohio	134	129	194	258	132	129	194	258
Tennessee	37	48	67	93	36	47	64	89
Upper Mississippi	314	477	695	956	305	392	563	775
Lower Mississippi	39	59	79	114	38	58	75	110
Souris-Red-Rainy	19	21	29	40	19	21	29	40
Missouri	368	521	726	1,015	355	502	701	980
Arkansas-White-Red	150	228	318	443	146	223	311	433
Texas-Gulf	100	180	300	440	100	170	280	410
Rio Grande	69	70	70	70	68	69	69	69
Upper Colorado	11	15	20	25	10	14	20	20
Lower Colorado	15	20	30	40	12	15	25	35
Great Basin	16	20	30	40	11	15	21	29
Columbia-North Pacific	59	77	107	147	55	71	100	137
California	80	110	150	220	50	80	90	160
Alaska	....	....	....	....	....	....	....	....
Hawaii	3	4	5	6	3	4	5	6
Puerto Rico	6	10	15	20	6	10	15	20
Total	1,726	2,375	3,397	4,660	1,626	2,177	3,077	4,238

easily obtainable because both the proportion and the magnitude of public investment are greater. The Bureau of Reclamation estimated that the total Federal investment in single-purpose irrigation facilities of reclamation projects from 1906 to 1965 was about $1.1 billion; and in multiple-purpose projects about $2.5 billion, a large part of which was for irrigation.

Special reports from the Census of Agriculture provide information on investment by irrigation organizations in the 17 Western States and Louisiana. These organizations include mutual irrigation organizations, commercial water suppliers, irrigation districts, Bureau of Reclamation projects, Bureau of Indian Affairs projects, and some States and cities. They furnished water for nearly 18 million acres in 1959, the latest year for which data were available. The organizations reported gross capital investment of $2.4 billion as of 1959. This figure does not include replacement costs, but, rather, reflects historical investment. Gross capital invested from 1950 through 1959 was slightly more than $1 billion. The average gross capital investment of the organizations was $6,319 per irrigated farm, or $137 per acre of irrigated land.

Information from the Census of Agriculture combined with other studies indicates that the national average of on-farm capital investments for irrigation was $153 per acre in 1959. This average was about $217 per acre in the 31 Eastern States, and $138 in the 17 Western States.

Future investment in irrigation will depend to a large extent on Federal policy toward water resources development and on cost-price relationships in farm production. Per acre costs are expected to increase as less desirable storage sites are developed, as water is transported greater distances, and as general construction costs move upward.

Federal agricultural water management policy should include consideration of both the policy's overall effect on agricultural production, and the productivity of investment in irrigation relative to alternative investments such as drainage, clearing of land, and other technological developments. In some cases, investments in water resources developments which provide supplemental water to land now being irrigated might be more productive than those which would bring new land into production.

The effect of cost-price relationships on investment in irrigation is difficult to predict. If water costs advance relative to other factors of production, investment in irrigation would be less attractive. Conversely, increases in the costs of other factors of production might well stimulate greater investments in irrigation by both private and public interests.

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CHAPTER 5

Navigation Uses

INTRODUCTION

This chapter provides a brief assessment of the nature and extent of inland navigation works currently in use in the United States, the present and projected uses of these improvements, the impacts of waterborne transportation on water resources, and the future of navigation in this country. Data and information on the nature and extent of Federal improvements on inland waterways are readily available and are generally adaptable for the purposes of this Assessment. The same cannot be said for non-Federal improvements, but because of the minor role of such improvements in the overall navigation system, the absence of this data and information has little effect on the value of the Assessment.

Various types of data on the use of the water resources for waterborne transportation have been collected since 1922. Data most useful in assessing the role of waterborne commerce in the overall field of transportation are in terms of tons or ton-miles for several categories of waterway traffic and commodity classifications. These data are adequate for an assessment of the current waterborne traffic on an annual basis. However, because of changes in reporting criteria, the use of these data to define trends in waterborne commerce requires considerable judgment. Furthermore, data needed to define seasonal variations in the use of improved waterways are not generally available.

In general, the information available on waterborne commerce is related to established routes and improvements for navigation. While information on the extent of traffic and the performance of navigation equipment is available, specific data on the performance of the facilities, particularly with respect to overall water or flow requirements are not generally available. Thus, the relationships of waterborne commerce to the water resources are largely a matter of judgment. In the cases of the use of the water resources by recreation craft and the use of unimproved water courses for commercial or recreation traffic, even greater reliance must be placed on judgment.

BACKGROUND

The rivers and lakes of the United States have served as avenues for transportation from the time of the earliest inhabitants. Beginning about 1770, several States and local groups became seriously involved in improving the more important river channels in the northeastern United States and in constructing barge channels to interconnect river systems and to bypass major obstructions to navigation. Early examples of these endeavors were the highly successful Erie Canal constructed between 1817 and 1825 to connect Lake Erie with the Hudson River, and the Louisville-Portland Canal constructed in 1830-1831 to provide passage around falls on the Ohio River.

In 1824, Congress authorized the Corps of Engineers to remove snags and sandbars from major navigable rivers. About the same time, feeder and interconnecting canals were being extended by private enterprise and States into an extensive navigation network. Such waterway improvements and the introduction of steamships during the first half of the 19th century promoted a rapid rise in river navigation. With the advent of the Civil War and the railroads, however, river traffic declined rapidly until in 1908 it was only a fraction of the 1860 traffic. By 1908, States and private canal companies with significant Federal assistance had spent over $300 million to construct over 4,000 miles of navigation channels, of which about one-half are still in use.

Federal activities in waterway improvement increased when canalization of the entire Ohio River to 9-feet minimum depth was authorized in 1910. These improvements were completed in 1929, but further improvements have been made periodically and are continuing to be made to modernize the waterway in keeping with traffic needs. The heavy burden placed on the Nation's transportation system by the First World War caused renewed Federal interest in improvement of the Nation's inland water transportation. In 1918, the Federal Government pro-

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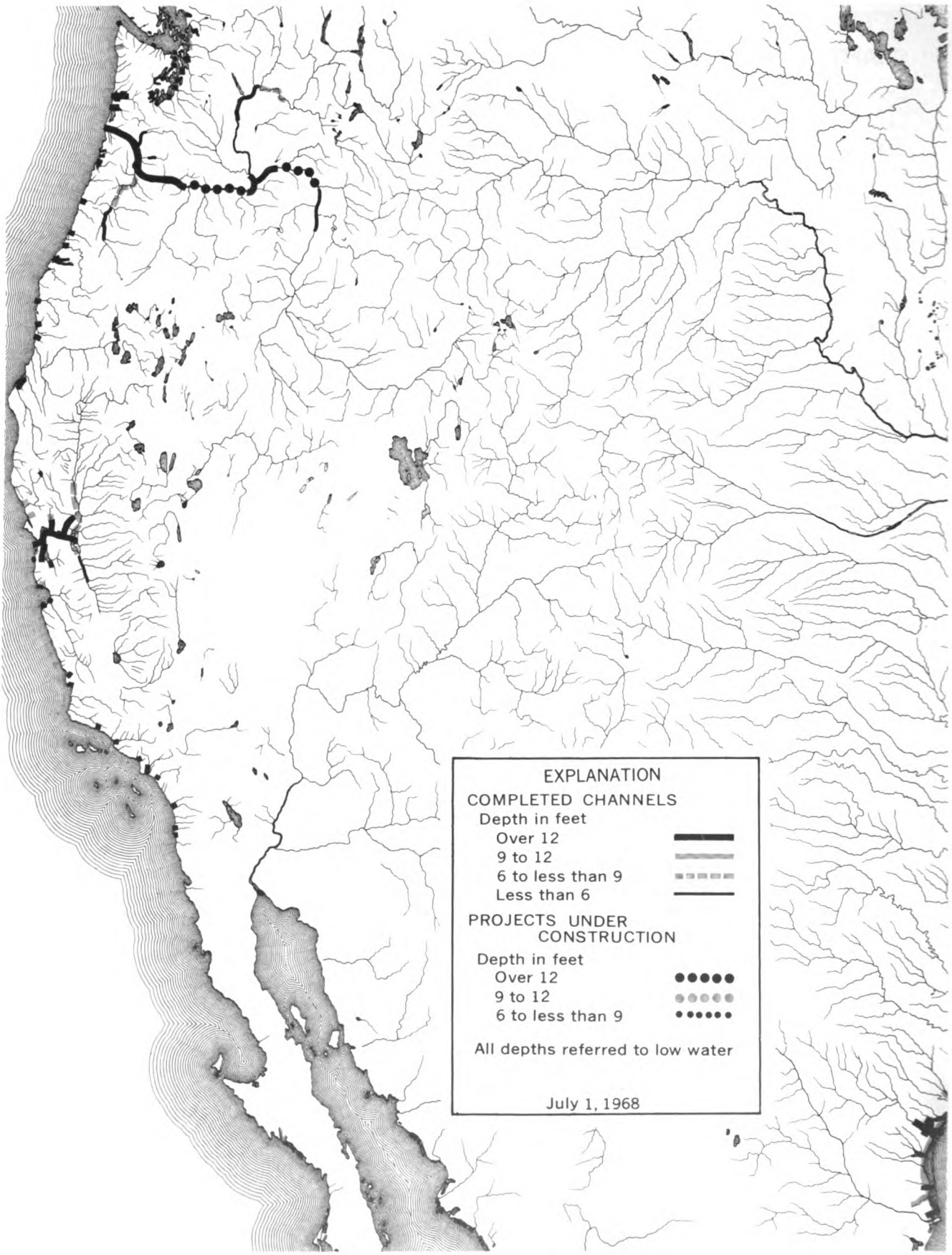

FIGURE 4–5–1.—*Principal waterways of the United States.*

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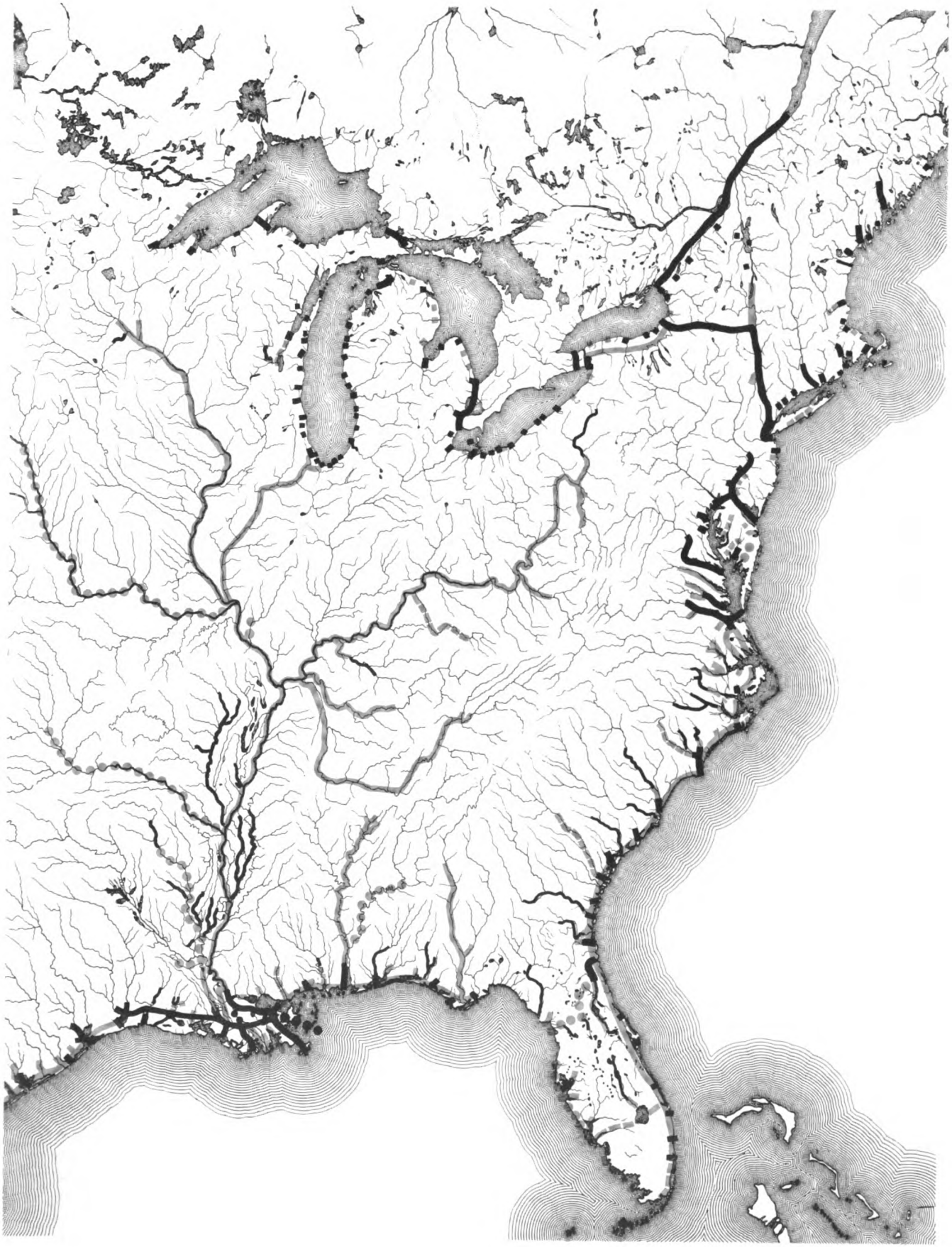

4–5–3

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moted barge operations utilizing relatively efficient propeller-driven towboats powered by diesel engines. These events gave tremendous impetus to increasing the volume of navigation on the entire Mississippi River system and ushered in the modern era of river commerce. Many of the early canals in tributary areas gradually gave way to competing modes of transportation, leaving primarily a vastly improved main-stem navigation system. Many reaches of the present system now accommodate modern towboats of over 5,000 horsepower (25 times the horsepower of the old paddle wheel steamboats) that can handle tows carrying 40,000 tons in 20 or more barges.

In contrast, while intensity of use is low, water transportation provides access to many parts of Alaska where there is no road or rail access.

EXISTING WATERWAYS

Federal laws provide for the protection and preservation of improved and unimproved navigable waterways in the United States. Federal interests are widespread under such laws, but presently the Federal Government only exercises regulatory powers concerning dredging, location of structures, etc., on inland navigable waters totaling approximately 60,000 miles length in addition to the shores of the Great Lakes and seacoasts. In addition, the Federal Government maintains surveillance over conditions and structures that may affect stream flows in navigable waters.

The Federal Government has improved over 22,000 miles for commercial navigation. In addition, over 500 miles of State canals are in commercial operation. Also, several thousand miles of river channels, lakes, and tidewater bays and estuaries are used in their natural state for commercial navigation. Of these, the Great Lakes are the most notable. The Great Lakes have a surface area of about 95,000 square miles, of which about 61,000 square miles is in the United States. The lakes have a combined length of 1,360 miles. The lakes, together with 175 miles of connecting rivers and channels and various dredged entrances in shallow parts, form the Great Lakes waterway system. The 185-mile-long St. Lawrence Seaway connects the Great Lakes to deep water at Montreal; and the Illinois waterway connects the lakes at Chicago to the Mississippi River waterway system. The locations of the Nation's improved waterways are shown in figure 4–5–1.

WATERWAY COMMERCE

General

A good measure of the instream use of water by commercial navigation is the commerce carried. In 1946 and 1965, the percentages of the total intercity traffic carried by the four principal types of carriers were as follows:

	1946	*1965*
	Percent	
Railroads	68.2	43.0
Highways	7.3	22.5
Inland waterways (including Great Lakes)	14.0	15.5
Pipelines	10.5	18.8

Commercial waterborne commerce is generally transported in three main general types of carriers, developed for the different navigation conditions prevailing, namely, deep draft seagoing ships; lake ships of 20 to 27 feet draft plying the Great Lakes; and barges and towboats of 5 to 12 feet draft that operate in the shallow protected inland waterways of rivers, bays, estuaries, and intracoastal channels.

Statistics of waterborne commerce have been compiled on an annual basis for each waterway and port. Summaries are published annually by the Corps of Engineers in several volumes under the main title "Waterborne Commerce of the United States." These show the amount of instream use of water by commercial navigation of waterways, and are summarized under the following categories: (1) Inland and intracoastal channels; (2) Great Lakes harbors and channels; and (3) coastal. Cargo handled in tons has been summarized by foreign imports and exports through coastal ports or Great Lakes ports; and domestic traffic classified as coastwise, lakewise, internal, intraport, local, and intraterritory.

Nationwide Tonnage of Traffic

In 1965, total domestic waterborne traffic was 829.2 million tons consisting of 201.5, coastwise; 153.7, lakewise; 369.6, internal; 102.9, local; and 1.5, intraterritorial. This excludes foreign traffic of 443.7 million tons. The domestic waterborne traffic by major commodities carried in 1955, 1960, and 1965 is given in table 4–5–1. Readily available 1964 information indicates that most of the internal traffic was carried on the Mississippi River, the Ohio River, and the Gulf Intracoastal waterways which carried 102 million, 96 million, and 72 million tons, respectively. The principal commodities carried on waterways

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TABLE 4–5–1.—*Domestic waterborne commerce by major commodities*

Commodity	1955		1960		1965	
	Million tons	Percent	Million tons	Percent	Million tons	Percent
Petroleum and products	283.8	38.1	317.9	41.8	321.7	38.8
Coal and coke	142.3	19.1	133.1	17.5	157.5	19.0
Sand, gravel, stone	90.9	12.2	90.0	11.8	100.3	12.1
Iron ore, iron, steel	103.5	13.9	81.3	10.7	75.5	9.1
Logs and lumber	27.6	3.7	28.1	3.7	29.0	3.5
Chemicals	12.7	1.7	17.5	2.3	27.4	3.3
Seashells	19.4	2.6	21.3	2.8	24.1	2.9
Grains	8.2	1.1	11.4	1.5	18.2	2.2
All others	56.6	7.6	60.0	7.9	75.5	9.1
Total	745.0	100.0	760.6	100.0	829.2	100.0

have been petroleum, coal, gravel, and iron ore. In recent years, tonnage of grains, chemicals and chemical products have been increasing rapidly.

Nationwide Ton-miles of Commerce

Waterborne commerce, exclusive of ocean mileage, has increased from 163 billion ton-miles in 1950 to 265 billion in 1966 equal to a 62% increase in 16 years. These figures include deep-draft commerce, both foreign and domestic, on the inland waters of the United States from the seacoast to the ports, and the entire trip mileage between United States and Canadian Great Lakes ports. During this time span commerce on the Great Lakes fluctuated greatly with no significant increase in total, while commerce on the inland and intracoastal waterways increased rapidly. The growth in ton-miles of waterborne commerce on the inland waterways is shown on figure 4–5–2, along with the projections of total inland waterborne commerce.

Inland Waterways Exclusive of the Great Lakes

The freight carried annually by inland waterways (including intracoastal and internal deep-draft approaching seaports) has grown from 298 million tons in 1950 to 467 million tons in 1965. The Mississippi River system and Gulf Intracoastal Waterway carry most of this tonnage and a schematic representation of the traffic movement thereon is shown on figure 4–5–3. Since 1935, the growth in ton-miles of inland and intracoastal waterborne commerce has increased over 10 times from about 14 to 153 billion. The increase, including internal deep draft entering seaports, has been 114%, 227%, and 56%, respectively, during the 3 decades from 1935 to 1965. Data available for inland and intercoastal waterways from 1961 to 1965 show that the annual rate of increase has been about 7%. The growth in ton-miles of inland waterborne commerce has been increasing more rapidly than the growth in tonnage, indicating an increase in the average length of haul since 1950. This average haul was about 284 miles in recent years, exclusive of local traffic.

Much of this rapid growth can be attributed to deepening and improving waterways, improvements in towboats and barges, improved navigation aids, more frequent and dependable barge schedules, better control of streamflows, and adjustment of industrial production to opportunities of low cost water transportation—about 3 mills/ton-mile to the shipper.

The Great Lakes System

The United States commerce on the Great Lakes has fluctuated between 80 and 127 billion ton-miles annually since 1950, largely because of fluctuations in iron ore shipments from Minnesota. Traffic to and from foreign countries and United States ports on the Great Lakes increased quite slowly from 29 million tons in 1950 to 35 million tons in 1961. Since opening of the St. Lawrence-Great Lakes seaway to a depth of 27 feet in 1959 to accommodate ocean ships, the foreign traffic at U. S. Great Lakes ports has increased rapidly to 57 million tons in 1965.

Coastal Harbors and Channels

Ocean-borne traffic at coastal harbors has been increasing steadily from 324 million tons in 1950 to 589 million in 1965. This trend is expected to continue as foreign commerce increases. Coastal harbors such as New Orleans, New York,

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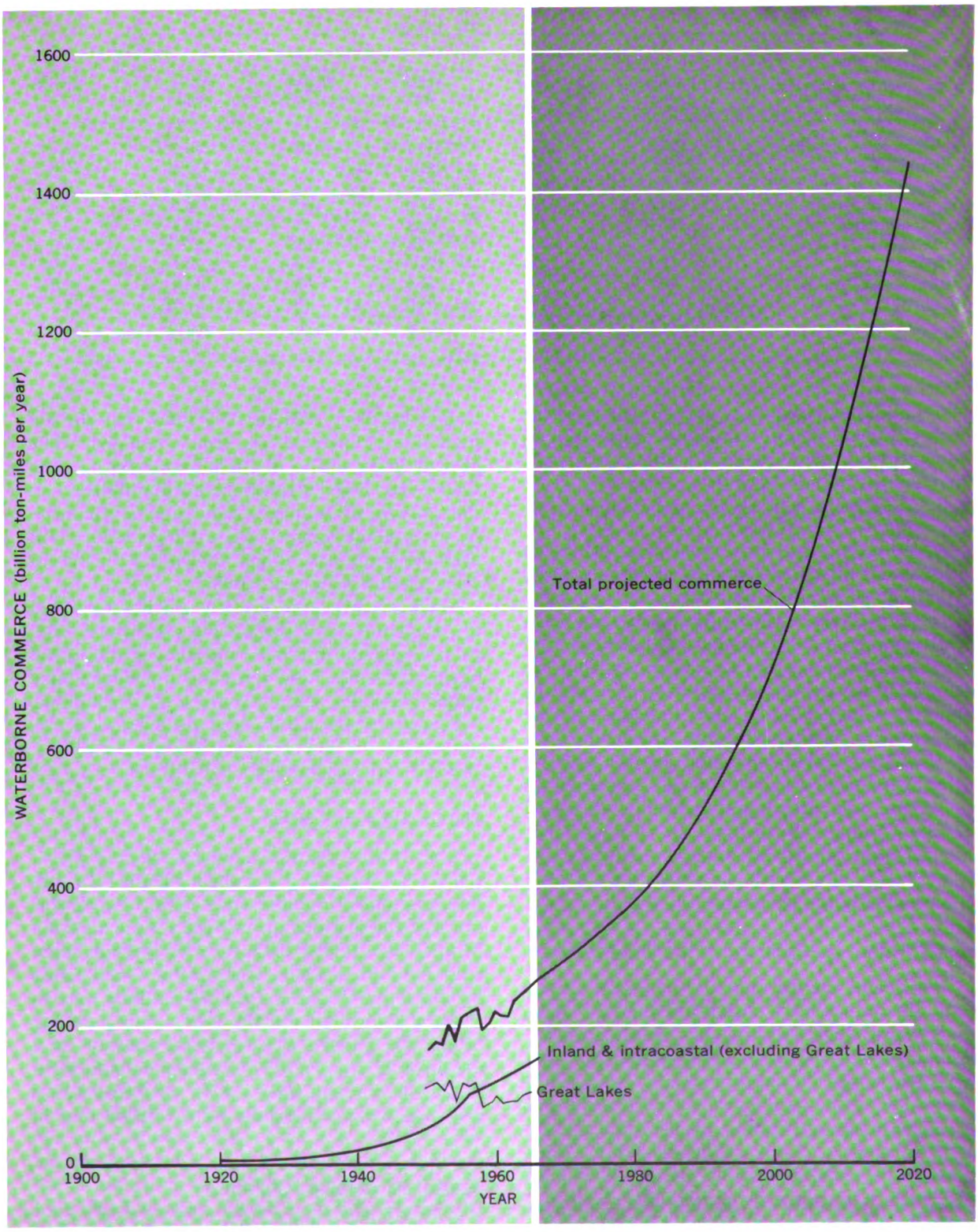

FIGURE 4–5–2.—*Historical and projected inland waterborne commerce, 1920–2020.*

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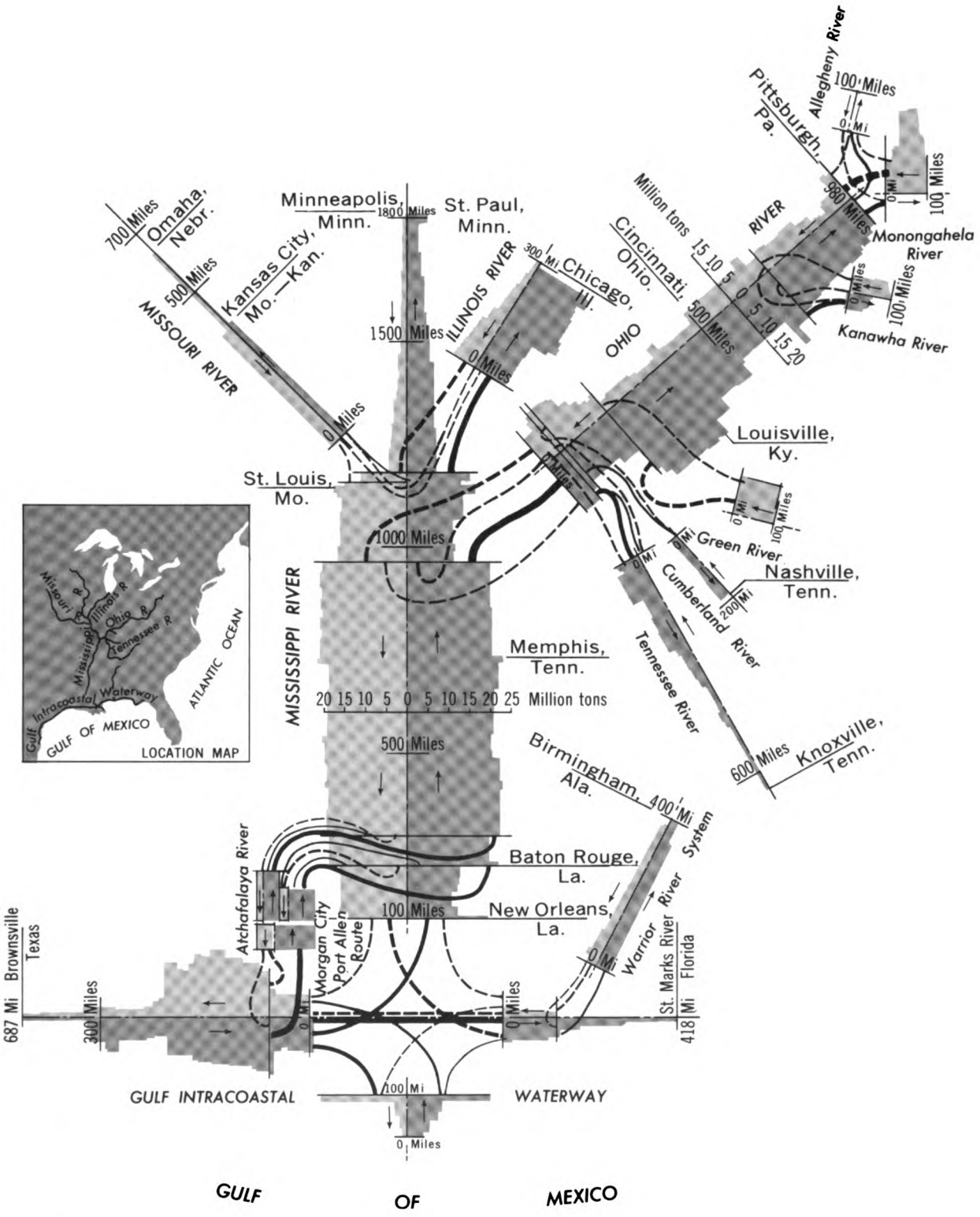

FIGURE 4–5–3.—*Inland freight tonnage on the Mississippi River system and the Gulf intracoastal waterway, 1964.*

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Portland, and others form important linkages to inland waterborne commerce.

Future Commerce

About 15% of the tonnage of intercity commerce in the United States is waterborne. Projections of intercity commerce to 2020 were made, based upon regression analyses of historic trends in and projections of the value of the commodity producing sectors (agriculture, mining, construction, and manufacturing) of the gross national product. The projected waterborne commerce was then calculated on the assumption it would retain its present share of the total intercity commerce. Historic records and these future projections indicate the growth of waterborne commerce, exclusive of ocean mileage, in billions of ton-miles as follows: 1950, 163; 1966, 265; 1980, 370; 2000, 710; 2020, 1,440. These figures include deep-draft commerce, both foreign and domestic, on the inland waters of the United States from the seacoast to the ports, and the entire trip mileage between United States and Canadian Great Lakes ports. The projections indicate an increase in waterborne commerce between 1966 and 2020 of almost 450%.

Because the mileage of the improved inland waterway system is only likely to increase about 20% by 2020, the density of traffic would have to increase about 350%. It is likely that constraints of lock or channel capacities, limited budget for improvements, congestion of waterfront locations, limitations of service areas, competition from other sources of transport, and other factors may result in actual traffic being lower in 2020 than is indicated by the projections.

Development of extra high voltage transmission lines and mine mouth and atomic energy powerplants will slow the rate of growth in the amount of coal transported in the future. Pipelines for carrying petroleum products may also tend to reduce the proportion of the petroleum transported by waterways. However, waterways are taking on special significance, out of proportion to the tonnage involved, as industrial plant machinery, electric generators, and missiles increase in size beyond those that can be handled by rail or truck.

Estimation of present capacity of all transportation facilities and the ability of each type to handle its share of the increased future commerce, while beyond the scope of this Assessment, could contribute substantially to the understanding of trends in future waterborne commerce.

RECREATION BOATING

The 22,500 miles of improved waterways in the conterminous United States provide a very important base for use of pleasure craft. In 1966, approximately 8,074,000 pleasure craft were in use within the United States. These consisted of the following: outboard motor boats, 4,700,000; inboard motor boats, 580,000; sailboats, 546,000; houseboats, 5,000; pontoon boats, 23,000; canoes, 250,000; and miscellaneous craft, including rowboats, 1,970,000. Pleasure boat usage of improved waterways approximated 38 million boat-days during 1965 and 414,000 pleasure craft passed through navigation locks requiring 199,000 lock operations exclusively for pleasure boats. Table 4–5–2 shows pleasure craft usage of major navigation systems.

TABLE 4–5–2.—*Use of improved navigation channels by pleasure craft, 1965*

Area	Pleasure craft passing thru locks	Lockages exclusively for pleasure craft	Estimated annual use (million craft-days [1])	Estimated peak day use (thousand craft-days [1])
Atlantic Coast	72,540	28,399	13.8	198
Gulf Coast	15,139	9,392	1.5	39
Mississippi River System	266,876	143,362	13.6	180
Pacific Coast	54,847	15,654	3.5	78
Great Lakes	4,800	2,390	5.6	94
Total [2]	414,200	199,200	38	...

[1] A craft-day is defined as one craft using the waterway for one outing during one day. (The average length of an outing was about 5 hours.)
[2] Totals rounded.

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A study made during 1966 of the usage of 7 locks located on the upper Mississippi, Ohio, Illinois, and Black Warrior Rivers showed that out of an annual total 37,437 lockage operations, 6,880, or 18%, were made exclusively for recreation. The study showed percentages ranging from 7% to 35% with the lower percentages being at locks with heavy commercial traffic, which frequently caused long delays for recreation craft and tended to discourage many recreation craft from using the locks. In many instances, the recreation craft are locked through with commercial craft that do not completely fill the lock. Similar percentages experienced on the Pickwick and Wilson Locks on the Tennessee River in 1964 were 30% and 23%, respectively. A study by the State of Wisconsin showed the number of recreation craft passing through Locks 3 to 10, inclusive, on the upper Mississippi River as increasing from 6,509 in 1953; to 37,377 in 1958; and to 48,718 in 1963.

The number of pleasure craft in thousands is estimated to have increased as follows: 1904, 15; 1913, 400; 1930, 1,500; 1947, 2,440; 1951, 3,710; 1961, 7,175; 1965, 7,865; and 1966, 8,074. It appears reasonable to expect that there will be 30 million pleasure craft by 2020.

TRENDS IN DEVELOPMENT

Improvements to Existing Waterways

The carrying capacity of the main river channels, such as the Mississippi, and channels between locks on the Ohio and Columbia Rivers are capable of carrying much more commercial traffic with only small increases in channel maintenance costs.

Practically all improvements to waterways and harbors are now being done by the Federal Government through the Corps of Engineers, the Tennessee Valley Authority, and the Coast Guard except for shore facilities and berthing areas which are provided by non-Federal interests. Major improvements are now being made on the Ohio, Arkansas, Ouachita, Columbia, and Tennessee Rivers, various harbors on the Great Lakes and seacoasts, and in the Chesapeake-Delaware Ship Canal. Most of these improvements to existing waterways involve deepening of channels to accommodate deeper and more efficient craft; enlarging and deepening locks to increase their capacities for handling traffic and reducing barge line operation costs; stabilizing river channels to reduce shoaling and hazards to navigation; and improving navigation aids. The Coast and Geodetic Survey is continually improving the navigation maps of the coastal areas.

New Waterways and Extensions

Major new navigation projects now under construction, along with their mileage and authorized depth, are the Florida Barge Canal, 184 miles, 12 feet; the Arkansas River, 446 miles, 9 feet; and relatively short extensions to existing waterways. In addition, the Trinity River navigation project in Texas has been authorized to a depth of 9 feet for 370 miles from Houston to Fort Worth; the lower 36 miles of the Kaskaskia River, Illinois, has been authorized for 9 feet of depth; and the waterway connecting the Tennessee and Tombigbee Rivers has been authorized for 253 miles of 9 to 12 feet depth. Various other local proposals for new waterways have been studied in varying degrees.

The longest waterways not yet authorized for construction which are being considered for possible construction before 2020 include the Ohio River-Lake Erie via Beaver River, 120 miles, 18 feet; Savannah River below Augusta, Georgia, 200 miles, 12 feet; Sabine River, Texas and Louisiana, 245 miles, 12 feet; Neches River, Texas, 115 miles, 12 feet; San Antonio River, Texas, 144 miles, 12 feet; Columbia River to Wenatchee, Washington, 125 miles, 14 feet; Yazoo River, Mississippi, 163 miles, 9 feet; and Bayou la Fourche (Louisiana Intracoastal Seaway), 68 miles, 40 feet. Also, planning studies have been authorized for a system of channels for the Wabash Valley of Indiana, Illinois, and Ohio, involving several hundred miles of waterways connecting the Ohio River and Lake Erie via the Wabash and Maumee Rivers with a possible connecting waterway to the Illinois Waterway or to Lake Michigan. Navigation improvements on lower reaches of the Red River in Louisiana and Arkansas have been authorized but are primarily in an inactive status at this time; however, a modified slack water project 294 miles long with 9 feet minimum depth is under consideration for submission to Congress for authorization.

Improvement in Navigation Equipment

By 2020, the horsepower of tow vessels is expected to double. Speeds are expected to increase about 25% to reach 12 to 14 mph where channel conditions permit. Improvement in the design of powerplant and propulsion units is continuing along with improvements in the hydraulic design of barges. These and the intro-

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duction of remote control equipment and improvement in navigation aids all lead toward higher efficiencies and reduced operating costs. Future improvements in waterways and equipment, however, are not likely to have as great an impact as in the past on the growth of waterborne commerce.

FACTORS AFFECTING WATER REQUIREMENTS

Generally river flows needed to maintain authorized depths of nontidal navigation channels are less than those required to maintain the quality and flow of water required for other purposes. The lower Missouri, Mississippi, and Columbia Rivers are exceptions during certain periods. The flow required for navigation is greatly dependent on the degree to which the waterways are canalized, the depth being maintained, the number of lockages, the degree to which lockage water is pumped back to upper pools, and other factors. The estimated river flows required at important navigation points are presented in table 4–5–3 for 1965 conditions, and for conditions after completion of presently authorized improvements.

There is no direct relationship between the amount of water needed for navigation and the traffic carried, especially in slack water channels where lockage water can be conserved, if necessary, by pump-back or other arrangements. In water-deficient areas, engineering and economic studies of water requirements of alternative methods of navigation development and alterna-

TABLE 4–5–3.—*Navigation water requirements for major inland waterways*

Major waterway	1965		Required flow with authorized improvements [2]
	Freight movement	Required flow [1]	
	Thousand tons/day	*cfs*	*cfs*
New York State Barge Canal	12	525	630
Savannah River below Augusta	72	6,100	6,100
Cross Florida Barge Canal			
to Atlantic Ocean	...	.....	305
to Gulf of Mexico	...	.....	427
Okeechobee Waterway			
to Atlantic Ocean	9	19	19
to Gulf of Mexico	...	25	25
Black Warrior-Tombigbee Waterway			
Mobile to Tuscaloosa	13	120	418
Upper Mississippi River			
mile 858 to 218	38	1,600	1,900
mile 218 to 203	88	1,600	1,900
Illinois Waterway at the lower 5 locks	84	350	800
Missouri River			
at Kansas City	10	35,000	32,500
at St. Louis	9	40,000	37,500
Upper Mississippi River, mile 203 to 0	90	54,000	54,000
Ohio River			
at mile 939	90	230	1,550
at mile 607	75	450	2,500
Tennessee River, mile 650 to 0	48	[3]	[3]
Lower Mississippi River			
Cairo to White River	164	150,000	150,000
Baton Rouge to Gulf of Mexico	...	150,000	150,000
Columbia River			
above Bonneville	7	110,000	[3]
at Bonneville	7	58,000	58,000
Willamette River above Portland	3	6,000	6,000
Columbia River below Portland	39	77,000	77,000

[1] Flow and lockage water necessary to maintain waterway at authorized depth under 1965 traffic conditions.
[2] Flow and lockage water necessary to maintain waterway at depth of authorized improvement under maximum traffic conditions.
[3] Slack water with nominal flows required immediately below dams.

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tive water uses are involved in determining water requirements for navigation. Because of the increasingly large flows required in the future for maintaining suitable water quality and supplying industrial needs in most water resources regions, the water required for navigation is generally not expected to be in serious competition with water required for other uses. Deepening of estuary channels may sometimes alter salinity conditions and have some influence on water supplies.

Water used, and improvements installed, for navigation can have very significant effects on other uses. A significant proportion of pleasure boating is for sport fishing, and coordinated planning of waterway alignment, disposal of dredging spoil, and the like can prevent losses to fish and wildlife resources or improve conditions therefor. By virtue of improved access, improved waterways can also increase human enjoyment of this resource. Under the Fish and Wildlife Coordination Act, Federal and State wildlife agencies provide consultative services to achieve these desirable results.

TRENDS IN INVESTMENT

The estimated investment by State and private interests in development of navigation waterways up to 1908 was over $300 million at historic dollar values. In addition, 4,424,000 acres of Federal lands were granted to the States between 1827 and 1866 to promote the construction of canals. Since 1910, States and local interests have participated substantially in the development of navigation projects by providing shore and berthing facilities and providing rights-of-way and utility relocations.

The Federal Government, through fiscal year 1966, has appropriated approximately $5.4 billion for new construction of navigation facilities. In fiscal year 1966, about $359 million were so appropriated, of which about $53 million represents navigation allocations in multipurpose projects. Approximately 58% of appropriations through fiscal year 1959 were for inland and intracoastal waterways, 11% for the Great Lakes system, and 31% for seacoast harbors. Federal maintenance and operation costs for the existing waterways were over $122 million in fiscal year 1966 of which over half was expended for maintenance dredging.

To complete the active authorized projects will require an estimated $4.8 billion of additional funds as of February 5, 1967. Indications are that by 2020 about 5,000 miles of new or improved waterways may be developed to depths of 9 feet and over, in addition to those presently authorized. The cost of constructing these future projects and of making improvements to the presently authorized waterways and harbors is likely to be about $16 billion at 1965 prices. Thus, a prospective total expenditure of $21 billion between now and 2020 for construction of navigation facilities may be expected.

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CHAPTER 6

Recreation Uses

INTRODUCTION

Americans continue to turn to the outdoors for recreation, relaxation, and rewarding use of leisure time. Many of the activities they choose and enjoy require various types of water and related land resources. During 1965, total outdoor recreation participation amounted to slightly more than 12 billion activity days. Trends indicate an increase to about 30 billion activity days by the turn of the century.

About one-fourth of all outdoor recreation is and will continue to be dependent on water. Participation in swimming, fishing, boating, water skiing, and ice skating accounted for 2.8 billion activity days in 1965 and is projected to increase to 7.7 billion by 2000. Further, the juxtaposition of water and land enhances the recreation experience afforded by such outdoor activities as camping, picnicking, and walking for pleasure. Two-thirds of all designated publicly administered recreation areas either have a body of water within their boundaries or are adjacent to accessible water. Water and related lands play a significant role now and will be increasingly important in the future as the resource base for providing outdoor recreation opportunities.

RECREATION WATERS

The Resource Base

Recreation waters in streams, lakes, estuaries, or oceans vary in utility according to surface area, depth, shape, salinity, color, temperature, flora and fauna, turbidity, ownership and users. Recreation values come from landscapes and waterscapes, permitting countless activities that change with time and season.

Waters at the source of our river systems include springs, ponds, seeps, swamps, bogs, glaciers, snow packs, and even geysers. Traditionally, people have sought springs as places to build homes, to water stock, to build churches, to promote health, or simply to picnic. Silver Springs, in the Ocala National Forest of central Florida, is one of many spring resources serving as nuclei of popular tourist attractions. Geysers and glaciers form some of the most spectacular attractions in our national parks and forests.

Runoff from the uplands collects in a myriad of small creeks, which empty in turn into streams, rivers, and eventually into the sea. These are waters in transit. Many rivers have been harnessed for navigation, flood control, hydroelectric power, and other uses. As such, they are used for many recreation activities. Some rivers and streams remain in a relatively free-flowing state unchanged by man. The adventure of recreation on free-flowing rivers is being "rediscovered" by an increasing number of vacationists.

Natural ponds and lakes and manmade reservoirs, both large and small, are waters at rest. Most manmade and natural lakes afford attractive sites for varied recreational activities. Small impoundments provide the points of interest in many areas used for recreation. Many larger manmade lakes serve as the base for development of outstanding recreation areas of national significance as, for example, Lake Mead National Recreation Area and Delaware Water Gap National Recreation Area. The swimming pool is a type of very small manmade reservoir which deserves special mention because of its recreation importance. Over 50% of all swimming activity in 1965 took place in swimming pools.

Near the mouths of rivers are estuaries, sounds, and bays and their flanking lands. Beyond is the edge of the sea. The shorelines of the Atlantic and Pacific Oceans, the Gulf of Mexico and another major shoreline, that of the Great Lakes, are valuable recreation resources. They provide the focal points for national parks and seashores, such as Acadia National Park, Point Reyes National Seashore, and Isle Royale National Park. They also provide locales for

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such nationally known resorts as Miami Beach, Florida; Atlantic City, New Jersey; and the Santa Cruz beaches in California.

Still other waters, in forms so unique as to deserve special mention, are the water wonderlands. In this category belong such areas as Okefenokee Swamp, Georgia; Crater Lake, Oregon; the Florida Everglades, Florida; the Boundary Waters Canoe Area, Minnesota; and Niagara Falls, New York. The first is now a national wildlife refuge, the second and third are national parks, and the fourth, a national forest wilderness. Niagara Falls is an international attraction.

The Effects of Modern Man

While the total supply of water is fixed, the amount of surface water potentially available for recreation use is being increased by man's efforts. There are 41.5 million surface acres of inland waters in the conterminous United States. The oceans and Great Lakes forming the Nation's boundaries afford about 22,000 miles of recreation shoreline.

There has been a remarkable increase in the amount of surface water in reservoirs in recent years, and much of it is available for outdoor recreation use. This increase has been greatest in the South and least in the Northeast. The upward trend in the number of reservoirs and in reservoir surface area, and a concurrent decline in the miles of free-flowing streams, is expected to continue. The increase will probably continue to be large in the South and much smaller in the Northeast. The increase in the amount of surface water which can be used for recreation has not taken place where it is most needed for recreation. This will be discussed in later sections.

Swimming pools, not included in the estimates of water surface area mentioned above, may be expected to increase at a rapid rate. There were over 645,000 swimming pools in the Nation in 1965. Increasing personal disposable income, the increase in suburban homes, improved methods of pool construction, and a tremendous increase in population in sunny California, Arizona, and Florida have all contributed to the growth of this resource.

Some of man's activities are responsible for making waters and related lands unsuitable for recreation use. He has created such situations as grossly polluted rivers, algae-choked lakes, oil-covered beaches, and urban and industrial encroachments on flood plains and tidelands.

WATER AND PEOPLE

Use and Projections of Use

Increasing use of water for recreation is reflected in part in the recorded use of existing water bodies, by surveys of participation, in consumer purchase of sporting goods, and in trends in travel.

In 1965, the American people engaged in 2.8 billion activity days of water-based recreation, according to estimates derived from the 1965 Survey of Outdoor Recreation Activities sponsored by the Bureau of Outdoor Recreation (table 4–6–1).

TABLE 4–6–1.—*Projected participation in major water-based recreation activities*

(Millions of activity days)

Activity	1965	1980	2000
Swimming	1,615	2,676	4,697
Fishing	577	738	1,020
Boating (all types)	465	774	1,353
Water skiing	73	146	296
Ice skating	108	183	325
Total of major water-based activities	2,838	4,517	7,691
Total of 25 recreation activities including the above	12,288	18,342	29,774
Water-based as a % of total	23%	25%	26%

Trends in the sales of pleasure boats and equipment from 1948 to 1965 approximate the growth rate in water-based recreation. The annual increase in these sales reached a peak of 13.5% in 1956. From 1956 to 1964, it dropped to an annual average of 7%, slightly in excess of the annual growth rate of the disposable personal income in the Nation.

The use of water for outdoor recreation is expected to continue increasing at a rate greater than the population growth. Projections of major water-based recreation activities indicate total increases of as much as about 60% between 1965 and 1980 and about 170% between 1965 and 2000.

Land and Facilities for Water-based Recreation

Land next to water is essential for access to and full enjoyment of water-based recreation. Conversely, water enhances the desirability of land for other types of recreation. Sixty-six percent of all designated publicly administered

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recreation areas either have a body of water within the area or are adjacent to accessible water. These areas amount to almost 400 million acres, which is only part of the water-related land available for water-based recreation. Table 4–6–2 shows the extent of publicly administered, water-oriented recreation areas and compares these figures to the total of publicly administered recreation areas.

Facilities, too, are necessary for the enjoyment of water-based recreation. The estimated replacement value of certain types of facilities for water-based recreation at publicly administered areas is shown in table 4–6–3.

TABLE 4–6–2.—*Comparison of publicly administered water-oriented recreation areas to total publicly administered recreation areas, 1965*

Administering Agency	Total public recreation areas		Water-oriented recreation areas [1]			
			Number of areas		Acreage	
	Units	*Thou. acres* [2]	*Units*	*Percent*	*Thou. acres* [2]	*Percent*
Federal	2,127	447,558	1,512	71	362,520	81
State	18,614	39,702	7,529	40	32,272	81
County	4,048	2,977	2,142	53	2,688	90
Municipal [3]	27,104	1,238	23,149	85	1,007	81
Total	51,893	491,475	34,332	66	398,487	81

[1] Having a body of water within the area or accessible adjacent water outside the area.
[2] Based on a sample of selected municipalities.
[3] Includes both land and water area within an area but not the accessible adjacent water outside the area.

TABLE 4–6–3.—*Facilities for water-based recreation at publicly administered recreation areas, 1965*

Administrative unit	Beaches	Pools	Marinas [1]	Boat access points [2]
U. S. Total:				
Sites (number) [3]	3,731	3,603	835	8,944
Area (acres)	23,249	645	7,196	17,592
Value (thou. dol.) [4]	767,200	465,500	179,900	263,935
Federal:				
Sites (number)	1,240	439	496	3,283
Area (acres)	6,237	73	4,418	8,184
Value (thou. dol.)	205,800	54,100	110,500	122,800
State:				
Sites (number)	1,170	195	148	3,797
Area (acres)	7,673	25	941	5,885
Value (thou. dol.)	253,200	25,400	23,500	88,300
County:				
Sites (number)	251	115	32	494
Area (acres)	1,329	26	253	714
Value (thou. dol.)	43,900	15,000	6,300	10,700
Municipal: [5]				
Sites (number)	1,070	2,854	159	1,370
Area (acres)	8,010	521	1,584	2,809
Value (thou. dol.)	264,300	371,000	39,600	42,135

[1] Marinas are sites designated for mooring boats, usually providing docks and slips, and parking space for autos. They may include boat service and sanitary facilities.
[2] Boat access points are sites designated for launching boats, usually providing launching ramps and parking space for autos and boat trailers. They may include boat service, picnic, and sanitary facilities.
[3] Sites are tracts of land or water within a recreation area designated for a particular activity.
[4] Replacement value based on standard cost data developed.
[5] Based on a sample of selected municipalities.

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A far greater amount of land and a great value of facilities used in the enjoyment of recreation in water oriented areas are provided by private individuals for their own use and by private individuals for commercial public use. Commercial public use of private land and facilities for water-based recreation is particularly significant near concentrations of population where high use helps to insure profitable operation.

National Interest

In recent years, there has been an awakening national interest in the recreation use of water and related land resources. The following congressional actions are representative of this interest.

Since 1961, the Congress has authorized the acquisition and administration of 16 Federally administered recreation areas of national importance. The primary asset in 14 of these is a water feature such as a seashore, natural lake, reservoir, or river. Scenic mountain streams are an important part of the recreation resource base in the two other areas. A proposed national program for the preservation of free-flowing and scenic rivers is also receiving public attention, as indicated in chapter 8 of part 5.

Recreation is also receiving increased attention and action in the planning of water resources developments. The Federal Water Project Recreation Act of 1965 sets forth the basis for recreation planning in connection with Federal water resource projects and provides uniform policies for including recreation and fish and wildlife enhancement features in multiple-purpose projects. Electric utilities, privately and publicly owned, are also providing for recreation use of the reservoirs they construct and operate under Federal Power Commission licenses.

Recent congressional actions in the field of water pollution control also reflect public interest in water quality and the desire to make more waters suitable for recreation use. More about this subject is contained in chapter 3 of part 5.

EMERGING PROBLEMS AND OPPORTUNITIES

Imbalance in Supply and Demand

Existing surface water would be adequate to serve projected recreation needs of the Nation beyond 2000 if it were equitably distributed. As is indicated in table 4–6–4, for example, the populous Middle Atlantic and East North Central States are well below the national average as to availability of surface area of inland recreation waters measured in terms of acres per capita, while the arid Western States are relatively well supplied with inland waters in terms of per capita measures.

The problem of geographical imbalance is largely the result of our industrial economy, which concentrates people and industry in urban complexes. This same economy provides more individuals with the money and leisure time to enjoy water-based recreation while placing competing demands on water for other purposes. There is a lack of access to waters suitable for recreation and convenient to people residing in large cities. A few individuals will travel long distances to their favorite recreation area. However, the majority of people travel less than 100 miles in the pursuit of water-based recreation, as is revealed by a number of recreation surveys. A 1965 preliminary analysis of visitor use at Corps of Engineers reservoirs indicates that 84% of visitors reside less than 100 miles away from the impoundment and 68% reside less than 50 miles away.

The trend toward concentration of population in urban areas is expected to continue. A study made by the Urban Land Institute estimates that by 2000 there will be three urban regions in the conterminous United States in which 60% of the population will live on 7% of the land. These projected urban regions are in areas already below the national average of available water-oriented recreation areas. The imbalance of supply and demand will be compounded in the future unless a concerted effort is made to make available additional water for recreation where it is needed.

Conflicting Uses of Water

In every basin, there is competition among the uses of water which may restrict the usefulness of water bodies for recreation. Reservoir levels, for example, may be drawn down to release water for municipal, industrial, or agricultural water supply; for hydroelectric power production; for water quality control; for navigation; or to provide storage space for flood control; and, thus, adversely affect recreational use of the reservoirs. Waste water disposal from urban areas may render waters totally unfit for recreational use. Where recreation waters are available, there may be conflicts among rec-

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TABLE 4–6–4.—*Inland water surface and shoreline available for recreation, 1965*

Census division	Population	Inland water surface [1]		Recreation shoreline [2]	
	In 1,000's	*Acres (in 1,000's)*	*Acres per capita*	*Miles*	*Linear feet per capita*
New England					
Maine, N.H., Vt., Conn., R.I.	11,146	2,523	.23	3,636	1.72
Middle Atlantic					
N.Y., Pa., N.J.	36,471	1,735	.05	1,494	.22
South Atlantic					
Md., Del., D.C., W. Va., N.C., S.C., Ga., Fla., Va.	28,748	8,079	.28	7,045	1.30
East South Central					
Ky., Tenn., Miss., Ala.	12,819	2,278	.18	407	.17
West South Central					
Tex., Okla., Ark., La.	18,540	7,746	.42	2,157	.61
East North Central					
Mich., Wis., Ill., Ind., Ohio	38,231	3,194	.08	3,546	.49
West North Central					
N. Dak., S. Dak., Minn., Iowa, Mo., Nebr., Kansas	15,858	7,353	.46	264	.09
Mountain					
Mont., Idaho, Wyo., Nev., Utah, Colo., Ariz., N. Mex.	7,693	5,318	.69	0	0
Pacific					
Calif., Ore., Wash. (excluding Alaska and Hawaii)	23,314	3,267	.13	3,175	.69
Total conterminous United States (or average)	192,820	41,493	.21	21,724	.60

[1] Excludes Great Lakes.
[2] Recreation shoreline of oceans and Great Lakes.

reationists for exclusive use of a particular body or part of the water area for different purposes.

There is a possibility that balanced recreation development will not be adequately considered in water resources planning and that only reservoir development for recreation will be planned. Full opportunity for water-based recreation can be achieved only with a variety of water resources. To achieve a full range of water-based recreation opportunities, flowing waters must be provided as well as lakes and reservoirs. Balanced recreation development can be achieved through measures which will retain flowing waters, improve public access to streambanks, develop boat access points and recreation areas, and develop headwater storage to augment seasonally low streamflows.

Competition and conflict cannot be eliminated. The conflicts can be diminished, however. The solutions devised may not be ideal for all interests concerned, but they should be reasonable compromises which represent the best use, or best combination of uses of water to meet human needs.

Competing Uses of Land

The use of land surrounding a body of water must be considered when preserving and developing the recreation and esthetic values of water bodies. Lands suitable for recreation or scenic purposes, which are adjacent to lakes, reservoirs, streams, and seashores, can be usurped or esthetically impaired by unrestricted and unplanned development—a problem which will become more acute with the steadily increasing demand for waterfront property.

There is a tendency for some real estate developers to subdivide every foot of shoreline into cabin lots of less than 50 front feet. Front porches hang over the water, public access is denied, shoreline forests are cut, and refuse and litter float in the water. The establishment of effective land-use controls through zoning easements, and other measures is essential to insure the protection, enhancement, and orderly development of water-related land. Such controls need to be geared to a regional plan of development for the public benefit.

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Construction of highways and railroads along water bodies can either seriously restrict the use of water or make water more accessible for recreation. The planning of highway routes offers the opportunity to insure access to the water through the acquisition of sufficient land next to the water for recreation development. Situations which are especially critical within urban areas are those where the only continuous strip of open land may be that which lies along a river or lake and planners propose to occupy it fully with a highway.

Urban waterfronts present both a problem and an opportunity. Where urban areas are located on water bodies, the utilization of waterfront areas for industry, commerce, and residences to the exclusion of outdoor recreation has been a natural development. Waters adjoining the expanding urban areas should be dedicated to and developed for outdoor recreation use. A planning goal for new urban waterfronts is that they be made available for both active and passive recreation through careful planning and control of potentially conflicting uses.

Waterfronts in older urban areas offer especially good opportunities for recreation use. Commerce is abandoning some waterfront areas because of changing technology. The incentive for recreation development of waterfronts is available in the form of Federal grants for urban development. In such cities as New Bedford, Gloucester, and Boston in Massachusetts, waterfronts are being turned into recreation areas. They are close to large numbers of people, particularly the disadvantaged social groups which otherwise would have little opportunity for outdoor recreation.

Augmenting Supply and Expanding Opportunity

There is a need to expand the opportunity for water-based recreation near urban areas. This can be accomplished by increasing the amount of surface water, by making existing waters more suitable for recreation, and by providing access, lands, and facilities adequate to meet the public needs. In areas of high population concentration, single-purpose water developments may well be justified economically in terms of recreation use.

Local and State levels of government have heavy responsibilities, particularly in urban environs, for providing outdoor recreation opportunities. Federally administered recreation areas can fill only part of the void. The local and State governments must proceed with the tasks of acquiring lands and waters, of providing the necessary recreation facilities, and of administering the recreation areas. A most important task is cleaning up pollution to make waters more suitable for recreation. The most obvious obstacle is financing. Other problems include lack of authority in some cases to control pollution as well as to acquire and manage lands for recreation. Imaginative planning and rigorous effort will be required to implement effective action programs.

The Federal Government is aiding State and local public agencies through technical and financial assistance programs. Federal agencies must be realistic, however, when encouraging local public agencies to assume long-term obligations for operating, maintaining, and repaying the initial costs of recreation areas. Private nonprofit organizations are also assisting, particularly through interim land acquisitions to preserve lands until public agencies are able to acquire them for recreation. Federal, State and local agencies should include private activity in their planning and technical and financial assistance programs. With proper safeguards private activity can greatly expand recreation opportunities.

The recreation potentials of existing water areas are being and will continue to be lost because of the inability of public bodies to plan and act fast enough to preserve or enhance these potentials before they are otherwise destroyed. Unguided actions may destroy potential recreation resources before action to preserve them can be planned and implemented. Means need to be found to accelerate the planning and development process for water-oriented recreation areas. Such actions as zoning, options to buy, and single-purpose reservations or withdrawals for recreation in advance of acquisition and development will assist in preserving and enhancing recreation potentials.

GOALS AND GUIDELINES

National Objectives

The basic objective of development for water-based recreation is to assure all Americans an opportunity to enjoy water-based recreation convenient to their places of residence, to the extent that the resource availability will allow. At the same time opportunities should be available for a variety of water-oriented recreation experiences, ranging from natural area recreation to recreation at highly developed areas. These opportunities can be made available through

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balanced development of water and related land resources, including both public and private action.

National, State, and local programs must provide a balanced variety of opportunities associated with each type of water, developed in response to preferences expressed by the people. This includes preservation of some areas in their natural state and development of others. It also implies geographic balances in recreation development within regions with opportunities for both urban and rural dwellers in accord with resource availability and needs.

Need for New Concepts

The shortage of available water-oriented recreation areas is most acute in the urban areas of the United States, and the situation may worsen in the future. A shortcoming, from the recreation viewpoint, of the pattern of river basin development in the past, where impoundments are constructed primarily for hydroelectric generation, irrigation, or flood control, is that these impoundments are located where the best damsites are found, which is often far from the urban centers. The developments not planned primarily for water-based recreation do not necessarily meet the recreation needs of an area. In contrast to the large reservoirs, the watershed protection program with its small reservoirs offer more flexibility in planning recreation development in areas of greatest need.

In addition to adjustments in multipurpose reservoir programs, there is a need to focus more effort on providing water-based recreation opportunities for people in the urban centers. This may be accomplished by putting greater emphasis on the development of small, efficient, and relatively inexpensive recreation facilities, such as swimming pools, in the central cities and by pollution abatement and revitalization of urban waterfronts. Medium-sized, single-purpose recreation lakes could be developed for many recreation activities in the suburbs. The river corridors radiating from the cities afford an excellent opportunity for recreation development of many types and could provide a means of linking recreation waters in the central cities with the recreation waters of our seashores and hinterlands. Such an approach would provide a more even distribution of the recreation waters available to the American public.

There is reason for optimism when regarding the future of our waters as a recreational resource. Much has been learned from past mistakes, and new philosophies are emerging. River basin planning today involves a multidiscipline approach. The public is becoming aware of the need to preserve and enhance the quality of the environment and will demand that planning decisions be made to serve that end. Such concepts as natural beauty, scenic rivers, and ecological values can and will become more than words.

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CHAPTER 7

Fish and Wildlife Uses

INTRODUCTION

Fish and wildlife are the most widely and deeply appreciated of our living natural resources. They add quality and vitality to our environment, and their variety, abundance, and well-being are positive indicators of the health of that environment. In common with many living resources they provide us food. They are important to our science, commerce, and industry, and they support a variety of sport and recreational activities. A comprehensive discussion of water based recreation is found in chapter 6.

Fish and wildlife are of special concern to the sportsman, naturalist, photographer, scientist, student, commercial fisherman, and trapper, but they also contribute variety and wholesomeness to the diet and embellish the attire of millions. Their beauty and grace add to the spiritual quality of life for all of us. They are the finishing stroke on our landscapes.

Pioneer America depended heavily on fish and wildlife for food, clothing, and industrial and medicinal products; today, as leisure becomes increasingly available in our society, their importance for sport and recreation is growing apace. Yet they still contribute to our physical and economic welfare, providing food, fur, and a great variety of products as well as employment through commercial harvest. They also stock our zoos, serve as medical and scientific test animals, and form a gene pool for genetic research.

Since fish and wildlife are intimately dependent on quality of the environment, many species are very sensitive to measures taken in the development of water and related land resources. Water is absolutely essential to fish and wildlife as it is to all life, but the quantity and quality required varies enormously. Desert life thrives with meager supplies while aquatic life survives only in a water-rich medium. In every case, however, water requirements of fish and wildlife must be met when they occur to assure survival and relative stability of desirable natural communities of plants and animals.

FISH AND WILDLIFE IN THE NATION'S ECONOMY

Fish harvested commercially from among the fresh water dependent species in the United States, representing 3% of the world production of fishery products, amounted to 3.5 billion pounds in 1965 (table 4–7–1). They are raw material for pharmaceuticals, industrial products, and pet and livestock feeds as well as human food. Commercial anadromous species include salmon, shad, and striped bass; estuarine species include shrimp and menhaden. Dominant commercial species of inland fresh waters are catfish, buffalo, carp, and chubs. Recent resurgence of the economic importance of fresh water mussel shell is due to its use by the cultured pearl industry. The regional distribution of the 1965 commercial catch of fresh-water dependent species is shown in table 4–7–2.

TABLE 4–7–1.—*Commercial catch of freshwater dependent fish resources, by type, 1965*

Species	Landed weight	Values to fisherman
	Mil. lbs.	*Dol.*
Fresh water	136.4	15,800,000
Anadromous	421.9	68,900,000
Estuarine dependent	2,947.6	230,500,000
Total	3,505.9	315,200,000

The commercial fishing industry also provides employment and income for about 0.5 million people in positions that range from fisherman to distributor to seller. The 12,300 commercial fishing vessels (5 net tons or over) and their crews form a pool of facilities and seafaring

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TABLE 4–7–2.—*Commercial catch and value of freshwater dependent fish and wildlife resources, by region, 1965*

Region	Fish		Fur animals	
	Million pounds	*Million dollars*	*Thousands*	*Thousand dollars*
North Atlantic ..	1,201.0	97.3	1,233	1,995
South Atlantic-Gulf	793.0	54.6	397	867
Great Lakes	56.0	5.8	856	2,138
Ohio	0.8	0.6	1,078	1,436
Tennessee	21.1	2.5	93	170
Upper Mississippi	28.7	1.8	1,471	3,214
Lower Mississippi	697.0	33.2	1,411	2,481
Souris-Red-Rainy	3.6	0.4	458	703
Missouri	4.3	0.3	790	1,558
Arkansas-White-Red	21.6	9.8	512	897
Texas-Gulf	153.5	35.7	69	94
Rio Grande	0.3	[1]	23	40
Upper Colorado	0	0	16	86
Lower Colorado	[1]	[1]	35	67
Great Basin	0.5	0.1	83	124
Columbia-North Pacific	72.5	17.2	176	575
California	168.3	6.6	77	98
Alaska	283.7	49.3	[2]133	[2]1,729
Total	3,505.9	315.2	8,911	18,272

[1] Less than 50,000.
[2] Includes hair seals but not fur seals.

know-how which historically has been significant to the Nation's welfare and security.

The largely water-based fur trapping industry also contributes to the Nation's economy. In 1965, there was an estimated harvest of nearly 9 million pelts valued at $18.3 million, as shown in table 4–7–2. The more important fur animals include muskrat, mink, raccoon, beaver, and nutria.

Sport fishing and hunting are among the most popular forms of outdoor recreation. The 1965 National Survey of Fishing and Hunting showed that the more avid hunters and fishermen (those who spend more than $5.00 and 3 days annually) spent $4 billion and traveled 31 billion passenger miles in pursuit of nearly 709 million recreation days. Each year, over 24 million people fish 80 million acres of fresh water fish habitat, including the Great Lakes. The 52,000 miles of tidal shorelines of the conterminous United States provide access to salt and brackish water fishing for additional millions.

The Sport Fishing Institute estimates that the sport catch now exceeds 1 billion pounds per year, and about 75% of the total poundage is fresh water dependent species. The most widely distributed, important fresh water sport fish is the largemouth bass. Crappies, sunfish, rainbow trout, and channel catfish also are high on the list of most commonly sought after fresh water species. Anadromous species such as salmon, striped bass, and shad are important adjuncts to fresh water and estuarine sport fisheries. Spot, weakfishes, flounders, and surfperches—all estuarine-dependent—also provide sport for coastal fishermen.

Nearly 14 million Americans hunt for sport. About 69% of their effort is spent on small game, about 24% on big game, and 7% on waterfowl. In addition, more than 12 million bird watchers and wildlife photographers of the Nation add to the long list of enthusiasts who enjoy fish-and-wildlife-associated interests.

RELATIONS WITH WATER AND RELATED LAND RESOURCES

The Nation's water resources have a vital relation to fish and wildlife. The high degree of dependence of a fish species on the particular characteristics of his water environment—the physical and chemical properties, the quality—is not widely appreciated. The drinking water required by most wildlife species usually is adequately supplied by the habitat. Even though spring development and installation of cisterns adapted for wildlife are the most effective means of increasing wildlife production in some arid regions, the quantities required to supply drinking water to wildlife are small. The significant water and related land resource needs of fish and wildlife are those required by fish, aquatic birds, and aquatic mammals—the stream, lake, and wetlands habitats and the quality and quantities of water required to maintain these habitats in productive status.

The fresh water and wetlands of the Nation are the natural habitat of many of our fish, waterfowl, and other animals. Table 4–7–3 indicates these habitats and also gives estimates of water use in significant wetlands and in fish and waterfowl developments. The vital but modest quantities of water required by non-aquatic forms of wildlife are not measured in this Assessment. Brackish coastal and estuarine habitats also are important to fish and wildlife and their productivity may be significantly affected by interior water and related land development; however, no data are available on the areal extent or the fresh water needs of these shore waters, and they are not covered in the estimates of table 4–7–3.

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TABLE 4–7–3.—*Freshwater areas, natural wetlands, and water use related to fish and wildlife, 1965*

Region	Fishable freshwater areas		Natural wetlands of significant value to fish and wildlife		Fish developments		Waterfowl developments	
	Streams	Lakes[1]	Area	Net consumption[2]	Withdrawn or impounded[3]	Consumed[4]	Withdrawn or impounded[3]	Consumed[4]
	Thou. acres	*Thou. acres*	*Thou. acres*	*mgd*	*mgd*	*mgd*	*mgd*	*mgd*
North Atlantic	839	3,453	3,395	3,940	154	38	32	164
South Atlantic-Gulf	639	4,037	29,936	18,700	118	[5]	98	595
Great Lakes	343	2,189	1,607	1,290	25	[5]	61	57
Ohio	607	478	647	173	45	4	32	17
Tennessee	35	896	207	55	198	[5]	[5]	[5]
Upper Mississippi	330	2,275	3,112	3,060	21	[5]	121	13
Lower Mississippi	1,011	504	8,927	8,780	94	39	273	184
Souris-Red-Rainy	25	1,475	997	982	[6]	[6]	388	85
Missouri	346	2,040	6,783	27,850	535	64	490	263
Arkansas-White-Red	589	1,864	4,610	2,670	2,435	645	309	215
Texas-Gulf	43	940	2,745	7,100	20	5	74	46
Rio Grande	25	165	383	2,040	68	21	111	75
Upper Colorado	65	235	34	151	178	13	68	40
Lower Colorado	19	173	36	164	96	20	110	87
Great Basin	25	423	1,873	5,850	115	[5]	884	310
Columbia-North Pacific	379	2,061	3,744	6,690	2,890	[5]	715	[6]12
California	213	828	1,888	11,250	270	[5]	378	[5]
Alaska	5,039	7,360	240	[5]	[5]	[5]	[5]	[5]
Hawaii	[5]	[5]	[5]	[5]	[5]	[5]	[5]	[5]
Total[7]	10,600	31,400	71,200	100,700	7,300	850	4,100	2,200

[1] Includes lakes, ponds, and reservoirs, but does not include the Great Lakes, which have a total area of 38 million acres.
[2] Net consumptive use (evapotranspiration less precipitation) for water identified to fish and wildlife purposes.
[3] Water withdrawn by diversion or pumping, and natural inflow to single purpose impoundments.
[4] Consumptive use of water withdrawn or impounded for these developments.
[5] Negligible or data unavailable.
[6] Federal developments only.
[7] Totals rounded.

THE IMPACTS OF WATER AND RELATED LAND DEVELOPMENT

Water and related land developments, properly planned, have provided and can continue to provide widespread and important fish and wildlife benefits. The Nation's 15 million acres of large impoundments (1.6 billion gallons and over) add greatly to our fishing and other water-related outdoor recreational opportunities. Those located near urban centers will be especially important. They will become increasingly important in the future as both demand and area of impoundments increase.

Multipurpose reservoirs not only support substantial sport and commercial fisheries and, in many cases, waterfowl use, but they may store waters to enhance fisheries, through improved temperature and flow of streams, or waterfowl and other wildlife by supplying water for refuges and wildlife production areas. Irrigation service areas usually support significantly increased production and hunting of small game and waterfowl.

On the negative side of water development, dams can block fish migrations and divert streamflow. Reservoirs can inundate wildlife habitat and fishing streams as well as reduce downstream flooding that benefits fish and wildlife of bottomlands and estuaries. These harmful effects can be critical, even overriding in significance, but in most cases they can be ameliorated if not fully compensated by carefully planned facilities, measures, and operational adjustments.

However, other water and related land developments such as river channelization, dredging and filling of shallow waters, and draining and filling of wetlands cannot be satisfactorily mitigated in many cases.

Overall, the impacts of water and related land developments are great and important, changing for better or worse the variety, abundance, and availability of fish and wildlife for human uses. The expanding demands of our growing population for food and sport as well as water will sharpen these impacts, increasing harvests and threatening depletion of some fish and wildlife

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species. If fish and wildlife are to maintain their important place in our life and economy, every opportunity must be taken to improve their habitat and minimize their damage in the development of water and related lands.

Many of our cities were located on watercourses to exploit commercial advantages. These advantages are less compelling now, and city waterfronts and waters hold great potential for recreation, including fishing and hunting. Much of the tedium and stress of metropolitan life could be relieved if cities reclaimed their waterfronts and made their waters fit for recreaction. Such reclamation equates with the conservation of human resources, the most important of all.

Urban expansion on shores of streams and in the shallow waters of estuaries and on related wetlands supplants important fish and wildlife habitats and sites for recreation. Dredging and filling for other land uses, navigation, and flood control also can doom these rich fish and wildlife resources. Industries often occupy shore areas because of available water, ease of waste disposal, access to navigation, or low land cost. Such human uses of shores may destroy estuarine environments playing a crucial role in the lives of anadromous and other fish species making up 96% of our freshwater commercial catch as shown in table 4–7–1. Estuaries are the primary habitats of oysters, clams, and crabs; the nursery grounds of shrimp, our most valuable commercial fishery resource; and menhaden, our most productive one; and passageway for species that make annual migrations to inshore and fresh waters to feed or spawn.

Riverine and estuarine lands and associated wetlands are also essential habitats of waterfowl, shorebirds, and numerous other birds and mammals of esthetic, sporting, and commercial value. The fertility of the waters of rivers, bays, and sounds is enhanced by the exchange of nutrients in overflow and tidal areas, but this process is compromised by dredging and filling of shore areas. Interior pothole wetlands are of singular importance as waterfowl breeding and rearing sites.

Our wetlands, acre-for-acre the most productive fish and wildlife habitat of the Nation, are disappearing at an alarming rate. In intensively developed areas, millions of acres of marshes, swamps, and overflow lands have been drained and filled, and only remnants of wetlands remain. Also, coastal and interior lowlands have been drained for agricultural and residential land development. While level ditching of coastal marshlands can benefit fish and aquatic birds and mammals if permanent waters are formed, drainage associated with these works may seriously lower the value of shallow-water habitats.

The vast right-of-way needs of our highway and airport systems often involve destruction of wetlands. Yet roadside ditches and earthfill borrow areas often provide excellent habitat for fish and wildlife and new opportunities for their enjoyment, as do ponds and dugouts built for farm and home uses.

Nevertheless, further loss of wetlands to agricultural, urban, industrial, and transportation uses is of major concern. This concern is especially crucial in relation to the Nation's coastal fisheries, as discussed above, and to waterfowl resources. About one-half of the waterfowl production habitat in the northern prairie States has been permanently destroyed by drainage and put to other uses.

The potential effects of dredge and fill and drainage projects on fish and wildlife populations must be comprehended in planning and the proper safeguards incorporated so that the productivity and recreational potentials of the areas will be maintained and improved where feasible.

Great efforts are being made to slow the losses of pothole wetlands but more intensive and effective efforts must be made if waterfowl are to continue to be a viable resource fully enjoyed by the public. For further discussion of land drainage, see part 5, chapter 7.

The maintenance, and restoration, of water quality is essential if the Nation's fish and wildlife resources are to be preserved. Implementation of present Federal and State pollution control legislation on an effective scale should go far toward the realization of the objective. Public investments in additional reservoir storage for flow augmentation, or for other works to improve quality, must be considered as supplemental to investment in treatment facilities at the potential sources of pollution. The success of this two-pronged approach depends on the mutual determination of government, industry, municipal, and individual interests, each assuming its equitable share of the responsibility. Water quality management is covered in part 5, chapter 3.

Growth of the Nation's economy and population will continue to exert pressures for development, often leading to the destruction of natural areas. Even though water and related land development programs sometimes contribute to such destruction, they can be and are beneficial to fish and wildlife where appropriate

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conservation measures are built into the programs as discussed at the beginning of this section.

A prime example of equitable sharing of available water and related land resources with fish and wildlife is found on the over 650 million acres (almost 29% of the land areas of the United States) managed by the Forest Service and the Bureau of Land Management. Within this area, there are more than 6 million surface acres of lakes and reservoirs and 205,000 miles of permanent streams that are open to public fishing under the laws and regulations of the respective States. These waters, generally free of municipal and industrial pollution and effectively managed, are among the best quality fishing waters in the Nation. Federal, State and local parks, refuges, and green belts provide similarly for fish and wildlife as do certain lesser areas of private reserves.

Fish and wildlife have a special role in the growing public demand for natural beauty and for quality in our environment. Water and related land development programs, therefore, should embrace the conservation and improvement of resources related to fish and wildlife as part of the overall attempt to improve the quality of man's environment.

NATIONAL NEEDS

Fish and wildlife resources provide outdoor recreation for about 40% of our people. Surveys indicate that millions of others, especially those in urban areas, would participate in these sports if the facilities were available.

Areas of fishable fresh waters will change over time. In the future some stream sections important as fishing water will be lost in reservoirs, though total acreage of fishable water will increase with the construction of more reservoirs and farm ponds and the restoration of polluted waters.

The national demand for fishing and hunting is closely related to the population level, personal income and leisure time, and urbanization as well as resource availability. By 2020, the population of the United States is expected to increase over 150% while sport fishing participation is expected to increase 200% and hunting participation, almost 100%. During the same period, the consumption of food fish is expected to increase 100%, and the value of these fish to commercial fisherman is expected to increase nearly 200%.

Projections of regional demands for hunting and fishing opportunities, based on current indexes are given in table 4–7–4. Future compre-

TABLE 4–7–4.—*Existing and projected demands for fresh-water sport fishing and hunting*[1]

(Million man-days use)

Region	Sport fishing				Hunting			
	1960	1980	2000	2020	1960	1980	2000	2020
North Atlantic	43.8	75.9	99.5	133.7	37.0	51.3	48.3	32.0
South Atlantic-Gulf	79.6	131.8	188.5	266.0	28.8	44.1	59.6	74.0
Great Lakes	40.6	61.8	79.9	105.5	28.1	38.0	40.2	38.6
Ohio	21.6	35.2	40.6	51.3	23.8	27.3	28.5	30.5
Tennessee	22.5	33.2	44.4	59.6	7.1	10.0	12.5	15.9
Upper Mississippi	66.7	90.3	116.0	151.7	26.6	35.3	49.0	54.7
Lower Mississippi	17.1	21.2	27.2	33.9	8.8	11.8	14.6	18.4
Souris-Red-Rainy	6.1	6.8	7.7	8.9	2.1	2.3	2.9	3.7
Missouri	28.5	38.9	54.5	76.2	15.6	21.5	30.3	41.7
Arkansas-White-Red	76.0	101.7	133.4	174.9	20.3	25.3	32.4	41.7
Texas-Gulf	27.2	47.3	68.6	96.5	8.4	13.7	18.9	25.2
Rio Grande	3.7	7.3	11.3	16.3	1.5	2.0	3.2	4.7
Upper Colorado	4.4	6.6	8.7	13.2	1.3	1.5	1.9	2.5
Lower Colorado	5.2	11.7	18.2	27.1	2.5	4.0	6.2	9.1
Great Basin	2.5	4.6	6.7	10.2	.9	1.2	1.7	2.5
Columbia-North Pacific	13.2	18.8	24.0	31.8	7.7	10.3	13.7	18.1
California	12.7	27.6	42.3	62.5	10.9	22.9	29.7	35.1
Conterminous United States[2]	470	720	970	1320	230	320	390	450

[1] Data were developed basin-by-basin using factors adaptable to projection. It is improper to compare the 1960 total to data reported in the National Survey of Fishing and Hunting which were estimated on other bases, even though such comparison might fall within the area of statistical probability.

[2] Totals rounded.

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hensive studies on individual water resource regions will provide firmer projections.

In view of future demands, increasingly intensive fish and water-oriented wildlife management and production will be required. This will be particularly true for resources in and accessible to urban areas. Habitat manipulation to maximize natural and seminatural production will continue to be the preferred method of management, but other means will also become increasingly important. New, expanded, more efficient fish hatcheries and game farms will be added by Federal, State, and private organizations. Production will also be increased by stocking selectively bred fish and wildlife; and new species that can better use available habitats will be developed and introduced. In the future, the artificial culture of food fish is expected to increase, both in fresh waters and in coastal brackish waters where oysters, shrimp, and other species are grown.

With the multitude of options to provide new or increased opportunity to hunt or fish, converting future demands to acres of water and associated lands could be misleading. Although it is expected that water area useful for fish and wildlife purposes will increase and the area of wetlands available for them will decrease, no good bases for statistical projections are known.

PROBLEM AREAS

Some resource development conflicts will become more acute as water and related land development intensifies. These include encroachment on flood plains and the drainage and filling of prairie potholes, bottomlands, hardwood swamps, coastal salt marshes, estuarine habitats, and wetlands. In the future, flood plain management may be improved by zoning. The probable public economies of zoning often would be increased by concurrent conservation of fish and wildlife habitat, timber stands, and related recreation sites. Though the importance of wetlands to fish and wildlife is widely appreciated, it will be difficult to slow their loss because most wetlands are privately owned. Usually the private owner cannot fully benefit from the essentially public values of wetlands, and he must forgo important economic benefits if he preserves wetlands and refrains from developing them. Legislation has preserved some wetlands, but urban, industrial, and agricultural encroachments can only be ameliorated. In some cases, it may be possible to preserve wetlands as public parks and recreation areas, and to induce private developers to preserve some of the qualities of the natural environment. In other instances, protective easements have been purchased. Additional material on this subject is presented in part 5, chapter 8.

Reservoir development will continue to present its own complex problems. Reservoirs may inundate premium wildlife habitat, and crowd animals into habitats often already supporting capacity wildlife populations. In arid areas, the new water area which inundates river bottoms may destroy the only segment of a large area suitable as habitat for many species of wildlife. Or inundation may eliminate an essential habitat, such as winter range for big game or a production area for migratory waterfowl. At the same time, new water areas may change the distribution and harvest of waterfowl and wildlife, as well as the pattern and intensity of wildlife depredations on nearby agricultural crops. These effects will become more significant and more vexing in the future.

The quality of trout waters is reduced by siltation and warming resulting from overgrazing, deforestation, and highway, reservoir and other construction; and by flow depletion, enrichment, and pollution from diversion and return of water for competing uses. The problems facing anadromous fish, especially salmon, continue to be critical. Salmon are subject to the same influences as trout. Also the problems involved with the passage of migrants over dams and through slow-moving impoundments, for example, have not yet been fully solved.

Fish-associated problems which can be expected to increase in significance include pollution from municipal, industrial, and agricultural return flows; heat pollution from steam-electric power and industrial cooling; inundation, channelization, and dewatering of spawning and nursery grounds; and other depletions of river flow and of outflow to the sea by consumptive uses of water. The reduction of fresh water flow to estuaries will be especially harmful to species which support commercial and recreational fisheries and are dependent on a narrow range of estuarine salinity gradation. Such reduction may change the ecology of estuarine areas—saline waters may extend farther up the rivers, and undesirable species of fish may also invade the areas.

There is also a bright side to the resource development picture. New Federal and State programs are encouraging research in the water and related land resources field and promise to improve water quality and implement improved management practices. Fishery research is

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pointed toward better utilization of existing waters and development of more productive and more adaptive strains of fish and means of increasing the productivity of waters. Access to public lands and waters is being improved. The Fish and Wildlife Coordination Act and Federal policies, standards, and procedures provide that there be full and equal consideration of fish and wildlife resources in water and related land resource planning and development.

In many cases, these Federal policies are not implemented because of apathy or a lack of local public understanding and acceptance. This helps explain cases where the acquisition of land necessary for fish and wildlife conservation does not receive the essential support. Local interests may consider the lands more valuable for other uses; or they may object to acquisition for fear of tax losses. These objections seem more often persuasive in case of acquisitions for fish and wildlife purposes than in those for other public purposes. The same lack of public understanding seems to underlay part of the difficulties associated with the monetary evaluation of fish and wildlife benefits, the allocation of project costs to fish and wildlife enhancement, and the cost-sharing provisions required of local interests under the Federal Water Project Recreation Act. Solution to these problems seemingly awaits public education and full public acceptance of fish and wildlife values.

Other institutional problems concern the inadequacies of present water laws. Laws governing diversions from natural waters, for example, may favor narrow interests rather than a broad public interest. In some States where diversions are regulated by State law, no provision is made for maintaining minimum flows in the stream. Water use for fish and wildlife purposes may not be recognized as beneficial; and public values in wetlands and estuarine areas may be protected only in part or for temporary periods. These and other institutional problems require legislative remedy.

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PART 5

Management of Water and Related Land

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Management of Water and Related Land

INTRODUCTION

Management of water and related land involves several Federal departments and agencies, numerous regional organizations, one or more agencies in every State, thousands of municipal and county governments, hundreds of special districts, and innumerable private entities.

These government agencies, private companies, and individuals have constructed about 1,400 major reservoirs and many more minor reservoirs, thousands of miles of conveyance and distribution systems, and millions of wells to control and supply water for various uses. Work is under way on new technology for augmenting water supply and for improving the efficiency of water use.

Both large and small reservoirs are used to hold back floodwaters. Management of floodwaters and reduction of flood losses are also provided by channels, levees, and watershed treatment; by regulation of land use; and by flood-proofing facilities in the flood plain. These measures may be accompanied by flood-warning systems, disaster operations, and flood insurance when it becomes available.

Growing concern with the effects of ever-increasing pollution loads on the Nation's streams, lakes, and coastal waters has stimulated a vigorous national effort for water quality management for beneficial uses. Technical and financial assistance for waste treatment measures and in achieving suitable water quality standards are the major thrusts of this effort.

While the Nation has made great strides in the purity of its drinking waters and control of waterborne diseases, prudent management requires constant safeguards against potential hazards to the Nation's health.

The protection and management of the Nation's watersheds to maintain and enhance the quality and quantity of water yield from these lands is an important and continuing task. Soil erosion and the resulting sedimentation of streams, lakes, and estuaries remains a critical problem.

People like to live and play at the water's edge, and these beaches, shorelines, and riverbanks will require increasing protection against erosion and storm damage as their use and value increase.

Preservation and enhancement of the water-related natural environment must be balanced with the objectives of economic development and improving the well-being of people in water resources planning, and reasoned choices must be made among these sometimes conflicting objectives.

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CHAPTER 1

Water Supplies

INTRODUCTION

The focus of the National Assessment is on the adequacy of the Nation's water resources to meet present and future demands. The measure of adequacy is at the point of need. This chapter briefly outlines some of the methods utilized to develop supplies and convey water to the water user.

In today's highly urbanized society, water supply and control systems are usually complex, varying widely in character and in the institutions responsible for providing the service. Virtually all industrial and municipal water supply systems, and a major share of irrigation systems, are administered by non-Federal entities.

The development of water resources has played a large role in the ascendancy of the United States to its present world lead in living standards. Water supply problems have attracted attention from time to time; however, they have usually been of a local or regional nature. In relation to water supply, the thoughts of a large proportion of our population seldom extend beyond their household faucets. Yet, in an average day almost 240 billion gallons of fresh water are withdrawn from our Nation's rivers, streams, lakes, and reservoirs and from underground sources, and delivered by a fantastically intricate system of man-made works. In addition, almost 30 bgd of saline water is withdrawn for cooling in steam-electric plants and for other industrial cooling processes.

The systems existing today have grown over the past two centuries, most of them planned to meet a specific need at a specific time. In terms of numbers and disregarding size, most existing developments serve a single purpose. Municipalities have developed water supplies for municipal and industrial needs. Individual farmers or associations of farmers have developed supplies for agricultural uses. Power companies and other non-Federal entities have developed supplies for the generation of hydroelectric power. The Federal Government has developed water for all of these purposes and many other purposes where the Federal interest has been established, including flood control and navigation.

Federal policies advocating comprehensive development of water resources to obtain multiple benefits were promulgated early in this century, as exemplified by the Federal Water Power Act of 1920 and the General Dam Act of 1910. However, a water resource undertaking by an entity to encompass more than one of these purposes was infrequent until the mid-thirties. Recreation, fish and wildlife enhancement, and water quality control were largely coincidental, and in many cases were purposely avoided to eliminate interference with the principal function.

The advent of the purposely conceived and planned multiple-purpose water resource development occurred almost simultaneously with the concept of total river basin development. The rate of transition from the purely local, single-purpose project to the broader multipurpose project has been rapid in recent years, motivated by consideration of economic efficiency and concern for conservation and development of all water-related resources. Construction of a single large facility serving many purposes in a broad area is considerably more economic than the construction of a number of smaller facilities each serving a specific purpose or a smaller specific area.

Consider an upstream reservoir constructed to capture high winter flows for later release to meet mid-summer irrigation requirements. Usually, very little additional cost and storage space will be required to control floods. Releasing the water through hydroelectric generators further enhances the total value of the facility. Maintaining a reasonable minimum storage level can add valuable recreational and fish and wildlife values at the reservoir. Water released from the reservoir during periods of low flow may further enhance downstream recreation and

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fish and wildlife values as well as provide a more satisfactory level of water quality and, where appropriate, navigation. The same water facilities can be made to serve many purposes. The total water required will be much less than the sum of the individual needs.

Table 5–1–1 shows the regional distribution by number and capacity of nearly 1,400 reservoirs in the United States having a usable storage of 1.6 billion gallons (5,000 af) or more. Many natural uncontrolled lakes having a wide range of capacity and man-made reservoirs of less than 1.6 billion gallons capacity are also utilized to meet some water demands.

The Columbia River development in Washington and Oregon, the California State Water Project, the Tennessee Valley development, the Niagara-St. Lawrence development, and the Missouri River Basin development are some of the more spectacular examples of multipurpose developments. The latter project spreads its multiple benefits over all or part of ten States, embracing over 525,000 square miles—about one-sixth of the conterminous area of the United States. Six mainstem and 46 tributary reservoirs provide a multipurpose control system for the Basin (fig. 5–1–1).

TABLE 5–1–1.—*Major reservoirs in the United States, 1963*

Region	Number [1]	Usable storage (billions of gallons)
North Atlantic	239	4,486
South Atlantic-Gulf	80	7,478
Great Lakes	51	812
Ohio	69	4,418
Tennessee	30	4,889
Upper Mississippi	83	1,417
Lower Mississippi	12	1,479
Souris-Red-Rainy	30	3,302
Missouri	151	28,101
Arkansas-White-Red	105	12,553
Texas-Gulf	89	4,739
Rio Grande	31	2,464
Upper Colorado	34	8,814
Lower Colorado	23	11,508
Great Basin	36	1,273
Columbia-North Pacific	138	9,867
California	176	9,121
Alaska	9	173
Hawaii	3	7
Puerto Rico	8	55
Total	1,397	116,956

[1] Storage facilities having a usable capacity of 1.6 billion gallons (5,000 af) or more completed or under construction as of January 1.

FIGURE 5–1–1.—*The Missouri River basin system of mainstem and tributary reservoirs, 1967.*

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CONVENTIONAL SYSTEMS FOR WATER SERVICE

Considering all systems normally providing water service—municipal, industrial, and irrigation—the relative adequacy of the method chosen to provide water service frequently determines whether the user has sufficient water to meet his needs at all times. Localized shortages of water arise more from defects in supply systems than from the absolute availability of raw water. This is especially true of municipal systems, where enlargement has not kept pace with growing demands.

Municipal Systems

The exacting requirements for a safe and dependable supply of water for municipal use places great emphasis on the reliability of such systems. Economy is important but not at the expense of reliability. Generally, municipal systems are publicly owned and operated, subject to local governmental control. A growing number of special districts for water service exist, primarily to serve metropolitan areas. In 1962, there were about 1,500, many of which developed from an amalgamation of smaller service systems. The private utility municipal system, usually serving small and medium-sized communities, is still important. Some 15% of municipal water utilities are of this type. Both types of ownership provide essentially the same service but with obvious differences in financial and managerial arrangements.

Regardless of ownership, large capital investments in storage, conveyance, and ancillary facilities are required along with technical and administrative staffs. Gross investment in the municipal water service industry amounts to many billions of dollars, and several billions are invested each year to improve and extend service.

Problems of health protection for community water supplies are covered in chapter 4. Briefly, it is estimated that over one-third of the Nation's public and semipublic water supplies do not meet adequate levels for health protection. Health problems range from inadequate treatment and defects in distribution works to the potential long-term hazards of new chemicals and other substances in water.

Municipal systems have the following general physical characteristics:

Collection.—Few municipalities are fortunate enough to be located adjacent to a flowing stream or a large lake adequate in quantity and quality to supply its needs during periods of low flow. Storage reservoirs, sometimes quite remotely located, are nearly always required to assure a dependable supply. Conveyance systems from the initial source to the municipality are an equally vital element of the collection system. The conveyance lines for San Francisco and New York extend over one hundred miles, while Los Angeles reaches out several hundred miles for its raw water.

Many communities located conveniently close to large supplies of underground water may be spared the cost of some surface storage, and their treatment costs are generally low.

Treatment.—Treatment may range from simple disinfection to complex settling, filtration, and modification, including fluoridation. Each system of purification is designed for the peculiar chemical and organic character of the raw water, the more complex systems being required for the less desirable raw water. For public health and psychological reasons, municipalities desire high-quality raw water, even to the extreme of transporting it from great distances beyond the most readily available source.

Transmission.—This part of the system provides wholesale delivery of treated water to strategically located points where the distribution process can effectively take over. It includes the large pipelines, pumps, and treated water reservoirs designed to permit equalized flow in the distribution system as well as to accommodate varying demand rates in separate areas.

Distribution.—The distribution system is the final delivery network providing individual service to the consumer, including fire fighting water service. In growing cities this part of the overall system is constantly under strain and must be continuously expanded to keep up with new developments. Inadequacies will result in interrupted service or insufficient pressure, often with pyramiding complications throughout the entire system from collection through distribution.

An example of a fairly complicated but efficient municipal water supply system is shown in figure 5–1–2.

Industrial Systems

Industries using large amounts of water usually rely upon their own supply systems or use a combination of municipal and self-supply systems; those located beyond the range of a municipal facility must, of course, be self-supplied. The range in water requirements for various industries, both quantity and quality

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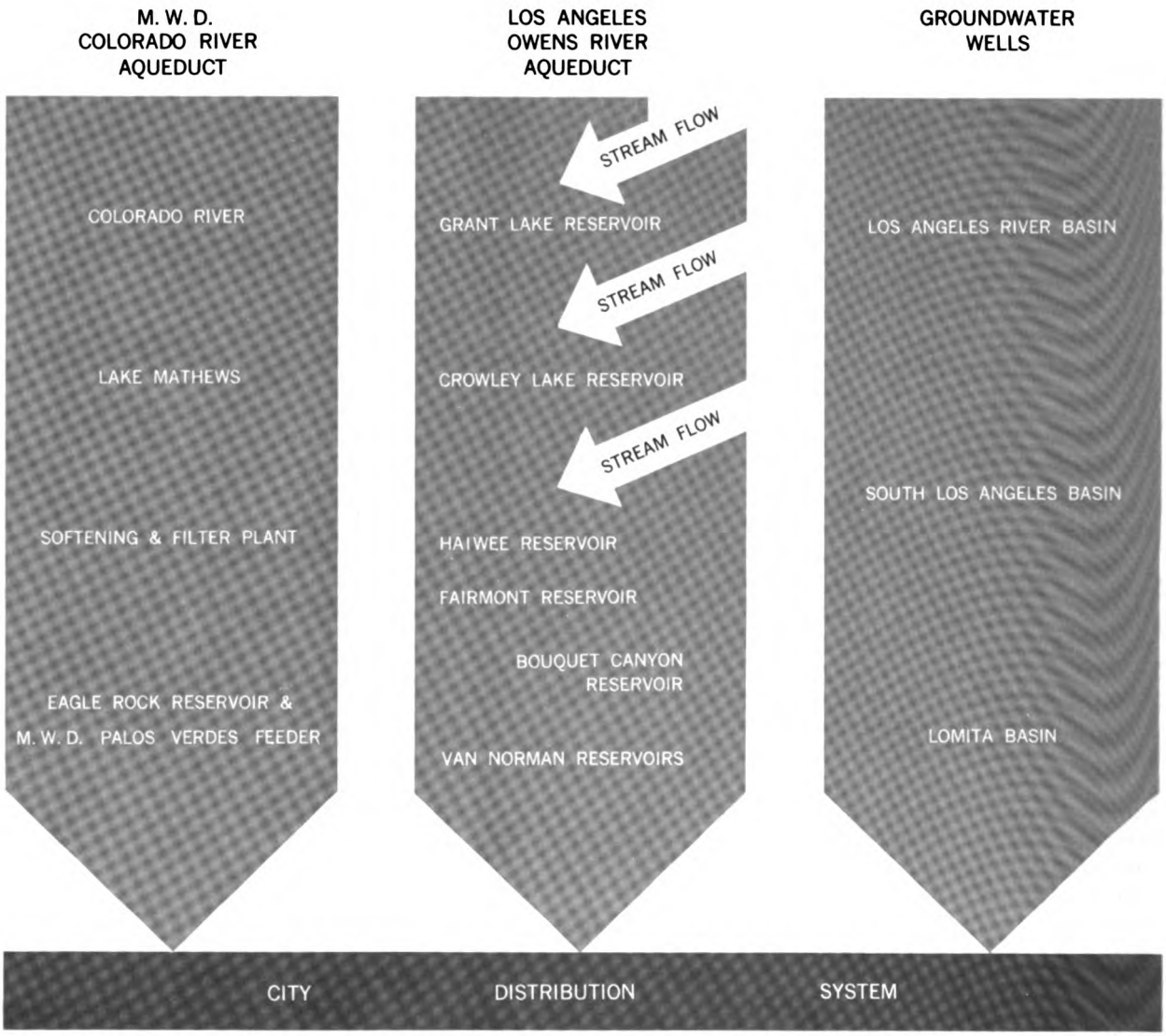

FIGURE 5–1–2.—*Municipal water supply system, Los Angeles, Calif.*

wise, is so great that a wide range in character of systems is necessary.

The location of plants for industries that have traditionally used large volumes of water is frequently determined by the water supply. A notable example is the pulp and paper industry which traditionally has located plants on large streams providing both ample supply and capacity to handle waste waters.

Because of the need for large quantities of water, or water of an exceptional quality, many industrial users employ extremely sophisticated internal water systems. These include recirculating systems where actual in-plant water use may be up to 40 times as great as the quantity of water withdrawn; closed systems where the same water is used, treated, and reused, and systems where normally satisfactory water supplies may be refined to a distilled or nearly distilled condition. Some industries, notably pharmaceutical, require water of extreme purity to a degree that elaborate distillation methods are employed.

Many industries engaged in the processing of raw materials produce a waste water considerably more toxic or polluted than untreated municipal waste water. There is a growing tendency toward pretreatment of such industrial wastes prior to discharge. A large portion of industrial pollution of water arises from its use

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for cooling purposes wherein the temperature of the water may be raised significantly. The use of devices to cool industrially heated water prior to discharge is growing in acceptance by industry.

The investment in self-supplied industrial water supply and in internal water systems is enormous. Since in most cases such costs are included in overall plant costs, precise and accurate statistics on this element are difficult to obtain.

Irrigation Systems

Irrigation water supply is derived from both surface and groundwater, and in some cases from the conjunctive use of both sources. Irrigation in the arid areas of the West is essential to practically all agricultural production except pasture and early maturing forage. In more humid areas, its principal function is either to increase production by supplementing soil moisture available from natural rainfall, or as a form of insurance against seasonal or cyclical drought. Irrigation is also used for frost protection and control of high temperatures for specialty crops.

Unlike water demand for most other purposes, irrigation water demand is limited to the seasonal growing period. In the western regions which account for over 90% of the total irrigated area of the Nation, about 85% of the precipitation occurs during the November-April period. Few western rivers have a significant natural flow during the critical growing season from June through September. Thus, successful irrigation requires that winter and spring flows be stored for use in the summer and early fall. Such storage can be achieved artificially in reservoirs or naturally in the form of groundwater where suitable underground aquifers exist.

Irrigation water supply systems utilizing surface water range from very simple single farm facilities to extremely complex systems such as the Central Valley Project in California which makes water available to millions of acres. Groundwater use for irrigation is particularly amenable to development for individual farm use since capital investment may be quite low, although many complex and expensive systems have been developed in areas of extensive subsurface water. In areas where water has become relatively scarce and thus expensive, more elaborate water-saving features are included in irrigation systems to reduce losses and to provide greater efficiency in water use.

In addition to the source of supply, irrigation water supply systems include conveyance facilities from the source. These may be as simple as a small ditch or pipeline extending to a single farm or they may be huge canals extending hundreds of miles with intermediate deliveries throughout their length. In some instance where irrigation supplies are stored in upstream reservoirs, natural stream channels may be the principal conveyance system with the water diverted for use at points many miles downstream.

Irrigation water removed from the main conveyance is carried throughout the irrigated area by laterals and sublaterals which serve individual fields. Most of the irrigated area of the Nation is served by systems constructed and operated by local governmental or quasi-public entities such as irrigation, water, or conservancy districts. Privately developed systems predominate in the East. Usually, Federal irrigation development in the West is achieved through multiple-purpose water resource development.

An example of an irrigation system is shown in figure 5–1–3.

MEANS OF AUGMENTING NATURAL WATER SUPPLIES

The average fresh water supply of the Nation is of course fixed by nature. At the same time, the average year, the average month, or the average day, seldom if ever occurs in nature. What we experience and what must be managed is an unpredictable pattern of wet and dry seasons, wet and dry years, near average conditions, and overriding wet and dry cycles. Properly planned and constructed, conventional systems will normally be adequate to cope with natural variations in the water supply cycle for which it has been designed. Promising new techniques and methodologies are being developed to satisfy the water needs of many areas where future demands will outstrip available supplies. The arid areas of the country and the burgeoning metropolitan complexes often have compelling reasons to seek augmentation of natural supplies.

Conventional methods.—Quite naturally, the best source of a good water supply is the most inexpensive source. Usually, this means the closest source. When the water demands of an area outstrip the locally available supply, further growth may be stifled, use patterns may be altered, or more remotely located expensive sup-

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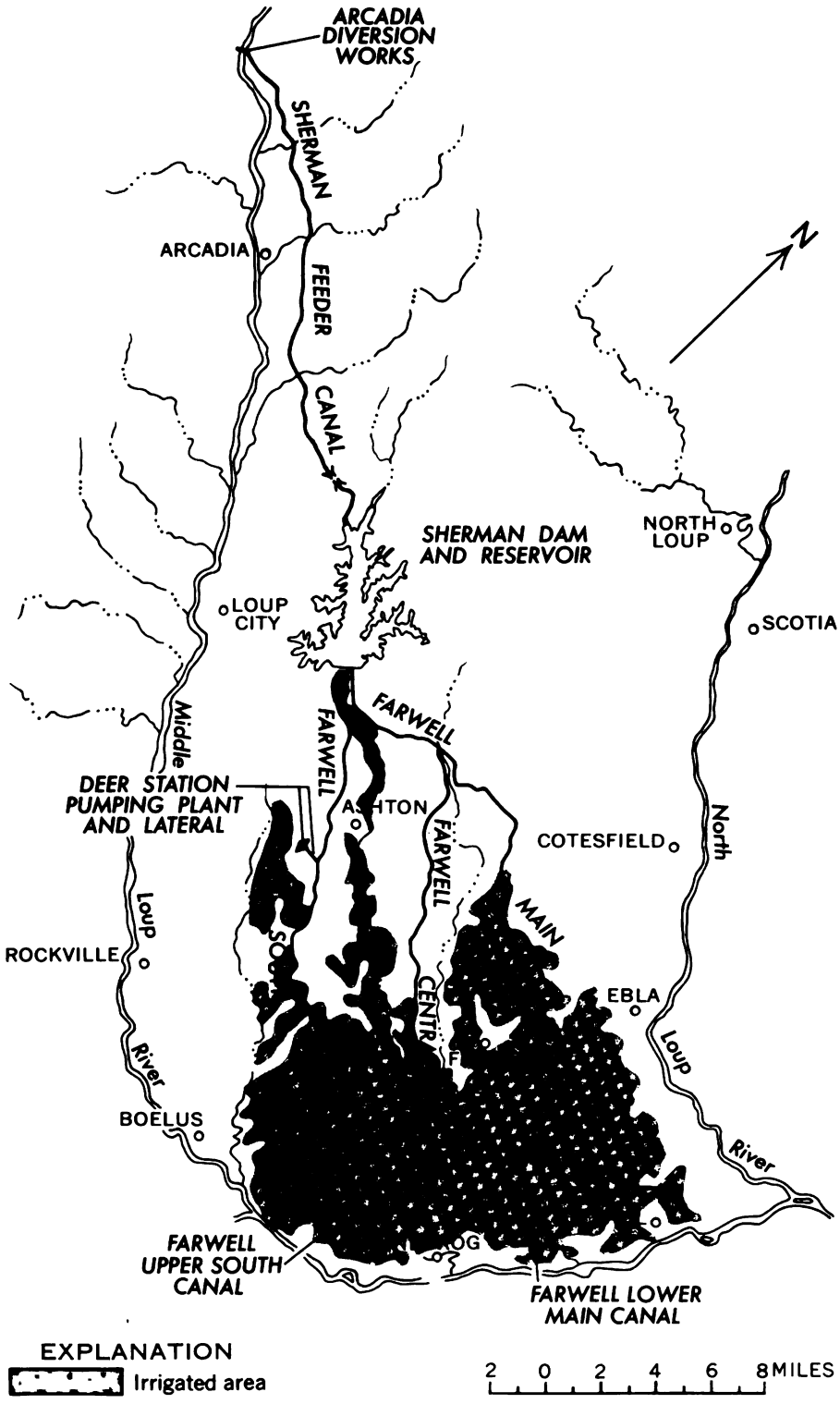

FIGURE 5–1–3.—*Irrigation water supply system, Farwell unit, Missouri River basin, Nebr.*

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plies must be sought. Physical availability, economic, and legal and political jurisdiction must be weighed, and may in fact limit or even preclude the further development of new supplies. The diversion of water from areas of surplus to areas of shortage has been successful in some instances. Many such opportunities exist and may need to be implemented.

More effective development and management of the Nation's groundwater potential offers considerable promise for fully utilizing our available water supply. The occurrence, movement, and replenishment of subsurface water is not as fully understood as surface waters. With time and adequate research, significant quantities of additional subsurface water in the Nation's water budget can be developed for use.

Desalination.—In recent years real or threatened water shortages have stimulated extensive research into refinement of techniques to produce water from new sources at acceptable cost. Desalination or desalting, the process by which potable water is produced from saline or brackish waters, is one of the methods which has developed from this stimulus. The research and pilot plant operations have been relatively successful. This can be measured by the steadily declining costs for converted water and the number of actual commercial applications of the method.

Research and development have been directed toward finding new and economic methods of developing fresh water from brackish or salt water and several medium-scale demonstration plants have been built and operated and, most recently, a large-scale facility near Los Angeles has been authorized for construction. This is a joint multipurpose effort of the Metropolitan Water District, private and public utilities, and the Federal Government to provide fresh water from the desalting of ocean water combined with the generation of commercially salable electric power from a nuclear power plant.

For the more critically water-short areas of the country where relief measures are expensive, saline water conversion already offers one of the most attractive solutions. At present, saline water conversion is, in many instances, a relatively expensive method for alleviating large-scale water shortages. The long-term outlook for the method to become more attractive is promising. Costs for conversion are expected to decline further while the outlook for conventional alternatives for alleviating water shortages appear to be progressively more expensive. Saline water conversion also has the potential to enable reuse of the conventional water sources by the removal of pollutants.

In 1952, in the few small land-based plants, the cost of fresh water produced ranged upward from $4 per 1,000 gallons. Technological advances since 1952 have reduced costs to roughly $1 per 1,000 gallons for plants with capacities of 1 mgd. Figure 5–1–4 shows projections of sea water desalting costs in distillation plants ranging in size from 1 mgd to 1,000 mgd for the period 1965 to 1990. These projections are based on anticipated changes in a variety of underlying factors including distillation technology and energy costs. Other desalination processes such as electrodialysis, vapor-compression, reverse osmosis, and freezing, as well as all desalination processes applied to brackish waters, are not sufficiently advanced to permit their inclusion in the projections. Some of these other processes, however, may eventually produce fresh water at costs lower than do distillation processes. Sometime beyond 1975, the cost of desalting in large-size plants may have decreased sufficiently for such water to be used extensively by municipal and industrial purposes and quite possibly even for irrigation purposes at prices competitive with those for conventional fresh water. It must be realized, however, that the projected cost decreases hinge on technological innovation in large-scale desalting developments, and on the attainment of low-cost heat sources such as breeder nuclear reactors. Considering the significant advances in the past 16 years, projected advances for the next 15 to 20 years seem modest.

Weather modification.—Extensive research and development have been undertaken in the past two decades to exploit, in nature, the laboratory creation of artificial precipitation. The benefits that would be derived from successful full-scale application almost stagger the imagination, but the equally obvious effects on the ecology arising from small changes in weather must also be carefully analyzed and taken into account. Because of the possibility of widespread benefits and also adverse effects, the Federal Government has taken the lead role in this research effort.

Although there are many aspects of weather modification, this discussion is limited to the possible effects of controlling or inducing precipitation. Results of early sporadic and relatively uncontrolled field experiments to induce precipitation, especially in the mountainous areas of western States, have been encouraging but not conclusive. This has led to more systematically controlled large-scale experiments.

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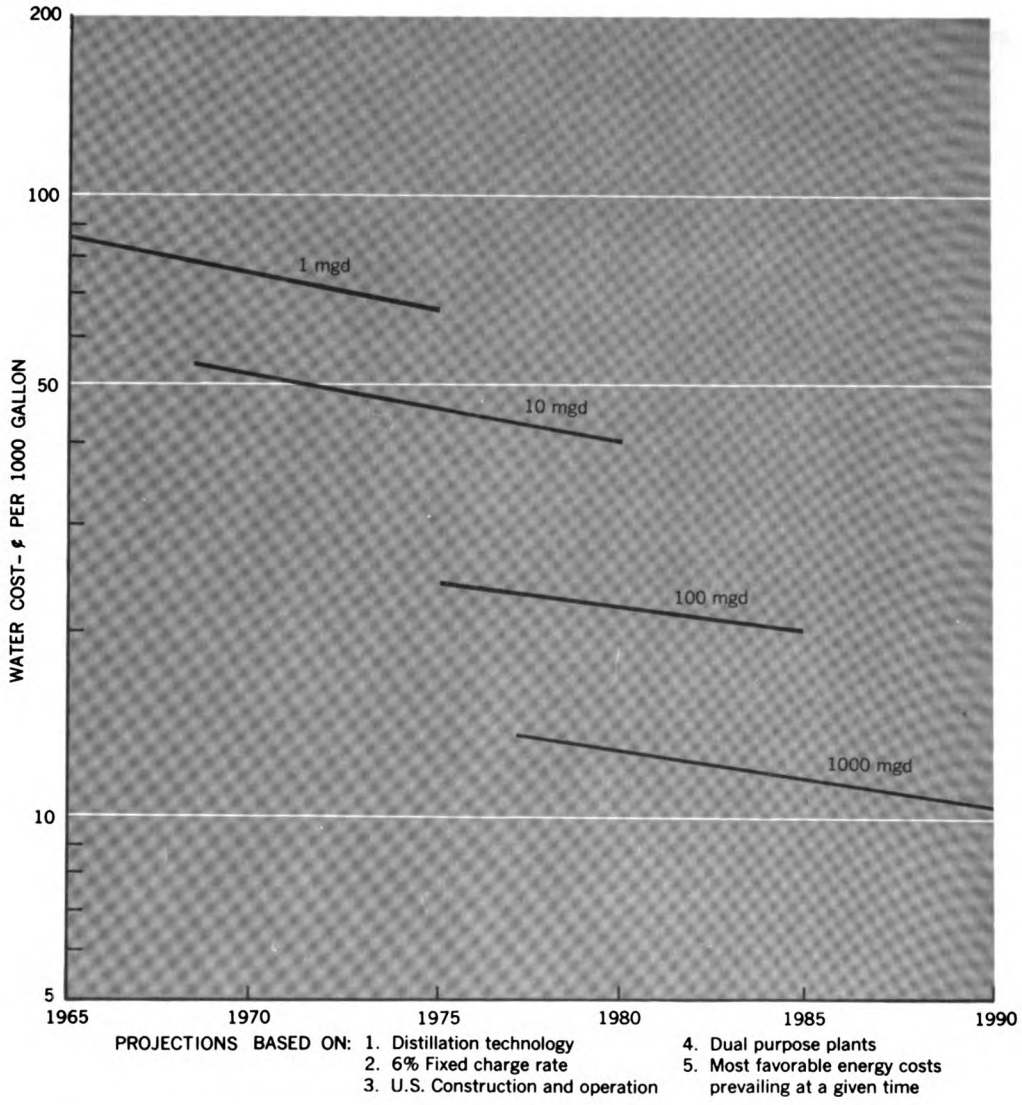

FIGURE 5–1–4.—*Projections of seawater desalting costs for range of plant sizes, 1965–1990.*

One of the major efforts of the present program is to identify those clouds which can be successfully seeded, and to establish a statistically reliable scientific method of determining the amount of precipitation actually created by artifical means. Because of the many social, legal, and ecological considerations, it is essential that artificial precipitation be carefully controlled and understood.

Weather modification offers some promise as an economic method of obtaining additional water supplies. Further research is needed to answer important questions on methods and procedures for insuring success. The present time-table envisions a pilot program for augmenting the flow of the Colorado River by 1972. Preliminary estimates suggest that up to 1.8 bgd (2 maf/yr) of streamflow can be provided in the Colorado River basin at costs of about 1.5 to 5.0 cents per 1,000 gallons.

Because only about 10% of the available moisture that passes over the Nation each year actually falls to the earth as precipitation, opportunities are great. If the yield from the potential can be increased by only 1%, the water supply would be increased by 10%.

Vegetative manipulation.—The feasibility of converting part of evapotranspiration to streamflow or groundwater through programs of scientific management of forested lands has been

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demonstrated. The measures used include snowpack management in the upper timber zone, brushland conversion in the areas below the commercial zone, treatment of riparian vegetation and management of the commercial timber zone for a variety of water augmentation purposes. Such programs designed for water yields but compatible with the ecology of the area are now under way on a modest scale on lands in the National Forest System and hold promise for improving water supplies from watersheds having substantial areas in forest or related vegetation types.

In the snowpack timbered areas an increased yield of over 4 inches on a treated watershed has been realized in operational programs. Phreatophyte eradication has produced increases of 6 inches from the cleared area; and vegetative manipulation in chaparral has resulted in additional yield of slightly under 1 inch.

Improving utility of waters of submarginal quality.—Effective quantities of raw water for many purposes can be augmented by reduction or elimination of the causes of pollution or degradation. For example, water of a highly polluted stream can be made usable by effective pollution abatement or by extraordinary treatment prior to use. In other cases, the selective exclusion of highly saline or polluted inflows from otherwise useful waters can increase the quantity of usable water. New, improved, and more effective methods of water treatment can render previously unfit water usable if the economic cost does not exceed the value of the water. Methods developed from the saline water conversion program will be increasingly employed to achieve this end.

Other methods.—Evaporation suppression methods have recently been tested and considered for widespread application to reduce water losses from lakes and reservoirs, especially in arid and semiarid areas and from snowpacks in the upper commercial timber zone. There has been success with evaporation reducing films applied to water and snow surfaces, but additional research is needed to maintain the film in areas of high wind and wave action. Another method suggested for reducing evaporation losses is to store more water underground through induced recharge. This practice is really one facet of more effective use of groundwater. Promising results have been achieved on a small scale, notably in California and in parts of the Northeast where water spreading practices have captured and placed in underground storage significant volumes of local surface runoff. Methods utilizing artificial recharge of wells have been difficult to sustain, and a great deal of knowledge of the geologic and hydrogeologic character of the underground strata is necessary.

ALTERNATIVE MEANS OF MEETING DEMANDS

The usual practice of satisfying growing demands for water has a counterpart in the possibility of conservation of use. This is a particularly pertinent consideration for the United States because many water use practices have developed in the context of abundant supplies. By the standards of many countries, we in the United States are very wasteful of water. Thus, one consideration in achieving a solution to water shortages is to examine critically the water-use practices to try to reduce wastage. The systematic allocation of available water resources to its most economic use is considered by many to be a desirable method of achieving water economy. This concept has had practically no application in the United States, perhaps because we fundamentally take the view that water should be available for all purposes rather than restricted to those purposes which can afford the highest price.

Reallocation, however, has been achieved unintentionally by the conversion of irrigated and other cropland to residential or urban use. In some circumstances, water rights for irrigated lands have been obtained by purchase of lands that were subsequently used for another purpose. This conversion method, however, frequently creates some serious economic maladjustments in the area divested of its waters.

Recirculation.—Recirculation is now used quite extensively in industry as a method of increasing the usable water supply without actually creating new water. The simplest and most common practice for water use in industries is for a "once-through" use, i. e., water is used once and returned to the source. This can be a profligate use, especially when the waste water is significantly reduced in quality, and suggests the logic of reducing water use by recirculation within an industrial plant and treatment to recondition the waters for reuse. Two purposes are achieved in such practices—a reduction of water withdrawal and a reduction of pollution. The obvious deterrent to greater reuse has been the added cost that it entails. However, this may be more apparent than real, since true cost comparisons should include the cost of cleaning up the receiving waters. While there are opportunities for recirculation in other

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than industrial uses, it is in that category that the greatest potential exists for water economy. (See, also, chapter 2 of part 4, "Industrial Uses.")

Reduction of losses.—Mention has already been made of the potential of suppression of evaporation losses. Other possibilities lie in the reduction of direct losses in water service systems. Leakages and "conveyance losses" frequently account for loss of a large portion of the available water actually diverted for use. In poorly maintained municipal systems, leakage and other losses may account for 35% of the total supply and irrigation systems may have losses as high as 50% of the amount diverted. In some water systems additional losses may be induced by water-loving vegetation along the canal banks. Not all seepage and leakage losses result in a net waste because much seepage will eventually return to a stream system where it is available for use.

A significant loss occurring in many water systems is from wasteful use of water. In many cases this may be only a local loss with a downstream recovery possible, while in other cases such excessive use may result in a real net loss to a river system.

Pricing.—Pricing of water services is a highly complex subject which has implications to water use practices. Thus far in the United States this mechanism, which is available mostly for local application, has not been widely used. There are many who feel that certain pricing practices, such as flat-rate charge for unmetered services, induce wasteful practices. This consideration is a highly complex subject which must be carefully evaluated in all potential applications.

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CHAPTER 2

Floods and Flood Damages

INTRODUCTION

In any assessment of the adequacy of supplies of water to meet the water requirements of the Nation, the control of floodflows occupies a peculiar role because it deals primarily with flows that are in excess of acceptable stream levels and in excess of water requirements. However, facilities to temporarily impound excess floodflows may provide potentials for long-term storage of water for other purposes and are directly related to comprehensive plans for the control and use of water and related land resources. Furthermore, controlled use of flood plains, including flood insurance, flood warning services, channel improvement, levees and other local protection works are alternative measures for controlling or alleviating the adverse effects of floodflows. Thus, the problems of flood control and flood damage prevention are closely related to the overall management of water and related land resources.

As a means of assessing flood management procedures, this chapter provides summaries of existing flood control programs, their costs and their effectiveness in preventing flood losses, and presents appraisals of future flood management problems. The summaries consist of available information contributed by a number of Federal agencies concerned with flood control and related activities. Data obtained from these varied sources may lack consistency and uniformity owing to variations in the degree of accuracy and detail, and to the lack of uniformity of approach used in their development. For example, summaries of the upstream program include data on projects for which some measures are not yet operational and this is true to a lesser extent in the downstream program. Efforts to include projects and their effects for all flood control programs were not entirely successful, particularly in the State and local sectors and in the upstream areas. Also, investments are in terms of Federal appropriations and include funds being expended on ancillary programs, on projects yet to be completed, and, in some instances, on projects not yet started.

In the upstream area, estimates of damages prevented are based on flood prevention benefit values listed in watershed work plans developed to date. They include changed land use and more intensive land use benefits induced by the projects. In the downstream area, estimates of historical damages prevented by existing works are for major floods based on current development conditions within the protected areas.

Future flood damage potentials for the Nation are summaries of regional projections of remaining damages based on extensions of past trends in land use and economic indicators, and reflect current project conditions. For the downstream areas, present estimates of future flood damage potentials for 2020 compare reasonably well with those presented in the Senate Select Committee Report extended to 2020 ($1.2 and $1.4 billion, respectively). Future damage potentials have not been adjusted to take into account the effect of future programs for management of flood-plain use and development or for construction of future flood control works. Since background and experience on costs and effects of flood plain management activities are yet to be developed, the effectiveness of this new and important program has been treated in general terms.

Estimates contained in the chapter and in the accompanying tables and charts should be viewed as preliminary in the light of constraints and limitations therein and used with caution. The need for collecting more complete information on a consistent national basis was recognized by the Task Force on Federal Flood Control Policy in its report of August 1966, *A Unified Program for Managing Flood Losses* (HD 465, 89th Congress). Work on the program recommended in the report is under way, including action to remedy some features of the data problem.

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BACKGROUND AND RESPONSIBILITIES

Although flood control in the United States began as a matter of local concern, the Federal interest in the problem has grown until flood control has become one of the major public works activities of the Federal Government. The Federal concern for flood control was first advanced in the Sacramento and Mississippi River Basins in 1917. With enactment of the Flood Control Act of 1936, the Federal Government accepted a high degree of responsibility for controlling floods throughout the Nation, in cooperation with "States, their political subdivisions and localities thereof." Flood control legislation enacted since 1936 has broadened the Federal interest from a single-purpose effort to reduce flood damages to consideration of flood control as a major element in the multiple-purpose development of the Nation's rivers and streams. In recent years, the Federal Government has recognized and fostered the concept of restricting flood losses through gathering and disseminating information on flood-prone areas. This information provides a basis for correction of existing flood problems and also for coordination and planning of useful development of these areas.

Prior to 1936, organizations such as improvement districts, conservancy districts, flood control districts, other local and quasipublic entities, and private interests assumed primary responsibility for flood control. While some still retain this responsibility for individual projects, most others participate in flood reduction measures undertaken under existing Federal flood control legislation. Local organizations help to provide lands, easements, rights-of-way, and relocations, and also provide assistance in formulating projects suitable to local needs and conditions that are acceptable to local residents. Obtaining and disseminating information on flood-prone areas is an activity assumed by the Federal Government in cooperation with State and local governments. The planning and coordination of the development of these areas are, however, primarily an activity of State and local government.

FLOOD DAMAGES

In general, the term "flood" refers to overflow or inundation that comes from a river or other body of water and causes or threatens loss of life and/or damage to goods and services in immediate and adjacent areas. Floods may be classified as downstream floods for those experienced on the mainstem and major tributaries, and as upstream floods for those experienced on creek and headwater areas. Data and information presented in this chapter have been divided into "upstream" and "downstream" categories wherein upstream refers to those streams above a point where the total area drained is 250,000 acres (390.6 sq mi) or less, and downstream refers to the stream pattern below that point.

Estimates of flood damages are used to express the economic loss caused by floods and to provide a measure of the Nation's flood problem. Flood damage surveys for major flood occurrences have been conducted on a national scale for more than 60 years and these data have been published since 1902. More recently, the Federal agencies concerned with flood control have made numerous determinations of flood damage potentials within reaches of streams and river basins and in headwater areas that would be affected by Federal or Federally assisted flood control works under study. They also have determined the flood damages experienced and eliminated below existing works. A complete inventory of nationwide flood damages has never been undertaken. In instances where the record is incomplete or lacking, reasoned estimates of flood damages are used.

Floods of the past which resulted in great loss of life and those which caused extraordinary property damage are listed in tables 5–2–1 and 5–2–2, respectively. The record indicates that while there has been a reduction of frequency of loss of life from floods, the frequency of major property damage from floods has increased. Floods causing damages of $50 million or more, based on 1966 price levels, were experienced during the period 1900–1940 on an average of about once every 6 years. Since 1940, floods causing damages in this order of magnitude have occurred on an average of once in less than 2 years. Since there is no evidence that floods themselves are increasing in magnitude and frequency, this increase in occurrence of property damage seems indicative of the expanding economy of the Nation, with the increased development and use of the flood plain made possible, in many cases, by partial protection works.

Before 1940, most of the floods causing heavy property damage also resulted in great loss of life, as shown in tables 5–2–1 and 5–2–2. But since then the loss of life caused by floods has been much less—probably a reflection of better flood and hurricane warning systems. Sixty per-

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TABLE 5–2–1.—*Floods causing 100 or more deaths*

Year	Stream or place	Lives lost	Cause
1831	Barataria Isle, La.	150	Hurricane tidal flood
1856	Isle Derniere, La.	320	Hurricane tidal flood
1874	Connecticut River tributary	143	Dam failure
1875	Indianola, Texas	176	Hurricane tidal flood
1886	Sabine, Texas	150	Hurricane tidal flood
1889	Johnstown, Pa.	2,100	Dam failure
1893	Vic. Grand Isle, La.	2,000	Hurricane tidal flood
1899	Puerto Rico	3,000	Hurricane tide and waves
1900	Galveston, Texas	6,000+	Hurrciane tide flood
1903	Central States	100+	Rainfall-River floods
1903	Heppner, Ore.	247	Rainfall-River floods
1906	Gulf coast	151	Hurricane tidal flood
1909	Gulf coast—New Orleans	700	Hurricane tidal flood
1913	Miami, Muskingham and Ohio Rivers	467	Rainfall-River floods
1913	Brazos River, Texas	177	Rainfall-River floods
1915	La. and Texas Gulf coast	550	Hurricane tidal flood
1919	La. and Texas Gulf coast	284	Hurricane tidal flood
1921	Upper Arkansas River	120	Rainfall-River flood
1926	Miami and Clewiston, Fla.	350	Hurricane tidal and river flood
1927	Lower Mississippi River	100+	Rainfall-River flood
1927	Vermont	120	Rainfall-River flood
1928	Puerto Rico	300	Hurricane tide and waves
1928	Lake Okeechobee, Fla.	2,400	Hurricane tidal flood
1928	San Franciscquito, California	350	Dam failure
1932	Puerto Rico	225	Hurricane tide and waves
1935	Florida Keys	400	Hurricane tidal flood
1935	Republican R., Kans., Nebr.	110	Rainfall-River flood
1936	Northeastern U.S.	107	Rainfall, snow melt-River floods
1937	Ohio River	137	Rainfall-River flood
1938	New England Coast	200	Hurricane tidal and river flood
1955	Northeastern U.S.	115	Hurricane rainfall-River floods
1957	West coast, La.	556	Hurricane tide and river floods
1960	Puerto Rico	107	Hurricane, rainfall-River floods

cent of the floods causing 100 or more deaths were hurricane associated.

Average annual flood damages have been estimated by the Federal agencies concerned with flood control and include, as nearly as practicable, an appraisal of all downstream and upstream flood damages. For the downstream damages, the estimates were based on flood-plain areas subject to inundation, while for the upstream damages the estimates include, in addition to damages by inundation in upstream flood-plain areas, the damages due to bank erosion in upstream flood-plain areas. Based on the current status of flood control works and projected conditions of flood-plain use and development, the total annual flood damage potential for the Nation is anticipated to increase from $1.7 billion in 1966 to $5.0 billion in 2020 (fig. 5–2–1). Average annual flood damage estimates by water resources regions are listed in table 5–2–3 for 1957 and 1966, as well as projections for 1980, 2000, and 2020 of potential annual flood damages assuming 1966 project conditions and with established trends in flood-plain development. These trends do not reflect the national flood-plain management program just getting under way.

EXISTING PROGRAM

In downstream areas, the existing flood control program includes some 900 projects estimated to have cost about $7 billion. These consist of over 260 reservoirs containing over 36,000 billion gallons (110 maf) of storage space for flood control, and local protection projects providing over 6,000 miles of levees and flood walls and over 8,000 miles of channel improvement works. Projects having an estimated total cost of $6.1 billion are under construction and active projects having a total cost of about $3.4

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TABLE 5–2–2.—*Floods resulting in damages exceeding $50,000,000*

Year	Stream or place	Damage (million dol.)		Cause
		Contemporary dollars	1966 dollars	
1844	Upper Mississippi River	NA	1,161	Rainfall-River flood
1889	Johnstown, Pa.	20	84	Dam failure
1900	Galveston, Tex.	25	100	Hurricane tidal floods
1903	Passaic & Delaware Rivers	25	273	Rainfall and dam failure
1903	Missouri River basin	50	NA	Rainfall-River flood
1913	Ohio River basin	150	516	Rainfall-River flood
1913	Brazos & Colorado Rivers, Tex.	128	349	Hurricane rainfall-River-floods
1921	Arkansas River	15	64	Rainfall-River flood
1926	Miami & Clewiston, Fla.	70	130	Hurricane-Tidal & River floods
1926	Illinois River	NA	51	Rainfall-River floods
1927	New England	50	178	Rainfall-River flood
1927	Lower Mississippi	284	NA	Rainfall-River flood
1928	Puerto Rico	50	90	Hurricane tide and waves
1935	Susquehanna—Delaware Rivers	36	185	Rainfall-River flood
1936	Northeastern U.S.	221	374	Rainfall-River flood
1936	Ohio River basin	150	371	Rainfall snowmelt flood
1937	Ohio River basin	418	996	Rainfall-River flood
1938	New England streams	125	376	Hurricane tidal & Riv. floods
1938	California streams	100	294	Rainfall-River floods
1942	Mid-Atlantic coastal streams	28	103	Rainfall-River floods
1943	Central States	172	NA	Rainfall-River floods
1944	South Florida	63	117	Hurricane tidal & River floods
1944	Missouri River basin	52	NA	Rainfall-River floods
1945	Hudson River basin	24	75	Rainfall-River floods
1945	South Florida	54	98	Hurricane tidal & River floods
1945	Ohio River basin	34	61	Rainfall-River floods
1947	South Florida	60	88	Hurricane tidal & River floods
1947	Missouri River basin	178	NA	Rainfall-River floods
1948	Columbia River basin	102	226	Rainfall-River floods
1950	San Joaquin R., California	32	57	Rainfall-River floods
1951	Kansas River basin	883	NA	Rainfall-River floods
1952	Missouri River basin	180	NA	Snowmelt floods
1952	Upper Mississippi River	198	NA	Rainfall-River floods
1954	New England streams	180	216	Hurricane tidal floods
1955	Northeastern U.S.	684	879	Hurricane tidal & River floods
1955	Calif. and Oregon streams	271	405	Rainfall-River floods
1957	Ohio River basin	65	72	Rainfall-River floods
1957	Texas Rivers	144	188	Rainfall-River floods
1959	Ohio River basin	114	120	Rainfall-River floods
1960	South Florida	78	86	Hurricane tidal & River floods
1961	Texas coast	300	336	Hurricane tidal floods
1964	Florida	325	342	Hurricane tidal & River floods
1964	Ohio River basin	106	112	Rainfall-River floods
1964	California streams	173	183	Rainfall-River floods
1964	Columbia R. — N. Pacific	289	311	Rainfall-River floods
1965	South Florida	139	144	Hurricane tidal & River floods
1965	Upper Mississippi River	158	162	Rainfall snowmelt River flood
1965	Platte River, Col. — Nebr.	191	NA	Rainfall-River flood
1965	Arkansas River, Col. — Kans.	61	65	Rainfall-River flood
1965	New Orleans and Vicinity	322	338	Hurricane tidal flood

NA—Not Available

billion have not been started. Although this program is carried out primarily by the Corps of Engineers, flood control is an important feature of projects constructed by the Bureau of Reclamation and the Tennessee Valley Authority. The Federal investment and pertinent data on downstream works are shown in table 5–2–4.

In the upstream area, 1,129 watershed projects have been approved for construction. The land treatment and structural measures which are completed or will be completed within the next

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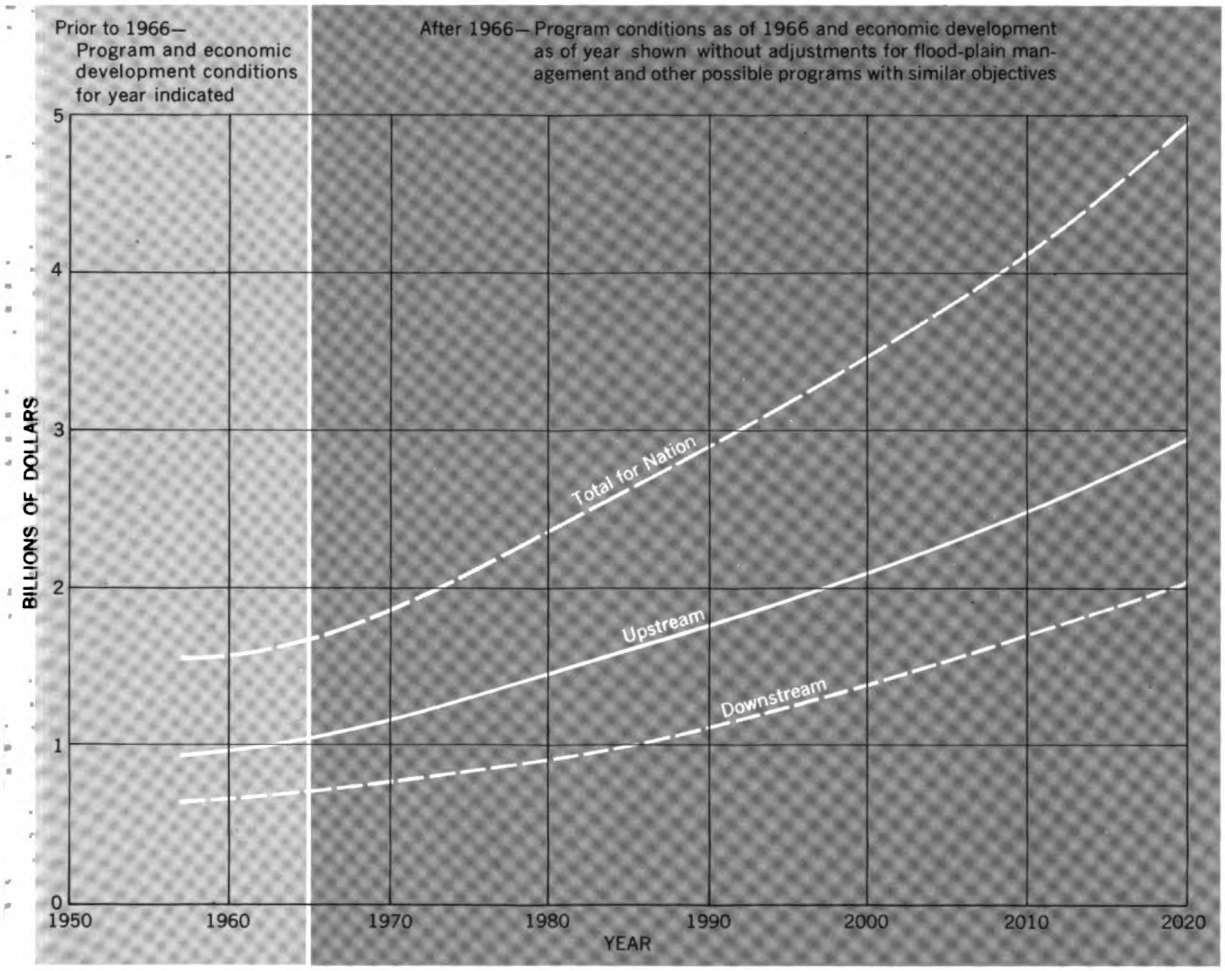

FIGURE 5–2–1.—*Projections of potential flood damages without flood plain management or new flood protection works, 1957–2020.*

6 years will cost approximately $2.1 billion of which $1.37 billion is a Federal cost. Structural measures including over 4,300 flood water retarding structures providing about 1,500 billion gallons (4.6 maf) of storage and 3,200 miles of channel improvement have been constructed in upstream areas in accordance with the approved watershed projects. Although this program is carried out primarily by the Soil Conservation Service, flood control is an important feature of small projects constructed in the upstream areas by the Corps of Engineers, Bureau of Land Management, Forest Service, and Bureau of Reclamation. The Federal investment and other pertinent data on upstream works are shown in table 5–2–5.

The Federal Government extends assistance to those endangered by an expected major flood, and to those suffering flood damages. Flood warning services extended by the Weather Bureau save lives and reduce losses of those endangered by floods. This nationwide service provides forecasts for over 1,200 communities on principal river systems. Federal expenditures for this program during 1959–1966 totaled almost $16 million.

Emergency operations for those suffering flood damages required Federal expenditures of $219 million during a 15-year period from 1951 to 1966. Those operations were administered by the Office of Emergency Planning, the Department of the Army, and the Department of Agriculture.

Further Government assistance is provided through development of information on flood plains. Data made available by participating agencies show that information on flood magnitude and frequencies, and that flood-plain maps delineating areas subject to flooding have been provided in about 170 reports for some 300 com-

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TABLE 5–2–3.—*Estimated annual flood damages*

(Million dollars)

Region	1957		1966		1980 [1]		2000 [1]		2020 [1]	
	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream	Down-stream	Up-stream
North Atlantic	64.3	62.6	63.1	70.7	75.6	91.2	89.8	120.9	116.2	163.3
South Atlantic-Gulf	46.7	109.6	44.1	123.8	55.8	183.2	74.8	267.3	90.4	383.7
Great Lakes	12.3	29.8	13.0	33.7	15.8	43.8	21.0	57.2	27.7	76.1
Ohio	78.7	49.2	73.9	55.6	99.5	68.3	151.0	90.9	237.0	116.6
Tennessee	3.5	27.3	4.9	30.9	7.6	42.6	8.3	58.3	[2]	80.2
Upper Mississippi	60.0	52.0	64.5	68.5	96.0	101.9	151.0	143.2	218.0	197.2
Lower Mississippi	66.0	38.5	86.8	43.5	117.2	55.3	164.2	73.5	224.5	100.1
Souris-Red-Rainy	5.8	13.5	5.6	15.3	6.4	18.4	7.5	24.1	8.6	32.2
Missouri	101.4	148.1	44.0	167.3	69.0	222.3	118.0	302.7	221.0	430.1
Arkansas-White-Red	48.6	129.2	50.0	146.0	61.6	184.0	90.6	245.3	127.0	330.0
Texas-Gulf	32.5	49.5	28.2	55.9	39.5	86.1	59.3	125.3	86.4	178.4
Rio Grande	12.2	10.4	14.7	11.8	14.8	19.5	15.8	30.9	18.8	44.9
Upper Colorado	0.9	16.9	13.0	19.1	19.0	27.4	30.3	42.1	57.0	62.1
Lower Colorado	5.4	25.8	10.0	29.1	20.2	59.3	42.2	93.3	96.7	141.3
Great Basin	3.0	8.4	4.1	9.5	6.7	17.5	10.2	27.5	14.1	42.0
Columbia-North Pacific	52.2	106.7	52.1	120.6	73.6	170.1	120.6	235.3	197.7	325.8
California	36.9	67.2	61.6	75.9	102.1	134.3	185.9	211.0	262.6	311.2
Alaska	3.2	[3]	4.3	[3]	5.6	[3]	8.4	[3]	12.4	[3]
Hawaii	1.2	10.6	1.8	12.2	2.2	16.8	2.8	23.7	3.6	34.0
Puerto Rico—Virgin Island	2.6	3.8	2.9	4.3	3.2	6.0	3.5	8.5	4.0	12.0
Total [4]	637	959	643	1,094	891	1,548	1,355	2,181	2,024	3,061

[1] Projected damages based on existing flood control works.
[2] Not reported.
[3] Not available.
[4] Rounded.

munities and localities covering some 5,400 square miles of flood-prone areas. These provide assistance to local interest for developing appropriate means to regulate the use of flood plains. Provision of information that local governments and their subdivisions need to enable them to put into effect zoning regulations is an important first step toward the more intelligent use of the flood plains. Federal expenditures for the program in 1966 amounted to more than $1.3 million. In connection with flood control studies of coastal or lake front areas, information is developed on the flooded area and on the degree and frequency of flooding produced by hurricanes, tidal waves, and similar sea conditions. Such information also is developed in connection with coastal mapping and charting activities.

Additional steps have been taken by the Federal Government to aid in managing flood-plain development. Executive Order 11296 directed all Federal agencies to consider flood hazards in locating Federal installations and in disposing of federally owned lands. The report of the Task Force on Federal Flood Control Policy proposed a many-pronged and coordinated attack on the flood-plain management problem.

Intensive efforts currently under way include the acceleration of flood-plain information studies, the provision of technical assistance and guidance in using the information for land use planning and regulation, research on the technical, legal and organizational problems, a gathering of more specific information about the Nation's flood problems, and studies of flood insurance proposals. One Federal agency has established flood-plain management services units in each of its field offices to work with the States and communities in more positive efforts to manage flood-plain lands. Several States are adopting flood-plain regulations or actively encouraging local governments to adopt regulations that put into effect plans for the best use of flood plains.

FLOOD DAMAGES PREVENTED

During the limited period that Federal flood control programs have been in operation, they

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TABLE 5–2–4.—*Downstream flood control works*

Region	Reservoirs			Levees and floodwalls			Channel improvement		
	Projects	Storage	Cost [1]	Projects	Structures	Cost	Projects	Improvement	Cost
	No.	*1,000 af*	*Mil. dol.*	*No.*	*Miles*	*Mil. dol.*	*No.*	*Miles*	*Mil. dol.*
North Atlantic	5	492	36.0	36	132	144.4	25	54	27.3
South Atlantic-Gulf	7	3,090	49.8	[2]	876	154.4	23	185	5.1
Great Lakes	1	377	23.4	6	7	1.3	9	28	7.1
Ohio	36	12,500	600.0	65	252	202.0	[2]	138	[2]
Tennessee	17	11,590	180.2	0	0	0	0	0	0
Upper Mississippi	14	3,020	54.0	65	861	242.0	19	70	8.7
Lower Mississippi	5	4,400	76.7	[2]	1,621	841.0	[2]	3,348	980.0
Souris-Red-Rainy	5	1,030	1.8	2	2	2.7	7	224	2.9
Missouri	56	20,700	656.0	50	1,130	193.6	7	75	22.2
Arkansas-White-Red	43	24,800	635.5	56	1,023	52.4	39	563	54.0
Texas-Gulf	20	8,600	234.2	5	128	121.4	8	106	94.4
Rio Grande [3]	4	795	31.1	5	205	7.6	7	114	10.5
Upper Colorado	3	1,500	5.5	8	5	0.2	1	1	20.0
Lower Colorado	6	12,100	59.6	2	7	3.2	1	4	0.5
Great Basin	6	386	7.4	4	33	1.6	3	23	1.4
Columbia-North Pacific	24	15,210	320.7	103	546	28.1	27	55	27.7
California	11	3,720	186.5	13	1,515	260.6	12	84	91.4
Alaska	0	0	0	2	3	0.6	1	1	0.1
Hawaii	0	0	0	4	6	0.2	4	3	0.2
Puerto Rico-Virgin Is.	0	0	0	0	0	0	0	0	0
Total [4]	263	124,310	3,158	426+	8,352	2,257	193+	5,076	1,354+

[1] Does not include cost of flood control storage in Bureau of Reclamation projects.
[2] Not reported.
[3] Does not include some facilities constructed by the International Boundary and Water Commission.
[4] Rounded.

have prevented about $14.6 billion in flood losses in downstream areas and $191 million in upstream areas. Summations of losses prevented by existing Federal flood control programs for important floods are shown on figure 5–2–2. Flood losses thus prevented should provide a measure of the effectiveness of the national flood control program. Under current conditions of project development, flood damage reduction benefits creditable to flood control works have been estimated at about $1 billion annually for downstream areas and $50 million annually in upstream areas. A major accomplishment to date is the virtual elimination of the possibility of major disasters for riverine flooding at those cities and localities where great loss of life and extraordinary property damages had previously been experienced. However, a disconcerting aspect of the flood control program is the fact that flood losses continue to increase in spite of the demonstrated effectiveness of the program to reduce floodflows and related damages.

FUTURE FLOOD MANAGEMENT PROGRAM

The Nation's flood management program can be expected to move ahead for some time to come under the impetus of the existing programs. Because of the physical characteristics of floods there is little likelihood that the structural measures used to store excess floodflows or otherwise control flows will change materially in the future. However, as potential sites for major reservoirs become more extensively utilized, increasing demands for multipurpose use of these potentials for all beneficial purposes are expected. Furthermore, as the best and least expensive of these potential sites are used, other programs to cope with the flood loss problem take on added importance. Current efforts to manage flood-plain use and development on a national basis are increasing. As the flood control program continues and becomes more complex the need for consistent basic policies becomes more pronounced.

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TABLE 5–2–5.—*Upstream flood control works* [1]

Region	Projects	Watershed area	Flood prevention cost			
			Land treatment	Reservoirs	Channel improvement	Total
	No.	*1,000 acres*	*Mil. dol.*	*Mil. dol.*	*Mil. dol.*	*Mil. dol.*
North Atlantic	120	4,906	27.0	108.8	52.5	181.3
South Atlantic-Gulf	163	8,897	93.9	88.6	75.5	258.0
Great Lakes	21	879	11.3	6.4	7.8	25.5
Ohio	89	4,442	45.5	78.8	30.7	155.0
Tennessee	21	1,440	11.8	18.8	10.1	40.7
Upper Mississippi	49	2,052	10.9	23.8	8.4	43.1
Lower Mississippi	104	6,895	80.6	65.9	65.9	212.4
Souris-Red-Rainy	21	2,882	3.8	4.0	15.8	23.6
Missouri	184	4,938	118.9	176.4	31.1	326.4
Arkansas-White-Red	153	12,438	94.4	274.1	27.5	369.0
Texas-Gulf	83	14,616	65.2	113.6	24.9	203.7
Rio Grande	29	1,512	4.7	14.3	2.0	21.0
Upper Colorado	6	517	3.2	9.7	4.3	17.2
Lower Colorado	10	884	5.6	17.0	7.7	30.3
Great Basin	13	871	5.6	8.8	1.2	15.6
Columbia-North Pacific	24	768	5.7	15.0	6.8	27.5
California	31	1,402	11.2	25.7	77.2	114.1
Alaska	0	0	0	0	0	0
Hawaii	5	278	0.5	0.9	10.3	11.7
Puerto Rico-Virgin Islands	3	252	2.7	3.2	7.6	13.5
Total	1,129	70,869	602.5	1,046.8	467.3	2,089.6

[1] Existing and approved program of the Soil Conservation Service only. In addition, there have been many projects in upstream area constructed by the Corps of Engineers, the Bureau of Reclamation, and the Bureau of Land Management. Neither the totals nor regional data are available, but this construction amounted to over 1,000 projects, with an estimated cost of about $1 billion.

The greatest impact on water resources probably will result from the expansion of programs to regulate rivers and streams for all beneficial purposes, including flood control. Federal flood control legislation should be brought into harmony with the need for regulated rivers to assure that developmental systems will meet the needs for all beneficial purposes. In some regions, municipal, industrial, and irrigation demands for water have already become so great that much higher dry-season flows are an immediate requirement. A system capable of providing a high degree of regulation for all levels of flow is not only a means of reducing the adverse effects of excess flows but also a means for providing a more stable flow so that the stream will be of greater value for water supply, power generation, quality improvement, navigation, and other purposes.

At the current rate of Federal expenditure, flood protection may not keep up with the increase in flood damages that may be anticipated as a result of intensive use and development of flood plains. Federal expenditures averaging over $1 billion annually under existing flood control legislation would be necessary to reverse the trend of increasing damage for short-term periods in the future. The prospect that Federal expenditures of this magnitude may be needed in the future to meet the Nation's growing flood problem emphasizes the urgent need for modification of existing program features and authorization of new programs for regulation and management of flood-plain areas.

The land requirements of our expanding economy will be reflected in the development and use of the flood plains. The national flood-plain management program is designed to address these problems directly and, thus, will have a significant role in reducing the level of the Nation's future flood losses. However, because of the apparent economic advantages of flood-plain lands in urban areas, their use will probably intensify in the future. Hopefully, the flood-plain management program will temper the rate of such development. A blending of the control of excess flows and the managed use and development of flood plains can be expected, generally, to provide an optimum program to reduce flood losses.

The currently authorized program, which provides for additional economically justified flood

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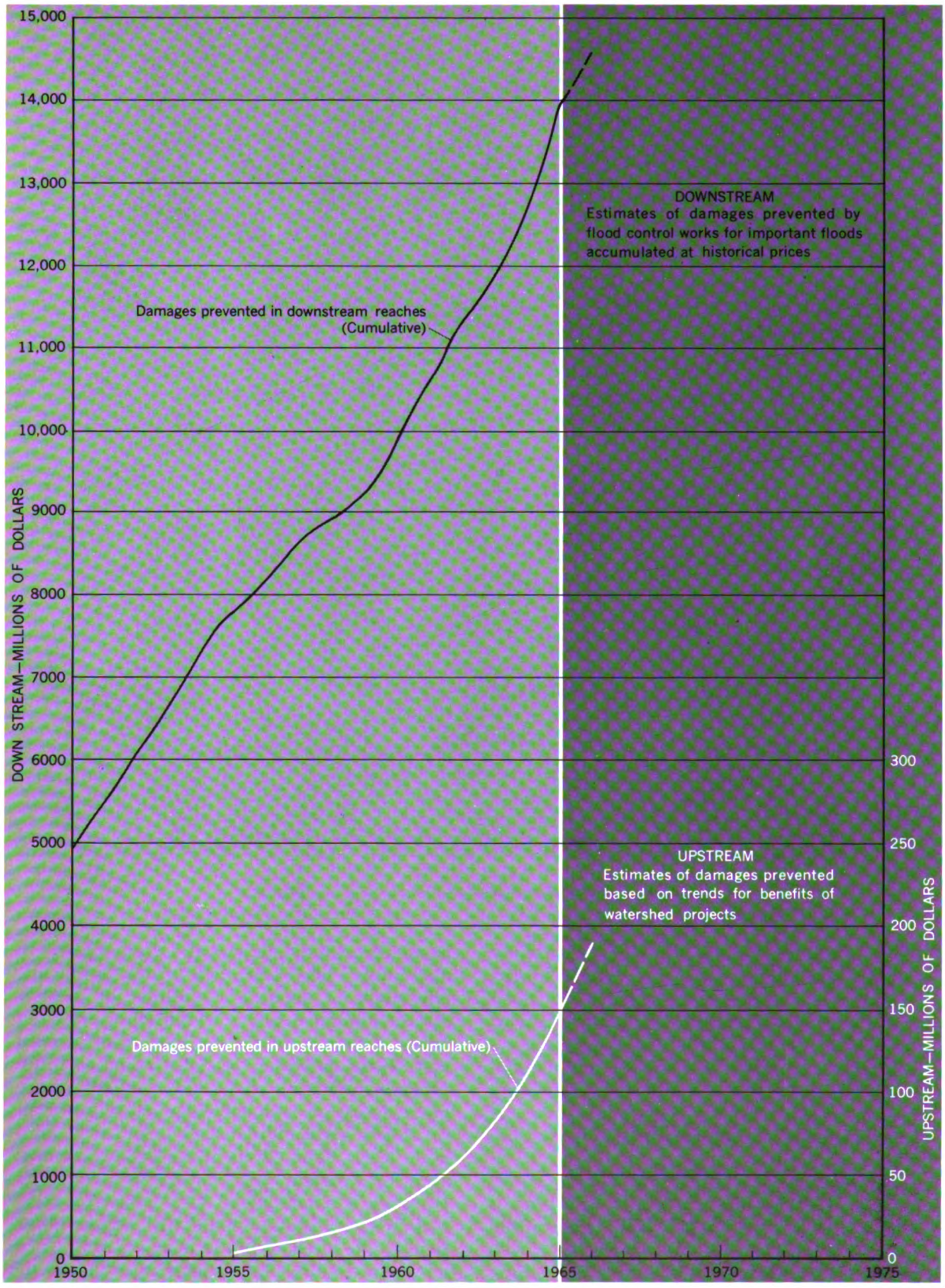

FIGURE 5–2–2—*Estimates of historical flood damages prevented, 1950–1965.*

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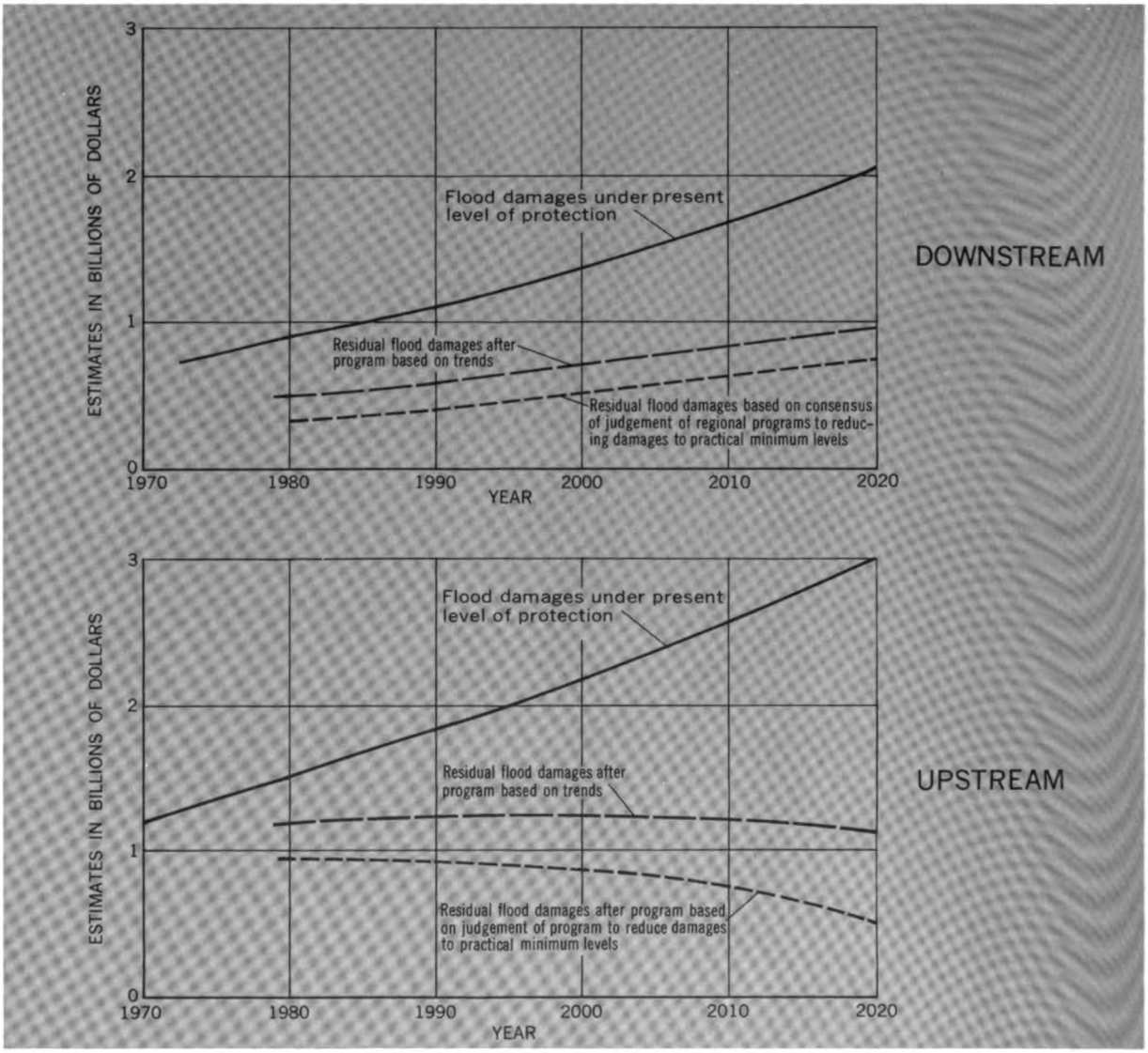

FIGURE 5–2–3.—*Projections of residual flood damages, 1980-2020.*

control projects, should continue to produce financial benefits for a long time in the future. Also storage requirements included in flood control projects are expected to place increased pressures on the diminishing reservoir resources of the Nation. Obviously, these latter requirements will need careful review to assure optimum use of the available reservoir resources. A national program to conserve these resources has been recommended.

Continuation of the existing flood control program at the current rate of expenditures is expected to reduce annual flood losses from about $2 billion to $1 billion by 2020 in downstream areas, and from $3 billion to $1.1 billion in upstream areas. Acceleration of expenditures based on regional judgment is expected to reduce annual flood losses still further to practical minimums of about $700 million by 2020 in downstream areas, and $500 million in upstream areas. Estimates of future flood damage residuals, shown on figure 5–2–3, are based on future programs reflecting past trends, and future programs based on regional judgment of programs capable of reducing damages to practical minimum levels. The effects of the flood-plain management program are omitted in both cases. However, it is anticipated that an effective flood-plain management program will permit reductions in the levels of future damages to practical minimums while permitting reductions in the extent of structural programs for flood control.

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CHAPTER 3

Water Quality

INTRODUCTION

Every day our cities, industries, and farms withdraw large quantities of water from the surface and subsurface water sources of the Nation. Our society is demanding that the streams, lakes, and coastal waters, in addition to serving obvious water supply needs, be fit for recreational uses such as swimming and boating, and also be pleasing to the sight and smell. To serve all the purposes we make of our water resources, adequate quantities of water of satisfactory quality must be available. Achieving satisfactory quality is the objective of water quality management.

Water quality requirements vary with the intended uses of water. To be suitable for municipal water supply and for recreational uses such as swimming and fishing, the water must be reasonably free from health endangering chemicals and bacteria as well as objectionable tastes and odors. Industrial water supply needs vary widely among industries; usually they must not contain damaging concentrations of corrosive chemicals, deposit or slime forming chemicals. In many cases, high concentrations of dissolved solids render water supplies unsuitable.

Water quality management problems hinge on whether or not existing or potential water uses are being or will be impaired. Fundamental here is the determination of the uses to be served by the water resource.

WATER QUALITY STANDARDS

The States are now in the process of establishing water quality standards on all interstate streams and coastal waters, action taken in response to the 1965 amendments to the Federal Water Pollution Control Act. These standards are based on the uses to be made of the States' surface waters. The uses were determined from historical information and from testimony presented in open hearings. From this, the appropriate State agency arrived at standards to be recommended to the Secretary of the Interior, the final approving authority. As of June 1, 1968, standards and implementing plans for 32 States have been approved in whole or in part by the Secretary. Basic discussions between State and Federal authorities have been completed for 10 other States, while basic issues are still under discussion with the remaining 8 States. Figure 5–3–1 shows those States with approved water quality standards.

SURFACE WATER QUALITY PROBLEMS

The fact that the Nation has serious water quality problems is all too evident: the lower Colorado River becomes more saline every year; the Hudson River flows through the metropolitan area of New York City, but the City has preferred to extend its pipelines to reservoirs more than 100 miles away to obtain purer water; Lake Erie is in a state of advanced eutrophication—it is becoming choked with plants, algae, and other organic material; and various estuarine areas have been closed to shellfish harvesting.

The sources of wastes that are damaging the Nation's surface waters are many and varied. Most critical and obvious are city sewage and industrial wastes discharging into rivers and the encroachment of sea waters into coastal estuaries. Raw or inadequately treated sewage from millions of people still flows into our streams. Every year another 1,000 communities outgrow their treatment facilities. Combined sewers persist as relics of the earlier days prior to widespread treatment plants and discharge raw sewage in times of high flow. The wastes from municipal and industrial sources inhibit water recreation, augment the cost of water treatment, impair the survival of both game and commercial fish, damage aesthetic values, corrode structures exposed to water and generally cause

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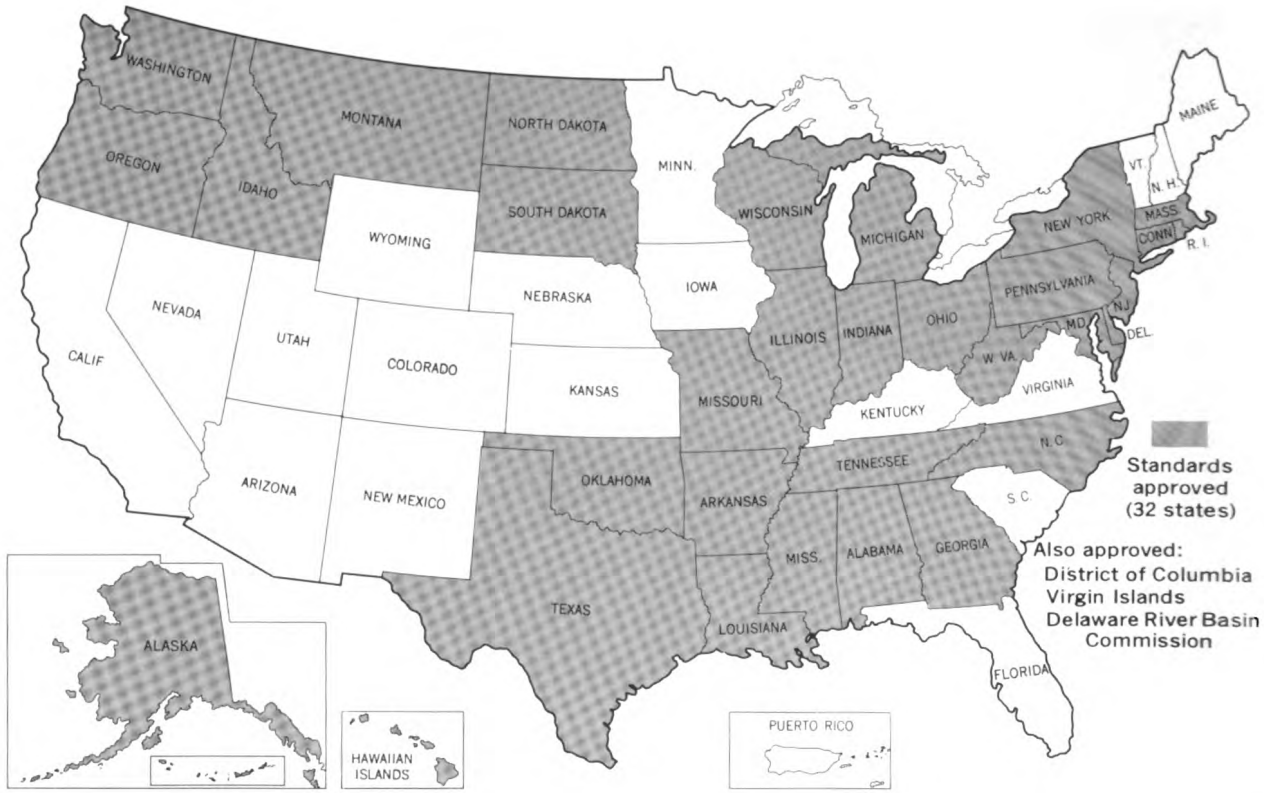

FIGURE 5–3–1.—*Approved water quality standards, June 1, 1968.*

deterioration of the fluviatile environment of man and fish.

Sediment is a major pollutant of surface waters. The dirty brown or gray appearance of a river or reservoir, after a rainstorm, is due to sediments washed in from croplands, unprotected forest soils, overgrazed pastures, or the bulldozed "developments" of urban areas. The presence of sediment generally increases the cost of water purification and reduces the value of water recreation. Nutrients adsorbed on sediment particles contribute to undesirable conditions of lakes. Furthermore, sediments adversely affect commercial and game fish habitats. Inflows of sediment also reduce the capacity of reservoirs. About 1 million acre-feet of reservoir capacity reserved for sediment deposition are filled each year. Rates of sediment production vary widely throughout the country. Regional values are shown in chapter 5.

Radioactive wastes from uranium mining, processing and use of radioactive fuels, and the phenols and pesticides released in manufacturing and agricultural use are all relatively new contaminants in the environment that are receiving attention.

Municipal and Industrial Wastes

Wastes from municipalities and industries that are discharged to surface waters are generally amenable to some form of treatment. Table 5–3–1 shows historical and projected gross municipal waste loads in the conterminous United States. Although this is simply an estimate, it does provide for a measure of the relative waste loads among regions. The estimate was derived on the assumption that the proportion of population served by organized municipal waste handling systems will increase over the projected period so that by 1973 the urban population will be completely served by sewers.

Table 5–3–2 shows the estimated capital outlays needed to obtain adequate municipal waste treatment for the existing and projected urban population of the United States to year 1973. The urban population in the United States is estimated at about 146 million persons in 1968; of this total about 82 million are served by adequate treatment facilities, about 32 million by less than adequate treatment, and another 32 million plus not served by any treatment whatso-

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TABLE 5–3–1.—*Gross municipal waste loads*[1] *in the conterminous United States*

(Millions of population equivalents)[2]

Region	1962	1980	2000	2020
North Atlantic	45.8	71.2	94.6	128.0
South Atlantic-Gulf	11.4	35.9	54.1	77.4
Great Lakes	15.6	41.5	54.5	72.8
Ohio	14.4	29.8	38.5	51.9
Tennessee	1.3	5.1	7.1	9.8
Upper Mississippi	15.7	18.0	24.4	33.0
Lower Mississippi	3.6	7.1	9.7	13.2
Souris-Red-Rainy	0.9	0.9	1.2	1.6
Missouri	6.3	12.0	17.2	24.6
Arkansas-White-Red	5.5	11.0	14.9	20.2
Texas-Gulf	6.9	15.4	22.8	32.6
Rio Grande	1.4	3.2	5.2	7.6
Upper Colorado	0.2	0.5	0.9	1.3
Lower Colorado	1.2	3.7	6.0	9.0
Great Basin	0.9	2.2	3.6	5.4
Columbia-North Pacific	3.7	9.3	12.9	18.0
California	14.7	35.0	54.3	80.6
Conterminous United States	149.5	301.8	421.9	587.0

[1] Biochemical oxygen demand (BOD).

[2] A population equivalent is the quantity of waste in terms of biochemical oxygen demand (BOD) produced by one person, approximately 1/6 pound per day.

ever. Thus, facilities must be upgraded and replaced where less than adequate treatment is provided, treatment must be provided where none now exists, and necessary sewers must be constructed.

As shown in table 5–3–2, it is estimated that $8.0 billion will have to be expended for construction of municipal waste treatment plants and interceptor sewers between now and 1973. In addition, costs of constructing sanitary collection sewers in communities where such facilities are needed now and over the next five years are estimated to be on the order of $6.2 billion. These expenditures will be an integral part of the overall costs of the municipal waste treatment needs.

Looking toward the future, the manufacturing industry will be the principal source of controllable waterborne wastes. Specifically in terms of generally accepted criteria for strength and volume, wastes from this source are about three times as great as those of the Nation's sewered population. The volume of industrial production has increased by about 4.5% per year and the volume of industrial wastes is expected to increase about three times as rapidly as population.

TABLE 5–3–2.—*Capital outlays (1968 dollars) needed to obtain adequate municipal waste treatment for the U.S. urban population, by water resource region, FY 1969-1973*

(Million dollars)

Region	Total	Upgrading of present facilities	Constructing new facilities for untreated wastes	Additional construction needed for increase in urban population	Allowances for depreciation
North Atlantic	2,392.2	746.6	801.6	512.1	331.9
South Atlantic-Gulf	921.9	172.5	367.7	259.3	122.4
Great Lakes	1,059.2	376.3	285.7	246.0	151.2
Ohio	674.6	205.8	172.3	180.7	115.8
Tennessee	60.1	8.9	25.5	18.3	7.4
Upper Mississippi	620.1	121.6	146.9	219.6	132.0
Lower Mississippi	219.1	25.4	97.7	73.7	22.3
Souris-Red-Rainy	9.0	2.5	2.6	2.2	1.7
Missouri	234.0	61.5	38.0	91.8	42.7
Arkansas-White-Red	216.5	41.9	39.4	92.2	43.0
Texas-Gulf	279.3	14.6	69.5	134.8	60.4
Rio Grande	60.5	2.6	11.9	33.4	12.6
Upper Colorado	13.8	1.3	6.2	4.6	1.7
Lower Colorado	100.8	4.7	29.5	53.3	13.3
Great Basin	122.4	2.3	79.4	28.9	11.8
Columbia-North Pacific	314.4	77.6	127.7	70.7	38.4
California	647.8	2.6	371.3	151.4	122.5
Alaska	12.8	—	7.0	5.0	.8
Hawaii	35.5	—	27.5	4.5	3.5
United States	7,994.0	1,868.7	2,707.4	2,182.5	1,235.4

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The chemical composition and toxicity of industrial wastes differ markedly from those of sewage. The specific locations of industrial discharges are not inventoried nor are specific effluents characterized on a nationwide, regular basis. For these reasons it is not now possible to present for industrial wastes data comparable to those shown in tables 5–3–1 and 5–3–2.

Reported quantities of industrial waste waters discharged in 1963 and the estimated quantities of biochemical oxygen demand and settleable and suspended solids are shown in table 5–3–3. It is significant to note that the waste load estimates, based on estimations of "average" quantities of pollutants per unit of product, show that the chemical, paper, and food and kindred products industries generated about 90% of the biochemical oxygen demand (BOD) in waste waters.

TABLE 5–3–3.—*Estimated volume of industrial wastes before treatment, 1963*

Industry	Wastewater	Standard biochemical oxygen demand	Settleable and suspended solids
	Bil. gal.	*Mil. lbs.*	*Mil. lbs.*
Food and kindred products	690	4,300	6,600
Textile mill products	140	890	not available
Paper and allied products	1,900	5,900	3,000
Chemical and allied products	3,700	9,700	1,900
Petroleum and coal	1,300	500	460
Rubber and plastics	160	40	50
Primary metals	4,300	480	4,700
Machinery	150	60	50
Electrical machinery	91	70	20
Transportation equipment	240	120	not available
All other manufacturing	450	390	930
All manufacturing	13,100	22,000	18,000
For comparison:			
Sewered population of U.S.	[1] 5,300	[2] 7,300	[3] 8,800

[1] 120,000,000 persons X 120 gallons X 365 days.
[2] 120,000,000 persons X 1/6 pounds X 365 days.
[3] 120,000,000 persons X 0.2 pounds X 365 days.

The minimum investment required to achieve acceptable levels of waste treatment, in this case the equivalent of secondary treatment of municipal wastes—85% removal of BOD and of settleable and suspended solids, is expected to be in the $2.6 to $4.6 billion range. Table 5–3–4 shows the ranges of cash outlays needed to meet the current backlog and accommodate projected increases in industrial waste loads.

TABLE 5–3–4.—*Estimated regional investment required to eliminate industrial waste treatment deficiencies accumulated through 1968, by water resource region* [1]

(Millions 1968 dollars)

Water resource regions [2]	Industrial waste treatment [3]
North Atlantic	210-530
South Atlantic-Gulf	70-180
Great Lakes	190-480
Ohio	130-340
Tennessee	34-85
Upper Mississippi	57-140
Lower Mississippi	87-220
Missouri	24-61
Arkansas-White-Red	17-42
Texas-Gulf/Rio Grande	120-310
Great Basin/Upper Colorado/Lower Colorado	9-24
Columbia-North Pacific/Alaska	48-120
California/Hawaii	39-98
Total	1,100-2,600

[1] Based upon the reduction of at least 85% of BOD and of settleable and suspended solids.
[2] Puerto Rico-Virgin Islands not included.
[3] All values rounded to two significant figures.

Other areas posing water quality management problems are outlined below. The paucity of data indicated by the following discussion is not intended to downgrade their relative importance in the overall field of water quality management.

Thermal Pollution

Water used for cooling purposes by the manufacturing and steam-electric generation industries produces temperature increases in receiving waters resulting, generally, in water quality degradation. Steam-electric power generation is a far greater source of waste heat than is industrial processing. Present estimates of the costs of investment for 1969 to 1973 to provide cooling equipment to return water to original temperatures before release are $1.8 billion (1968 dollars): $1.0 billion to correct the current backlog of needs, $600 million for expected growth, and $220 million for replacement. About $1.3 of the $1.8 billion would be required for the steam-electric power generating

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industry on the basis of returning water to original temperature; but it is recognized that a lesser overall temperature reduction may well prove adequate in the light of water quality standards that had not yet been approved when the above estimates were developed.

Other Forms of Pollution

Wastes from watercraft have been estimated to be equivalent to the wastes of a city of 500,000 population. *Wastes from Watercraft* (S. D. 48, 90th Congress) also estimates that the total cost of improving all U.S. watercraft to compliance with the proposed regulation is in the order of $600 million.

Current estimates are that over four million tons of acid equivalents annually are discharged to the Nation's streams from active or abandoned mining operations. These discharges cause significant stream degradation. Estimates of the costs of controlling these acid sources vary widely but there is little doubt that the eventual costs will involve expenditures running to several billions of dollars.

Other, even less well-defined, problem areas are drainage from animal feedlots, spills of oil and other substances from transportation and storage facilities, and runoff of pesticides and fertilizers from agricultural lands. Research on these specific problems is proceeding and should result in some recommendations for remedial action.

GROUNDWATER QUALITY PROBLEMS

The quality management of groundwater is also important to the Nation, because groundwater is used extensively as a source for domestic, municipal, industrial, and agricultural supplies. Contamination of groundwater may occur, for example, through discharge of wastes into seepage wells and septic tank fields. In some heavily populated coastal areas such as Long Island and southern California groundwater aquifers have become vulnerable to encroachment of salt water. In certain areas of the country the gradual formation of limestone solution channels may yield passageways from surface locations to groundwater sources. In such instances, wastes from a surface source may run directly into groundwater and present serious contamination problems. The subsurface aspects of the relationship between water supply and waste disposal represent some of the most complex parts of the total integrated water resources management program.

CONCLUSIONS

Water quality management planning efforts, now and in the future, must be dynamic, responsive to the changing nature of pollutants, and quick to utilize improvements in technology, if the present backlog of treatment needs is to be eliminated and estimated future needs are to be met.

Projected capital outlays for municipal and industrial waste treatment, sanitary sewers, and water cooling requirements are estimated at $20 billion (1968 dollars) for the 5-year period 1969 to 1975. This investment would catch up on the backlog of needs so that the annual rate to keep up with population and industrial growth could be somewhat less after 1973.

The water quality standards provisions of the Federal Water Pollution Control Act now provide both guidelines and an immediate focus for the development of intergovernmental basinwide programs and regionwide pollution control programs. Plans for providing continual revision of guidelines for needed immediate and long-range water quality management actions in river basins are being developed cooperatively among Federal, State, and local governments. This planning effort is designed to identify the institutional and financial arrangements necessary to effect basinwide and regionwide programs, as well as to find technical solutions to pollution problems. Moreover, water quality management cannot be divorced from water quantity management.

In the final analysis, the effect of such programs will depend on the availability of management organizations with recognized and acknowledged authority.

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CHAPTER 4

Public Health

INTRODUCTION

In any assessment of water supplies, special attention must be given to health protection for the ultimate users and intended beneficiaries—the people. Human disease and illness are attributable to a large variety of factors associated with water and related land resources. Major factors are discussed within the four following categories: (1) water supplies, (2) food supplies, (3) disease vectors, and (4) other environmental factors.

WATER SUPPLIES

As municipal water supplies are used for the domestic purposes of drinking and cooking, health and safety considerations are directly associated with those supplies. The considerations include epidemiological analysis, problems in public systems, and problems in individual systems (see also chapter 1, part 4).

Epidemiological data are inadequate and do not indicate the full extent of health damages resulting from water supply deficiencies nor do they adequately emphasize the needed remedial measures. However, a recent review of the period 1946 to 1960 disclosed 228 outbreaks of disease or poisoning, with 25,984 cases attributed to drinking water (table 5–4–1).

More disease outbreaks occurred in private and semipublic water systems (158) than in public water systems (70); but, because of the much larger populations served, the number of individual cases in public systems (19,928) far exceeded the number of cases in the private and semipublic systems (6,056). Distribution of outbreaks according to source is shown in table 5–4–2.

In 1965, there was a major outbreak of salmonellosis in which 18,000 cases were reported. The source of this disease was a public system using groundwater without treatment by disinfection.

TABLE 5–4–1.—*Waterborne diseases in the United States, 1946-60*

Disease	Outbreaks	Cases
	Number	*Number*
Gastroenteritis	126	13,630
Typhoid	39	506
Infectious hepatitis	23	930
Diarrhea	16	5,160
Shigellosis	11	5,653
Salmonellosis	4	24
Amebiasis	2	36
Other	7	45
Total	228	25,984

Epidemiological data indicate multiple causes of waterborne disease for community or private treatment and distribution systems. An improved program for gathering epidemiological data is badly needed. A qualitative and quantitative expansion of information would undoubtedly reveal new areas needing attention.

One of the most significant achievements in

TABLE 5–4–2.—*Percentage distribution of sources of waterborne disease in the United States, 1946-60*

Source	Outbreaks	Cases
	Percent	*Percent*
Untreated surface water	9.6	3.2
Untreated ground water	41.7	33.9
Contamination of reservoir or cistern	1.3	0.7
Contamination of collection or conduit system	3.1	4.6
Inadequate control of treatment	15.4	41.4
Contamination of distribution system	16.7	12.9
Miscellaneous	12.2	3.3
Total	100.0	100.0

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the past 100 years in the United States and in some other advanced nations has been the provision of safe and potable community water supplies. This initial achievement, however, was followed by a sense of complacency, and deficiencies and inadequacies in water supplies now exist. The solution to present domestic water supply problems has two aspects. First, data gathering must be improved so that present and potential problems, their scopes, and their dangers can be better defined; and, second, the necessary steps must be taken to reduce or eliminate known health hazards in our supply systems.

The Federal Government and the States maintain joint surveillance over 796 interstate carrier water supplies which serve a population of over 90 million persons. These supplies include those of major metropolitan areas supplying water for drinking and other domestic uses to trains, planes, ships, and buses engaged in interstate transportation. Presumably, they should represent the best supplies in the United States; yet, in 1967, 170 (21%) were classified as provisional or were prohibited from serving interstate commerce. Detailed information on all water supplies in the United States is not available; but it is estimated on the basis of general information and data on the interstate carrier supplies that over one-third of the Nation's public and semipublic water supplies do not meet adequate levels for health protection.

In addition to known health hazards in domestic and municipal water supplies, there are the unknown dangers posed by new detergents, pesticides, and other contaminants which enter streams daily. New chemicals are discovered, utilized, and released with other wastes by industries, for example, before they can be fully investigated and their effects on health determined and adequately evaluated. The Public Health Service Drinking Water Standards cover only traditionally known contaminants. The standards are predicated on the use of relatively unpolluted water as a raw water source; proposals for direct reuse of treated sewage as drinking water present a new problem that requires reevaluation of the principles on which the Standards are based.

A number of factors in water distribution systems are known to pose health hazards, including (1) a loss of chlorine residual (required for proper disinfection), and (2) contamination of distribution mains and reservoirs. The magnitudes of the dangers these and other factors pose, however, cannot be determined because the scope of current investigation and surveillance programs is too limited. However, a recent survey of 59 selected major water users in one city revealed that over 93% had connections between unsafe individual supplies and the treated community supply (cross-connections) or other deficiencies in their plumbing. It is estimated that large numbers of individual defects in distribution systems are present in community water supplies throughout the Nation. The problem is urgent and demands national, State, and local attention.

About 25% of the Nation's population lives in rural and in outlying suburban areas and is served daily by individual water supplies. A substantial number of interstate travelers use individual supplies in motels, resorts, and recreation areas throughout the country. Insufficient information exists regarding the health status of these supplies. However, epidemiological data have shown a larger number of disease outbreaks from these supplies than from public supplies; and it is suspected that more disease outbreaks occur than are reported.

Deficiencies in individual supplies include the following: inadequate well installations, inadequate disinfection, contaminated groundwater sources, and poor operation controls. Two important corrective steps would be (1) to strengthen State, local, and Federal programs for the improvement of individual water supplies, and (2) to extend or increase the availability of public water supplies to communities presently using individual water supplies.

FOOD SUPPLIES

Man's food supplies may be contaminated by water contact during their growth period if (1) they are grown in contaminated water media, or (2) if they are irrigated with contaminated water (see also chapters 7 and 4 in part 4). Experience has shown that ingestion of raw shellfish grown in contaminated water can result in disease, and that ingestion of raw food crops grown with the direct use of night-soil can result in enteric disease.

The earliest health hazard identified with eating raw shellfish grown in contaminated waters was typhoid fever. In recent years, however, infectious hepatitis has been the predominant known health hazard associated with their ingestion. During the 4 years, 1961 through 1964, four major epidemics involving more than 1,000 individual cases were attributed to ingestion of raw or partially cooked shellfish grown in contaminated waters. A significant number of iso-

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lated cases of infectious hepatitis, which continue to appear during non-epidemic periods, are thought to be attributable to this source. Better delineation of this disease aspect of shellfish production will depend on improved epidemiological surveillance and data gathering.

A cooperative Federal-State-industry program is operated for the sanitary classification of active shellfish growing areas. Table 5–4–3 indicates that 80% of the total acreage is fully approved; 1% is conditionally approved; but that 19% is closed because those areas do not meet the sanitary standards for growing waters. Disease problems attributable to clams and oysters are often associated with unauthorized harvesting (or "boot-legging") in closed areas. Expanded Federal-State and industry efforts are needed both to prevent the use of shellfish from closed areas and to reduce pollution loads which force closure of shellfish beds.

TABLE 5–4–3.—*Active shellfish growing areas, April 30, 1966*

Status	Areas	Acres	
	Number	*Thou.*	*Percent*
Fully approved	388	7,211	80
Conditionally approved	40	88	1
Sub-total approved	(428)	(7,299)	(81)
Closed	401	1,752	19
Total	829	9,051	100

In addition to known health hazards associated with shellfish, there are unknown hazards posed by the accumulation of toxic substances in the tissues of fish and shellfish. Research and investigations must be conducted with regard to the accumulation of new chemical substances, including herbicides and insecticides, in fish and shellfish, so that the proper steps may be taken to safeguard public health.

In the United States, direct use of night-soil for food crop production is negligible and expected to remain so; but the use of sewage effluents for irrigation is already significant and expected to increase. This is true in arid regions in particular where the pressures of economic development and population growth dictate optimum use of all waters, including sewage effluents. Although these waters are used only to the extent believed to be consistent with good health practices, insufficient information is available on the potential contamination hazards such use poses. Research and study in this area are urgently needed.

DISEASE VECTORS

A disease vector is an agent which carries the germs of disease from one individual to another. While the mosquito is undoubtedly the principal vector associated with water and related land resources (see, also, chapter 7), the tick is of major significance regionally because lands that it infests are frequently utilized for recreation purposes. Although vector disease reporting is partial and inadequate at present, the available epidemiological data do give some indication of its magnitude and threat to human health.

In the United States, the common mosquito-borne disease of malaria is held in check, although outbreaks of epidemic proportions are possible so long as hosts and the mosquitoes, the vectors of the disease, remain. In 1966 and 1967, over 2,700 cases of imported active malaria were identified in the United States, mostly among returned servicemen. The outbreak potential was actually realized in 1952 in Lake Vera, California, where 35 Camp Fire girls contracted malaria. The host was a returned serviceman who had a malarial attack while camping near the girls' campsite.

Encephalitis is also carried by mosquitoes, and it is now the most significant vector-borne disease in the United States. In the period 1955 through 1965, there were 2,716 cases of confirmed vector-borne encephalitis. Many more cases of the disease were reported during this period, but they were diagnosed as post infectious to some other disease, or were of unknown etiology. In 1965, 2,703 cases of the disease were reported and diagnosed as follows: vector-borne, 297; post infectious, 1,081; and etiology unknown, 1,425. The 297 confirmed vector-borne cases were attributable to four different viral strains. The California strain accounted for 59 cases; the Eastern strain, 8 cases; the St. Louis strain, 58 cases; and the Western strain, 172 cases.

Epidemiological studies of animal populations are also important for overall public health protection. Animals are the hosts for a variety of vector-borne disease, including encephalitis, and are themselves vectors of some other infectious diseases. The occurrence of a disease, limited or widespread in an animal population, is forewarning of the possible outbreak of the disease in human population. In one southern State, public health scientists have detected the

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Venezuelan strain of encephalitis in cotton mice and cotton rats. While the disease symptoms have not appeared in humans in the United States, laboratory tests reveal that some people in the area have built up antibodies to this virus, and, therefore, this variation of the disease must be considered a threat to public health.

The mosquito is of public health concern for other reasons, unrelated to vector-borne disease in human and animal populations. In a survey conducted in the irrigated areas of a western State, mosquito bites caused some injurious reaction, either through secondary infection or allergic reaction, in 8 out of 10 people interviewed.

Mosquito-borne disease problems are widespread in the vicinity of both natural and developed waters. Problems at developed waters in respect to the types of mosquitoes involved and the types of control techniques required, fall into two general groups—those associated with reservoirs and those associated with irrigation systems. Control-guidance documents for technical and lay use have been prepared for both problem groups. Federal water resources construction and operating agencies appear to recognize and follow good vector control practices. Many reservoir, irrigation, and other improvement projects, however, are State, local, and private. Currently, investigation and surveillance are inadequate and do not permit either full delineation of vector control problems associated with water resources, or proper evaluation of the adequacy and effects of remedial efforts.

Problems with tick-borne Rocky Mountain spotted fever are primarily associated with recreation areas infested with ticks. From 1955 through 1965, over 2,700 cases of the disease were reported, with areal concentrations along the Atlantic seaboard and in southern States. Remedial measures include clearing and spraying of pathways, use of insect repellent, and personal vaccination. At present, however, formal programs for gathering field information and for applying known remedial measures to Federal, State, and local recreation areas are inadequate.

State and local programs are contributing to vector control and to the prevention of vector diseases. A recent survey indicated that 32 States have some type of vector control program; of these, 23 States employ at least one full-time vector control specialist. In 29 of these States, there are 250 vector control districts supported, at least in part, by local funds. At the present time, these vector control programs are heavily oriented toward mosquito problems. With the increasing utilization of water and related land resources for home sites and recreation purposes, remedial efforts must be increased in this area; but they must also be expanded to include control of other vectors and vector diseases as well.

OTHER ENVIRONMENTAL FACTORS

Public health aspects of domestic water supply, food crops, and vectors have already been discussed generally; but there are other features of our environment associated with water and related land resources, not entirely separable from the aforementioned three broad considerations, that harbor health hazards. These include solid waste disposal and provision of recreation area facilities. Improper location of solid waste disposal sites or inadequate treatment of solid wastes can contribute to surface-water and to groundwater pollution. (See, also, chapter 3.) Good health should be assured in recognized public recreation areas in much the same way it is in permanent communities. A safe potable water supply, vector control, and adequate waste disposal facilities are essential in such areas because, as the number of picnickers and campers utilizing these areas increases, the health hazards and the potentials for disease outbreaks increase. It should be recognized, however, that seasonal operation and a variable population are two recreation area features which make public health protection more complicated. (See also chapter 6, part 4.)

In the future, air pollution and radiological hazards may become significant problems associated with water and related land resources development. Expansion of facilities using radioactive materials and increasing industrialization along the Nation's waterways, together with increasing knowledge of the interrelationships between elements of the environment, portend new dimensions for public health. Today, the primary problem with regard to public health aspects of water and related land resources is that insufficient information and data exist to delineate and quantify many of the factors of health significance. In the future, as in the present, needs will continue for increased and expanded research, investigation, and surveillance relating both to existing and potential factors affecting health, and to remedial measures for health protection.

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CHAPTER 5

Watershed Lands

INTRODUCTION

The shape of the earth's surface to a large degree has been carved by water in its journey from the atmosphere to the sea. As the principal geomorphic agent, water transports soil, rock, and organic matter from one place to another. In this process, nature seeks a balance of forces at work. Vegetation produced by moisture and the earth's minerals provides a protective cover that moderates geologic erosion and helps to maintain water quality. At the same time, a land resource is produced: the soil, a reservoir of minerals and organic materials, that man draws upon to feed, clothe, and supply a hungry and demanding civilization. But in the process, man also alters nature's dynamic equilibrium, watershed lands are sometimes damaged, and conservation measures become necessary.

Watershed protection and management programs are needed not only to protect and enhance land resources such as soil, vegetation, and wildlife and to improve the living environment, but also to insure the optimum combination of water quantity and water quality at a given location. It is fortunate that most conservation practices enhance the quality of water while they ameliorate the quality of related land resources.

Conflicts are inevitable in the competition for land and water resources. The growing demands for these resources raise important policy issues: conservation and natural resources based production on one hand versus the rapidly increasing demands for space for urban development on the other. An effective national land and water resources development program should minimize conflict between the various preservation, conservation, land use, and development policies. The principle of coordinated multiple use of land and water resources holds much promise in helping to minimize competition. Resources management agencies and many private landowners have adopted conservation programs. Land used for forest production, range, and farming can also provide recreation, wildlife habitat, and a dependable supply of good-quality water when managed properly. Open space land in metropolitan areas can also be used for multiple-purpose management programs.

PROBLEMS IN THE USE, TREATMENT, AND MANAGEMENT OF LAND

Agricultural, Range, and Forest Lands

Susceptibility of soil to erosion is probably the most widespread land management problem, as shown in table 5–5–1. Erosion is the dominant problem on about 740 million acres (51%) of the non-Federal rural land, but only 11 million acres (6%) of the National Forest lands. Seventy percent (123 million acres) of the public domain in the conterminous 48 States has either critical or moderate erosion problems, as noted in table 5–5–2. The erosion hazard is especially serious in the Missouri, Arkansas-White-Red, Texas-Gulf, Tennessee, Ohio, Rio Grande, Upper and Lower Colorado, and the Great Basin Regions. Only about 60% of the non-Federal rural lands subject to erosion can be safely used as cropland under present technology and require conservation practices to keep erosion rates within tolerable limits. The remaining 40% should be under continuous vegetative cover and be used for grassland, forest, recreation, or wildlife. Factors affecting erosion are rainfall, runoff, vegetative cover, soil characteristics, and ground slope.

Excess water due to poor internal drainage, wetness, high water table, and overflow occurs on 246 million acres (17%) of the non-Federal rural lands. These areas are more prevalent in the South Atlantic-Gulf, Great Lakes, and Upper and Lower Mississippi Regions. Only about 38% of this area is used for cropland. Much of the remaining area serves as wetland habitat for wildlife and timber production. Excess water is

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TABLE 5–5–1.—*Dominant conservation problems of non-Federal rural land when used for agriculture*

(Millions of acres)

Region	No problem (Class 1)	Erosion hazard	Excess water	Unfavorable soil	Adverse climate	Total
North Atlantic	1.8	33.5	16.5	44.8	[1]	96.6
South Atlantic	2.9	64.9	50.6	33.9	[1]	152.3
Great Lakes	0.7	15.7	29.1	20.2	[1]	65.7
Ohio	2.2	63.7	21.1	7.6	[1]	94.6
Tennessee	0.4	15.5	2.1	5.7	[1]	23.7
Upper Mississippi	5.8	49.3	35.6	14.6	[1]	105.3
Lower Mississippi	1.5	12.0	18.3	6.1	[1]	37.9
Souris-Red-Rainy	0.1	14.5	13.8	4.9	2.7	36.0
Missouri	7.1	160.3	17.4	78.3	15.0	278.1
Arkansas-White-Red	6.1	106.9	18.3	17.0	8.1	156.4
Texas-Gulf	2.5	73.8	13.7	15.2	7.5	112.7
Rio Grande	0.9	20.9	0.5	30.7	11.0	64.0
Upper Colorado	[1]	13.1	0.7	5.9	1.9	21.6
Lower Colorado	0.6	9.5	0.1	16.8	19.6	46.6
Great Basin	0.2	10.4	0.6	7.6	2.2	21.0
Columbia-North Pacific	1.2	48.0	3.3	25.2	2.7	80.4
California	2.3	26.6	3.9	17.7	4.2	54.7
Alaska	[1]	0.4	0.4	0.3	0.2	1.3
Hawaii	[1]	1.1	0.2	1.7	0.5	3.5
Puerto Rico	[1]	1.4	0.2	0.3	0.1	2.0
Total	36.3	741.5	246.4	354.5	75.7	1,454.4

[1] Less than 50,000 acres.

TABLE 5–5–2.—*Erosion problems, public domain in conterminous 48 states*

(Millions of acres)

Region	Extent of erosion			
	Slight	Moderate	Critical	Total
Missouri	7.5	9.0	5.2	21.7
Arkansas-White-Red	.1	.4	.2	.7
Rio Grande	1.3	6.4	3.6	11.3
Upper Colorado	4.1	14.4	8.3	26.8
Lower Colorado	2.4	13.8	7.9	24.1
Great Basin	15.4	20.1	11.6	47.1
Columbia-North Pacific	14.6	8.5	5.0	28.1
California	6.8	5.4	3.2	15.4
Total	52.2	78.0	45.0	175.2

not a major problem on Federal lands but poor internal drainage is recognized as a local problem. Additional material on drainage is contained in chapter 7.

About 355 million acres (24%) of the non-Federal rural lands have soils that are shallow, stony, saline, or which have low moisture holding capability or low fertility. Areas with unfavorable soil as the dominant conservation problem are concentrated in the Missouri, North Atlantic, and Rio Grande Regions. Comparable data are not available on Federal lands; however, much Federal land is known to have unfavorable soil.

Adverse climatic factors, including cold temperatures, short growing seasons, or lack of moisture, affect 76 million acres (5%) of the non-Federal rural lands. Lack of moisture is a major problem on Federal lands. Areas where these problems predominate are located in the Lower Colorado, Rio Grande, Missouri, Great Basin, Arkansas-White-Red, and California Regions. Only about 32% of the non-Federal acreage is used as cropland. With the existing water supply development, land in this class is best suited for range or forest production and for recreation and wildlife. Given an adequate water supply, the areas not affected by a short growing season may have high potential as irrigated land.

About 60% of the land expected to be in cropland by 1980 will need conservation treatment to minimize these problems. The specific treatment and development needs are as follows (million acres): erosion control practices (201); agricultural water management practices (72); practices to improve unfavorable soil conditions (82); and moisture conserving practices to

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minimize the effects of adverse climate (41). Nearly 125 million acres of cropland require two or more types of conservation practices. Included are nearly 27 million acres of irrigated cropland in Western States which require treatment for erosion, excess water or salinity problems.

Seventy-five percent of the pasture and range land require treatment to protect soil from erosion. The treatment needed includes (million acres) establishment of cover (72); improvement of cover (108); and protection of stands (185).

The dominant conservation problems of the non-Federal forest and woodlands are included in table 5–5–1. In addition, however, specific development and management needs for the immediate future on the 395 million acres of forest land in State and private ownership are estimated as follows (million acres): timber stand improvement (20); forestation (17); improved harvesting practices (23); improved fire protection measures (200); establishment of fire protection measures (150); improvement of forest pest control (160); establishment of forest pest control (200); and intensive watershed management (23).

Erosion from public lands is important where heavy recreation pressure, overgrazing by domestic and wild animals, and inadequate range and forest cover exist. Improper forest harvesting methods, particularly careless road location and construction, may cause serious erosion problems on both private and public forest lands.

The dominant and most urgent erosion control and stabilization needs of the Federal lands, primarily the 668 million acres administered by the Bureau of Land Management and the Forest Service, are being met by the planned application of these measures (million acres): Forestation (4.85); timber stand improvement (9.07); range rehabilitation (43.1); restoration of damaged watersheds (12). In addition, over 15,000 miles of streambank and shoreline stabilization and 50,000 miles of erosion control on roads and trails are required.

Urban and Other Lands

Lands undergoing urban development often demand more complex and costly management than do agricultural range and forest lands. The problems associated with these lands have wide significance because of the vast number of people affected. Extremely large temporary increases in sediment loads are likely to occur in areas where erosion is accelerated by urban construction. Sediment discharge rates depend on the intensity of construction activities and the degree of control employed as well as on the natural physical processes. In areas undergoing rapid urbanization, sediment derived from construction of subdivisions and highways may be as much as 80 tons per acre before the land is restabilized or as high as 57,000 tons per 1,000 increase in population. In the Potomac River basin, watersheds that are undergoing urban growth discharge 10 to 50 times as much sediment as similar watersheds in rural areas. Conservation plans for urban and suburban developments have recently been initiated in cooperation with zoning boards in the vicinity of Washington, D.C.

Waste disposal is one aspect of urbanization that creates serious land and water resource problems and reduces the quality of the environment. Some land and water areas have capacities too limited to assimilate the large amounts of wastes applied to them.

Resources management programs are needed for the solution for these problems in urban areas. Comprehensive planning at all levels of government which incorporates natural resources management plans and programs into the planning process offers a means of providing for urban development needs while maintaining or enhancing the quality of the physical environment. Urban land and water management techniques must be further developed and put into wider practice. Careful analysis of soils, geology and hydrology is basic to the sound management of land and water resources.

Other land use and management problems which significantly affect the water resource include streambank and roadside erosion. The movement of soil into streams from an estimated 300,000 miles of streambanks on non-navigable streams exceeds 500 million tons annually.

Approximately 20% of the 2.2. million miles of rural roads and highways need conservation measures for sediment control beyond those for normal maintenance. These unprotected roadsides contribute an average of 56 million tons of soil annually to streams, reservoirs, and harbors.

Surface mining presents severe land use and water management problems including sediment and mine drainage pollution (see chapter 3). In some local areas of Appalachia, sediment production from surface-mined lands has increased 70 times. Areas with major problems attributable to surface mining are concentrated in the North Atlantic, Ohio, and California Regions. Prior to 1965, about 3.2 million acres had been

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disturbed by surface mining and an additional 320,000 acres had been affected by mine access roads and exploration activities. About 2.1 million disturbed acres are considered to need treatment at the present time. It is estimated that at the present time 150,000 acres are disturbed annually—a rate that exceeds annual rehabilitation. The disturbance rate is expected to grow, and so will the backlog of disturbed acreage unless rehabilitation and land management efforts are greatly increased.

SEDIMENTATION

Sediments produced by erosion are the most extensive pollutants of surface waters. It is estimated that suspended solids loadings reaching the Nation's streams are at least 700 times the loading from sewage discharge. On the average about 4 billion tons of soil material are moved from place each year and transported by flowing water for deposition at another location. About 25% of this is discharged into the oceans. Excessive suspended sediment has a harmful effect on water supplies. Municipal and industrial uses require clear water and excessive amounts of sediment in raw water will increase the cost required for flocculating material and for cleaning sedimentation basins. Nutrients adsorbed on sediment particles contribute to undesirable conditions of lakes. Sediments adversely affect the commercial and game fish habitats, power turbines, pumping equipment and irrigation distribution systems. Sediments deposited during floods damage crops and, if coarse-textured, may reduce the productivity of the soil. On the other hand, some river valleys like the Nile are annually rejuvenated by flood-borne deposits of silt. Channels and drainage facilities may be impaired and the clean-up and removal of sediment from residential and other developed areas is costly. Storage capacity of artificial reservoirs in this country is being depleted at the rate of about 1 maf/yr by deposition of sediment. In addition to the loss of capacity, there is an adverse effect on those facilities for recreation. Potential storage sites to replace these depleted reservoirs are limited.

The total impact of fluvial sediment upon the national economy and quality of environment is of tremendous significance. Rough estimates show that annual sediment damages total in excess of $500 million.

The physical magnitude of the sediment problem is indicated in table 5–5–3. As shown, sediment yield can vary greatly in a region.

TABLE 5–5–3.—*Estimated ranges in sediment yield from drainage areas of 100 square miles or less*

Region	Estimated sediment yield		
	High	Low	Average
	tons/sq mi/yr		
North Atlantic	1,210	30	250
South Atlantic-Gulf	1,850	100	800
Great Lakes	800	10	100
Ohio	2,110	160	850
Tennessee	1,560	460	700
Upper Mississippi	3,900	10	800
Lower Mississippi	8,210	1,560	5,200
Souris-Red-Rainy	470	10	50
Missouri	6,700	10	1,500
Arkansas-White-Red	8,210	260	2,200
Texas-Gulf	3,180	90	1,800
Rio Grande	3,340	150	1,300
Upper Colorado	3,340	150	1,800
Lower Colorado	1,620	150	600
Great Basin	1,780	100	400
Columbia-North Pacific	1,100	30	400
California	5,570	80	1,300

WATERSHED MANAGEMENT AND TREATMENT ACCOMPLISHMENTS ON PRIVATE AND PUBLIC LANDS

Private Lands

Most land use and conservation treatment programs on private land are carried out through approximately 3,000 locally managed soil and water conservation districts. These districts cover 95% of the agricultural land of the Nation. More than 2 million landowners managing 685 million acres of land cooperate with conservation district programs. Cooperative forest management and assistance programs on private forest lands are administered by State forestry agencies. Some of the major land treatment accomplishments by private landowners each year for the past 5 years have averaged as follows: 5.3 million acres of contour farming, 2.8 million acres of range and pasture planting, 936 thousand acres of tree planting, 600 thousand acres of timber stand improvement, and construction of 57 thousand ponds.

Watershed protection projects carried out by local people with Federal and State assistance provide for a high degree of treatment on a watershed-by-watershed basis. The projects approved and being installed cover 50 million acres, involving about 3% of the private land base. This is only about 5% of the 1 billion acres (70% of the non-Federal rural land area)

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for which watershed protection projects are needed.

The total expenditure for land treatment programs on private lands is about $1 billion annually. About 37% is from Federal sources, 5% is from State and local sources, and the remaining 58% is provided by the landowners. The bulk of Federal expenditures is by the Department of Agriculture for technical, financial, and credit assistance. In addition, the Bureau of Indian Affairs assists in the management of the 56 million acres of privately owned Indian lands. Non-Federal contributions for land treatment have increased during the last 10 years and are expected to continue to increase.

Estimates of progress in providing protection to land in urban areas is not available.

Public Lands

Publicly owned lands comprise more than 868 million acres of which 88% are federally owned. The demands for most of the diverse uses of those lands have increased as a result of increasing population, income, and leisure. Timber harvest, range use, and recreation use have increased and the water yielding and sediment reducing functions of public lands have grown in importance. The Bureau of Land Management and the Forest Service, which manage 668 million acres, together with a score of other Federal agencies, have well developed land management programs that vitally affect a great part of the water yield and water developments in the Nation. State and local agencies are also making concerted efforts in this field. Federal land management agencies spend about $250 million annually for forest and range management programs that contribute to watershed development.

The major land treatment accomplishments of the Forest Service and the Bureau of Land Management on an average annual basis during the last five years include (thousand acres) forestation (286), timber stand improvement (423), range rehabilitation (705), and rehabilitation of damaged watersheds (50). In addition, 1,000 miles of streambank and shorelines and 4,275 miles of road and trail erosion are stabilized and controlled annually.

EFFECT OF WATERSHED PROTECTION AND MANAGEMENT ON WATER RESOURCES

Watershed protection and management measures required to meet the needs for food, fiber, forest products, urban development, and recreation, and at the same time conserve the soil resource, may result in some increase in water use. This added water requirement is minor in relation to total water yield, and is usually more than justified by the protection of the resource base, more economical agricultural production, improved and stabilized patterns of streamflow, reduction of sediment yields, more efficient urban development, and enhanced living environment.

In water-short areas, watershed management as it affects water yield is a critical issue. Among the several ways that watershed management may augment water supplies is in enhancing the natural recharge of groundwater. By slowing the rate of overland flow and improving the infiltration rate by proper vegetative and cultural practices, more groundwater can be made available for withdrawal.

Forest lands are significant as sources of water. In the Columbia-North Pacific, California, Great Basin, and Upper and Lower Colorado Regions, over 90% of the runoff originates in high altitude watersheds which are largely forested and predominantly in national forests. National forest lands in the western United States occupy 21% of the area (143 million acres), receive 31% of the precipitation (which averages 26 in/yr and totals 310.3 maf/yr), and furnish 53% of the streamflow (which averages 14.0 in/yr and totals 167.3 maf/yr). These areas could be significant in increasing water yield if such practices as selective removal of riparian vegetation, installation of snow barriers, manipulation of vegetation, and type conversion are used in conjunction with other resource management activities.

The range lands of the public domain are predominantly water deficient areas. In the Western States these lands occupy approximately 22% of the area, receive 13% of the precipitation, and furnish 5% of the streamflow. These areas have limited potential to provide additional water yield if such practices as type conversion, manipulation of vegetation, and water harvesting are used in conjunction with other resource management activities.

Available water resources in the western regions may be increased through reduction of consumption of phreatophytic plants. Phreatophytes occupy approximately 16 million acres and have a water consumption rate of 22 bgd (25 maf/yr). It may be possible to reduce this consumption by two-thirds through an effective control program. However, much of this would be utilized by beneficial replacement vegetation.

Sediment movement can be significantly re-

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duced with improved land use and intensified treatment, control, and management programs. On a regionwide basis it is estimated that conservation measures applied to watershed lands could reduce sediment yields by 10% to 30%. Studies show that agronomic and supporting mechanical practices have reduced the amount of sediment reaching reservoirs by amounts ranging from 28% to 73%. Sediment yield may be reduced by as much as 90% by changing the poorly suited cropland to continuous vegetation.

Additional benefits of conservation measures on watershed lands include the following: maintenance costs of roads, canals, and navigable waters will be lessened; the useful life of reservoirs will be extended; damages to fish, wildlife, and recreation values of receiving waters will be ameliorated; municipal and industrial water treatment costs will be lowered; safety hazards will be reduced; and the aesthetics of the landscape will be preserved and improved. These are in addition to the protection and enhancement of the productivity of the land on which these measures are applied.

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CHAPTER 6

Beach, Shore, and Riverbank Protection

INTRODUCTION

This chapter presents a description of erosion along the seashores, estuaries, lakeshores, and riverbanks of the United States, and measures for its control. Because basic data on this subject are limited, much of this appraisal is based on estimates. The chapter is concerned with past erosion of shores and rivers, the situation as it now exists, and anticipated developments in the future. Further material on land erosion and sediment is presented in chapters 3 and 5.

The length of the tidal shoreline of the United States, including Alaska and Hawaii, is 89,000 miles. The shoreline of the Great Lakes in the United States is 4,776 miles and the shoreline length of other fresh-water lakes, 10 square miles or larger, is estimated to total 5,500 miles. The length of rivers and streams is estimated to be 3 million miles. These shorelines are directly related to the use of water resources and constitute assets of great worth to the Nation.

The continual restless movement of the sea carries away tidal shorelands with persistent effectiveness. Lakeshores also suffer from everyday wind-induced movements of water surfaces as well as infrequent storm-lashed waves in the lakes. In the case of riverbanks, floodflows resulting from storms of rare occurrence may cause natural avulsions or radical realignments of channels, and day-by-day low-velocity riverflows are major causes of meandering in moveable-bed streams.

Shorelines and riverbanks were used and enjoyed by the earliest inhabitants of this continent. With the rapid settlement of the country since the 17th century, these resources became increasingly important to the Nation's social and economic welfare. Congress first recognized the need for riverbank protection in 1879 when it created the Mississippi River Commission. This group, composed of seven men appointed by the President of the United States, is charged with the preparation of plans to improve the river channel, protect its banks, and improve navigation, among other activities.

Serious efforts to prevent shore erosion and loss of coastal land have been made in this country for about 50 years with varying degrees of effectiveness. Efforts in New Jersey in the 1920's were disappointing, and in order to increase and centralize efforts toward the design of more effective protection, Congress authorized establishment of the Beach Erosion Board (now the Coastal Engineering Center) of the Corps of Engineers in 1930. The authorization directed investigations be made in cooperation with appropriate State agencies to devise effective means of preventing erosion of the shore of coastal and lake waters by waves and currents.

CAUSES OF EROSION

Although a great deal is known about the processes of erosion, these understandings are not so well developed that the effects of the various combinations of factors can be predicted in any meaningful way. Nor, for that matter, can the occurrence of these factors be predicted. The principal factors involved are the energy applied to the soil, principally in the form of precipitation, streamflow, or waves, and the reaction of those soils to the application of this energy. The material composition of land, shores, and riverbanks is an important factor in erosion. Given the time to study a reach of the river or section of beach, reasonably effective measures can be developed for abating the damaging processes. This following discussion is limited to beach, shore, and riverbank erosion, and the reader is referred to chapter 5 for a description of land erosion.

Waves are active along the water-land interface wherever wind can set water into undulatory motion. Waves generate currents in lateral directions as well as offshore-onshore. The tidal movements are a constant cause of transporting currents and scouring. On occasion, there are more dramatic tidal influences such as in the case of a bore where a wall of churning water surges up an estuary. Tidal currents also in-

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fluence the movement of shore materials placed in suspension by wave action.

In the case of riverbanks, a flood of a few days' duration may cause the major portion of the annual erosion. But some rivers, such as the Missouri, continuously pick up tremendous loads of sediment as they flow from bend to bend through deep-filled alluvial valleys. This continuous action results in braiding and meandering of the channel. Bank material in a curve of the river is picked up by a spiraling current and is dropped at the "crossing" or in midstream where the spiral fades and reverses as it enters the next curve. Riverbank erosion occurs according to the ease with which the material can be suspended and transported and to the velocity of flow, and may vary from reach to reach and between tributaries of a river system.

EROSION DAMAGES

The combined resources of ocean and estuary beaches, lakeshores, and streambanks are widely dispersed throughout our country. Thirty States have tidal or Great Lakes shorelines and all have river and streambanks.

The impact of shore and riverbank erosion is particularly damaging to the navigation channels of our major water routes. The cost for dredging, relocating navigation aids, and using professional pilots can be charged in part to deposition of material in channels from riverbanks and shores. Federal dredging expenditures for channel maintenance average about $75 million each year for removal of deposition in our Nation's navigable waterways. Additional millions of dollars are spent dredging and cleaning diversion forebays and irrigation canals on western rivers. Farm land and undeveloped areas along many miles of riverbanks are subjected to considerable area loss but land values seldom justify large expenditures for preventive treatment. Estimated average annual land losses from riverbank erosion are given in table 5–6–1.

Rates of erosion of beaches may vary from an aggrading condition to a loss of several feet each year, depending on the hydrodynamics of the sea and the physical characteristics of the shoreland. The Maryland Geological Survey has found that the shores of the Potomac River estuary have eroded an average of .08 acre per mile per year during the past 100 years. The average annual lineal recessions varied up to 10 feet per year in the wider areas of the estuary. Estimates of average annual losses of land from beach and shore erosion are given in table 5–6–2.

Residential, recreational, and commercial developments are particularly vulnerable to recession of the shoreline. The losses experienced by the resort area of Cape May, New Jersey, clearly exhibit the effects of the flows of ocean storms and tidal currents. The town of Strathmere in Cape May County has, in recent years, lost a strip 15 blocks long and 2 blocks deep.

TABLE 5–6–1.—*Estimated average annual losses of land by riverbank erosion*

Region	Areas of significant erosion	Average land losses
	River-miles	*Acres/year*
North Atlantic	Not significant	Not significant
South Atlantic-Gulf	5,100	350
Great Lakes	Not significant	Not significant
Ohio	Not significant	Not significant
Tennessee	Not significant	Not significant
Upper Mississippi	Not available	Not available
Lower Mississippi	1,044	4,705
Souris-Red-Rainy	Not available	Not available
Missouri	1,692	5,000
Arkansas-White-Red	2,300	7,300
Texas-Gulf	1,698	1,045
Rio Grande	250	150
Upper Colorado	Not available	Not available
Lower Colorado	Not available	Not available
Great Basin	265	150
Columbia-North Pacific	13,500	1,300
California	2,600	3,837
Alaska	80,000	5,000
Hawaii	Not significant	Not significant
Puerto Rico	Not available	Not available

TABLE 5–6–2.—*Estimated average annual losses of land by erosion of beaches and estuary shores*

Region	Average annual land losses
	Acres/mile
North Atlantic	0.12
South Atlantic-Gulf	0.11
Great Lakes	0.07
Lower Mississippi	—
Texas-Gulf	0.27
Columbia-North Pacific	0.02
California	0.13
Alaska	0.06
Hawaii	0.24
Puerto Rico	—

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On the other hand, the movement of shore material may aggrade the beach in some places and thereby improve the situation. Also, the natural repair of beaches damaged by severe storms may occur as beach profiles adjust to changes in types of wave action.

The fishing industry suffers the effects of shore and river erosion in that the clay and silt particles carried from the shore and riverbanks discourage spawning of finfish and may adversely affect shellfish beds.

The annual national loss from beach and estuary erosion is estimated to be $24.5 million. National loss from riverbank recession and channel braiding and meandering has been conservatively estimated to be $40 million per year.

EROSION CONTROL PROGRAMS

Programs for abatement of shore and riverbank damages are limited by the prohibitive cost of effective measures. There has been considerable treatment by local governments and private landowners, but it is frequently of little permanent value. State and Federal programs are directed to areas of heavy public use and high density habitation where impressive property damage or potential damage to concentrated public investment assures that the protective works would be economically feasible.

Riverbank treatment has been practiced in many locations in this country, the more noteworthy being on the Mississippi and Missouri Rivers. Permeable dikes, riprap, jetties, training walls, and mattresses of various design are included in the measures employed to align and stabilize eroding riverbanks. The extent of such protection is given in table 5–6–3. Federal assistance for bank protection is provided where works for flood control and navigation are causative factors or are adversely affected.

Much of the beach protection endeavor is expended at recreation areas. Such areas, often situated along sandy beaches where the surf is most active, usually become permanent developments. Generally, they are located very close to the beach where they are particularly vulnerable to damage. It is, therefore, often difficult and expensive to provide suitable shore protection, and some treatment measures are objectionable to the aesthetics of a natural beach.

PROBLEMS AND TRENDS

With the increases in population and accompanying commercial and industrial activities as

TABLE 5–6–3.—*Extent of riverbank treatment* [1]

(Miles)

Region	Mattress	Jetties	Training walls	Riprap	Revetment	Dikes	Other	Total treated
North Atlantic	—	18	18	—	—	—	—	36
South Atlantic-Gulf	35	67	—	—	—	—	—	102
Great Lakes	—	—	—	—	—	—	—	—
Ohio	—	—	—	50	10	—	—	60
Tennessee	—	—	—	—	—	—	—	—
Upper Mississippi	—	—	—	—	—	—	—	—
Lower Mississippi	573	—	—	—	—	75	5,836	6,484
Souris-Red-Rainy	—	—	—	—	—	—	—	—
Missouri	—	735	—	—	735	—	—	1,470
Arkansas-White-Red	250	1	80	—	—	140	—	471
Texas-Gulf	0	0	0	0	0	0	0	0
Rio Grande	—	250	—	—	—	—	—	250
Upper Colorado	—	—	—	—	—	—	—	—
Lower Colorado	—	—	—	—	—	—	—	—
Great Basin	0	0	0	0	0	0	0	0
Columbia-North Pacific	—	—	—	261	—	—	—	261
California	—	—	—	—	—	—	19	19
Alaska	—	—	6	—	—	—	—	6
Hawaii	0	0	0	0	0	0	0	0
Puerto Rico	—	—	—	—	—	—	—	—

[1] Corps of Engineers projects only.

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now projected for the future, the preservation of physical, aesthetic, and recreational values of shorelines and riverbanks is becoming a problem of significant proportions. The nature and extent of this problem is not expected to change materially, but the increased need for corrective measures will be felt. The increased social and economic activities in these areas will be important.

In order to develop patterns of coastal and riverbank occupancy, an appraisal has been made of the rates of development along beaches and waterways. Although modern transportation renders distance to the beach less critical, table 5–6–4 shows that people prefer to settle in close proximity to the water. This preference, with its attendant increase in property values, will require more shore and bank treatment to protect these areas.

Trends in weather modification research indicate the possibility that destructive storms may be diverted from our rivers and coastlines or reduced to less harmful intensities.

Technical and financial assistance will become more accessible to the private landowner and small businessman so that he may protect his property from the ravages of riverbank and shore erosion.

Because of excessive costs of protection, it will be even more desirable in the future than it is now to restrict or discourage use of land that is unstable and unsuitable for urban development. The trends to basinwide land-use planning could be extended to include developmental zoning of our shorelands. It is likely that zoning should be interspersed with protective measures. Many problems of the coastal community could be averted by such planning.

A national program of appraisal and data collection is needed to provide up-to-date quantitative as well as qualitative information. Synoptic aerial photography coordinated with the environmental setting would show relative positions and movement of shorelines and rivercourses. More comprehensive data must be obtained on tides, currents, waves, winds, and other physical and climatological factors pertaining to lakes, estuaries, and oceans. In addition, data must be collected pertaining to the mechanics of riverflows; measurement of suspended sediment at intervals would show net transport from a given reach or drainage basin. There is a need to know more accurately the extent of the problem, and the costs required for treatment programs. The opportunities for productive research in this field are great.

TABLE 5–6–4.—*Annual rates of population growth for Atlantic and Gulf Coast and riverbank areas of the conterminous United States*

(Percent)

Distance to water edge	1940 through 1960	1960 through 1980	1980 through 2000	2000 through 2020	1960 through 2020
Beach-Estuary:					
0 to 1 mile	4.9	2.9	2.8	1.9	3.3
1 to 5 miles	3.0	2.4	2.1	2.4	2.7
5 to 20 miles	1.8	1.7	2.3	1.7	1.9
Riverbank:					
0 to 1,000 feet	2.2	1.9	1.8	1.6	2.1
Total United States	1.5	1.6	1.6	1.6	1.6

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CHAPTER 7

Land Drainage

INTRODUCTION

Wetland as used in this chapter, is land on which excess water is a limitation to some of its potential uses. Land drainage is the removal of water from wetland; and the need for drainage depends on the intended use of the land. Additional information on land use is contained in chapters 5 and 8 and in chapter 3 of part 3.

In the early years of the development of the United States, there was a great need for increasing agricultural production. Millions of acres of the Nation's land were wetlands. The most fertile of those occurring in river and stream bottoms, coastal and lake plains, and upland prairies, were easily accessible; yet their use for agriculture is limited because of excess water. Recognizing the need to increase the Nation's agricultural production in the 19th century and to promote the development of wetlands, Congress passed the Swamp Land Acts of 1849, 1850, and 1860, which conveyed approximately 64 million acres of swamp and overflow land to 15 States. Many of these lands have been drained and are now among the most productive in the country. In addition, flood control and other major storage reservoirs on major rivers permitted agricultural development of fertile alluvial valleys subject to seasonal overflow.

The wetlands of the United States have undergone a century of drainage and agricultural development since passage of the Swamp Land Acts. It was only recently realized that undisturbed marshes, swamps, and overflow lands have a variety of aesthetic, environmental, and recreational values and a significant complex relation to their biotic communities. Some of these values are tangible and can be expressed in economic terms. Others are entirely intangible, but have become increasingly important to our modern society. These values are more fully discussed below and in chapter 7 of part 4.

CURRENT AND POTENTIAL USES OF WETLANDS

In the National Inventory of Soil and Water Conservation Needs, at least 238.2 million acres were classified as wetlands in 1958 (table 5–7–1). This acreage includes pasture and range needing treatment. The Inventory includes Federal lands that produce crops, but excludes other Federal lands, urban and builtup areas, and water areas. Nearly 84 million acres of crop and pastureland need some drainage improvements for full realization of their agricultural capabilities. The area of forest land on wet soils that could be improved silviculturally by drainage improvements has not been determined.

These millions of acres of wetlands, most of which are privately owned, have soils that would be highly productive agriculturally if adequately drained. As the Nation's needs for food and fiber increase, agricultural use of these lands may

TABLE 5–7–1.—*Land use and drainage potential, non-Federal rural land, United States, 1958*

(Thousands of acres)

Item	Total land	Wetland	Land needing drainage for agricultural purposes
Cropland	447,700	112,500	72,500
Irrigated cropland in western regions	(33,800)	(7,400)	(5,200)
Pasture-range	485,400	11,200+	11,200
Forest	452,700	98,800	[1]
Other land [2]	67,000	15,700	2,400
Total [3]	1,452,800	238,200+	86,100+

[1] Not available.
[2] Farmsteads, wildlife areas, recreation areas, idle land, and other land not used as cropland, pasture, range, or forest.
[3] Does not include urban and built-up areas, or water areas.

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become economically feasible. It is fortunate that the United States has this wealth of potentially productive land which can be brought into production.

The value of many wetlands in their natural state lies in the commercial and recreational value of the fish and wildlife they support. Most species of waterfowl and many fur animals are totally dependent upon wetland environments for their survival and well-being. Many marine, estuarine, and freshwater fishes of sport and commercial importance also depend on wetlands during part or all of their lives. As these creatures become less abundant, modern man often places a higher value on them; and wetlands become worth more than anything he can put in their place. The value of the wetlands in their natural state for compatible use, including water storage, stabilization of runoff, prevention of erosion, creation of firebreaks, production of timber, hay, wild rice, blueberries, cranberries, and peat moss, must also be recognized and appropriately evaluated.

As the result of a growing and shifting population, demands are being placed on wetlands for urban expansion, agricultural production, wildlife habitat, and recreation. These demands often conflict. The optimum use of these lands, consistent with their capabilities and the needs of the Nation, should be the criterion for resolving these conflicts. National policy regarding use of wetlands should undergo periodic reevaluation to give due consideration to changing needs.

DRAINAGE FOR AGRICULTURAL PURPOSES

During the past 20 years, land has been drained for agriculture chiefly to increase production and to reduce the cost of production on land already in cultivation or pasture. Some of the benefits of better land drainage in terms of agricultural use are the following: (1) Improved soil structure—aggregation of soil particles improves conditions for aeration and water supply to crops, (2) better utilization of available moisture—improved infiltration rate and permeability of soil provided tillage is done properly, (3) accelerated and improved microbiological processes—aerobic nitrogen fixation and decomposition of organic matter, (4) less compaction of soil from more effective tillage, (5) improved soil salinity control—downward movement of salts is improved and buildup in the rootzone prevented, and (6) deepened rootzone—an increased supply of nutrients is consequently available to the plant, and fertilizers are more effective.

Where there is a need for more agricultural production, land, which has previously been too wet to farm but is otherwise suitable for crop or pastureland, may be drained and brought into production. This is land reclamation, and it may be desirable from a national, regional, or local viewpoint. Estimates of the production increases that could be obtained from drainage improvements and land use conversions were published by the Senate Select Committee on National Water Resources in December 1959, and are presented in table 5–7–2. At present, policy does not permit Federal assistance to individual landowners for drainage improvements that would bring new lands into production, because there is already an excess capacity in agriculture.

Most irrigated land needs improved drainage. Improvement may range from smoothing the surface to prevent ponding, to construction of a

TABLE 5–7–2.—*Projections of drainage potential on lands suitable for cultivation* [1] [2]

Land use	Land subject to conversion to cropland [3]	Land conversion requiring drainage [4]	Existing cropland requiring drainage [4]	Value of increased output [4] [5]	
				1980	2000
	Thou. acres	*Thou. acres*	*Thou. acres*	*Mil. dol.*	*Mil. dol.*
Forest land	107,800	24,700	—	1,917.8	2,222.6
Grassland	110,800	10,100	—	630.1	829.6
Cropland	—	—	42,800	1,325.1	1,935.2
Total	218,600	34,800	42,800	3,873.0	4,987.4

[1] Committee Print 12, Senate Select Committee on National Water Resources, December 1959.
[2] Lands in USDA capability classes I-III.
[3] Conterminous United States.
[4] Eastern United States.
[5] Measured as increased feed production in 1947-1949 dollars.

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complete surface and subsurface drainage system. Good drainage practices are essential to proper irrigation water management. In humid areas where irrigation is used to supplement rainfall, adequate drainage facilities are needed to prevent waterlogging of the soil profile and excessive ponding when a rain directly follows an application of irrigation water. In arid and semiarid irrigated areas, the surface drainage systems may be simple and are usually included in preparations for delivery of irrigation water. The subsurface drainage improvements are usually more complex.

Control structures and pumps often permit ditches to be used as both irrigation canals and drainage ditches. Where water quality is suitable, return flows can be reused, and ditches can be used as storage reservoirs for low flows. Agricultural landforming practices are adapted for better utilization of rainfall, better irrigation water management, and more uniform drainage. The agricultural water management system should be planned to lower the cost of production with due regard to the capabilities of modern farm machinery.

DRAINAGE FOR OTHER PURPOSES

Land drainage may have many purposes other than agricultural. Forest managers have been applying drainage practices to their lands at a rapid rate, sometimes without regard to the consequences. The effect of drainage on hardwood timber stands varies according to species—it is detrimental to the growth rate of swamp and bottom land hardwoods, but increases the growth of other species. On wet pine sites, the production of pine timber is usually improved with drainage. However, on many pine-hardwood sites, drainage increases the growth rate of less desirable hardwood species to the detriment of the pine. Studies have shown that significant growth increases may be possible with adequate drainage on certain wet pine lands in the southeastern coastal plain. Pulpwood yields on many wetlands throughout the coastal plain can be nearly doubled by drainage.

Land drainage facilitates construction and maintenance of roads, railroads, urban areas, airports, parks, and recreation areas. Reclamation of wetlands often provides new lands for developments such as these at the lowest short-term cost, but the long-term economic cost to the public may be less favorable.

The elimination of mosquitoes by land drainage and other means of control is of great importance to the health and welfare of the Nation. There are still some parts of the United States where the Anopheles mosquito, a vector for malaria, is common; and periodically other Culex mosquitoes spread encephalitis to humans and animals in the United States. Mosquitoes also transmit anaplasmosis, fowl pox, and various other diseases to animals. They cause serious economic losses by lowering beef and milk production, reducing the efficiency of agricultural and industrial workers, interfering with recreation enterprises, and lessening the value of real estate.

In some areas, drainage facilities have been constructed for which adequate outlets were not available. This resulted in improper functioning of the drainage system and, in some cases, in higher downstream water stages. Prior to construction of drainage facilities, outlets should be found capable of handling expected discharges without causing significant damages above or below the points of discharge.

Construction of flood control levees often changes drainage patterns, causing seepage and ponding. Navigation projects involving increased river stages can result in similar problems. In both cases, drainage measures in affected land may be needed.

PRESENT DRAINAGE DEVELOPMENT

The 1959 Census of Agriculture, Volume IV, Drainage of Agricultural Lands, presents data for 8,461 drainage projects, each of which consists of 500 acres or more of agricultural land. Drainage measures in these enterprises range from the minimum requirement for agriculture to completely adequate drainage systems. Approximately 92 million acres of land in 39 States have been drained for agricultural purposes. It is estimated that another 39 million acres of land have been drained by individual farmers and by groups of farmers in enterprises with less than 500 acres of agricultural land.

Improvements reported in the 1959 census include approximately 189,000 miles of open ditches, 58,500 miles of tile drains, 9,800 miles of levees and dikes, and 3,400 pumping units. These improvements represent an investment of approximately $1.3 billion. About one-third of the total investment, or $42 million annually, was spent in the decade 1950–1959.

Under certain conditions the Soil Conservation Service assists individual farmers as well as groups of farmers with drainage improvements. In fiscal year 1966, this program assisted in the

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installation of 12,720 miles of drainage ditches, 25,553 miles of tile drains, 250 miles of dikes and levees, and 1,939 pumping plants. These facilities are estimated to have cost about $113.8 million.

Because there is some overlap between the census and the Soil Conservation Service figures for the cost of drainage operations, the figures are not additive. It is estimated, however, that the total investment in drainage facilities for group enterprises and individual landowners currently averages between $125 million and $150 million annually.

In addition to this, the Corps of Engineers and the Bureau of Reclamation do a considerable amount of drainage work each. The Corps of Engineers' work is related to flood control operations and involves major drainage channels and large pumping plants. The Bureau of Reclamation's drainage operations are in connection with large-scale irrigation developments in the western part of the Nation.

As drainage projects involving more than one landowner usually require some type of coordinating organization, most States have laws governing such organizations. In general, the objectives of these laws are to provide for effective cooperation in the planning, financing, constructing, operating, and maintaining of drainage projects.

The old concept of considering flood control, drainage, and irrigation of land as separate projects is gradually being replaced with the concept of multipurpose development of water and related land resources. This involves an inventory of all available resources and existing and potential problems and the development of a coordinated plan that will include both the maximum utilization of resources and the alleviation of problems.

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CHAPTER 8

Wilderness and Free-Flowing Rivers

INTRODUCTION

Throughout the Nation there is a growing demand for preservation and restoration of the natural environment. During the 19th and early 20th centuries, great areas of wild lands were cleared for farms, industries, and towns; other large areas were logged by crude methods and were carelessly burned afterward; natural range lands in the west were often subjected to destructive overgrazing. Many of these destructive practices have been abandoned and Nature has made giant strides in healing the scars. But a rapidly increasing population and new forms of carelessness still ravage the environment.

As our society becomes more affluent and leisure time increases, more and more people seek the remaining wild lands for primitive and unconfined recreation and inspiration. Because these areas serve scientific, historical, recreational, and inspirational purposes, positive steps are being taken for their preservation and for the management measures needed for their best use. Such preservation will certainly affect water and related land resources development in the future.

The natural environment means many things to different people. To an urban native, a 10-acre patch of woods in the suburbs may be a wilderness. To most people, the natural environment includes the many millions of acres in the public domain, the National Forest System, the National Park System, State forests and parks, together with extensive areas of farmlands and privately owned forests and all manner of other lands. To the purist, wilderness has a much more restrictive meaning that will be defined in detail later.

Not all of these forms of the natural environment are sufficiently water related to be discussed in this chapter. Wilderness and free-flowing streams will be examined in some detail as both are significant in the planning of water resources developments; the first constitutes an important source of water yield, and the second provides for unregulated transport of water toward points of use.

ECOLOGICAL CONSIDERATIONS

Protection and management of wilderness areas and free-flowing rivers are important requirements for achieving a balanced program of preservation of water resources. More broadly, however, there are requirements for recognizing ecological relationships among the various elements of water uses, and among water and related land resources.

For instance, the efforts at preservation of a free-flowing river may be disrupted by upstream pollution or unwise mainstream or upstream watershed developments that adversely influence the biotic balance of the affected area. Modification of even a single element within a natural community may seriously affect the ecological system on which the quality of a free-flowing river or a wilderness is dependent.

In a more general context, ecological balance and aesthetics should be accounted for in all water and related land resources planning, development, and management. The key interdependencies of water, land, and the biotic community need to be understood, and the results of water developments, such as dams, dredging, and wetland drainage on these factors, evaluated. Without this integrated approach to water planning, losses to wildlife, plant communities, scenery, timber resources, soils and watersheds will occur, bringing unforeseen consequences to the natural environment. In recognition of these interdependencies, the Council in its planning policies and procedures has provided for full consideration of and reasoned choices between the objectives of resource development, well-being of people, and preservation. Preservation is used here in its broadest sense. It means preservation, restoration, or enhancement of the quality and liveability of the environment, and these in turn are dependent on the wise management of an area's natural ecology.

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WILDERNESS

Definition of a Wilderness

The National Wilderness Preservation System was created by Congressional Act, September 3, 1964. The Act defined a wilderness as follows:

A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrampled by man, where man himself is a visitor who does not remain. An area of wilderness is further defined to mean in this Act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, education, scenic, or historical value.

Extent of Wild Areas and Wilderness

To date, 9.1 million acres of National Forest land (8 million of which are in the Western States) in 54 areas have been designated as Wilderness and included in the National Wilderness Preservation System. The Wilderness Act requires that additional land areas totaling 49 million acres be studied by the Forest Service, National Park Service, and Fish and Wildlife Service as to their suitability or nonsuitability for inclusion in the Wilderness System. These studies are under way and will be completed by 1974. The Bureau of Land Management is also studying lands of the public domain for their possible inclusion in the System. (See table 5–8–1.)

All of the designated areas and those under review are within the 766 million acres of Federally owned lands in the United States—many are in Alaska where half of the Federal lands are located. No lands may be added to the National Wilderness Preservation System except by specific act of Congress.

Much of the land under review by the National Park Service, Bureau of Sports Fisheries and Wildlife, the Forest Service, and the Bureau of Land Management is presently managed under regulations that preserve many qualities of the land in its primitive natural state. For any land area included in the National Wilderness Preservation System, there is even greater assurance that its natural uninhabited character will be preserved for future generations.

Other lands are owned and managed as wilderness by States and private interests. These lands include New York State's Adirondack and Catskill Forest Preserve areas, which embrace a total of 2.5 million acres. Baxter State Park in Maine is another example. Nonprofit organizations and universities also manage areas to retain the natural environment, often for scientific purposes. Timber industries and other corporations have holdings that include high-altitude lands and other areas that are retained in a primeval condition.

TABLE 5–8–1.—*Area of Federal lands included in and being investigated for inclusion in National Wilderness Preservation System*

Agency	National Wilderness Preservation System			
	Areas presently included		Areas being investigated	
	No.	*Mil. acres*	*No.*	*Mil. acres*
Forest Service	54	9.1	34	5.5
Fish and Wildlife Service	0	0	90	22.5
National Park Service	0	0	57	21.0
Bureau of Land Management	0	0	61	[1] 5.0
Total	54	9.1	242	54.0

[1] Not designated for study by the Wilderness Act. However, they have been identified for special consideration by the Bureau of Land Management.

Trends in Areal Extent

The extent of areas suitable for inclusion into the system is decreasing with increases in population and economic development. As this has been occurring, however, there has been increased support for the preservation of such areas in the public interest. These may not necessarily be preserved as wilderness. By 2020, it is likely that 20 to 30 million acres of land within the conterminous United States will be preserved under the Wilderness Act, in addition to extensive portions of Alaska.

Trends in Use

Improved primary, secondary, and tertiary road systems along with improved public and

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private transportation facilities now bring people from population centers to the doorstep of the wilderness. Lightweight camping gear and dehydrated food encourage wilderness experiences. While most use of wildernesses presently occurs in the summer and fall, there is a growing interest in winter use. The existing 54 units of the National Wilderness Preservation System were used 3,129,000 visitor-days in 1965 and 3,341,000 in 1966. By 2020, the use may reach 30 million visitor-days.

Management and Use of Water

It is expected that public lands placed within the National Wilderness Preservation System will continue to be managed by the present agencies having jurisdiction of these lands in conformance with the wilderness concepts established by the 1964 Act. Once a Wilderness has been designated, the natural conditions of the encompassed watersheds are essentially preserved. This, coupled with simple facilities for public use, tends to reduce man-made pollution problems, and to preserve natural runoff conditions. Such preservation prevents management for increased water yields and development of water control structures. It may act as a constraint upon water resources development, but it does not eliminate future consideration of necessary management and developments.

For the lands of the National Wilderness Preservation System administered by the Forest Service, the objectives of water management are to maintain and, where possible, improve soil cover-water relationships; to control activities so as to avoid pollution; and to harmonize water resources development projects with land management insofar as these are possible and compatible with wilderness objectives. The latter will preclude use of usual water-yield improvement techniques. Watershed restoration within Wildernesses may be undertaken where deteriorated soil and hydro-ecologic conditions caused by man or his influences create a serious threat to the wilderness resource; or where these conditions regardless of origin, threaten life, property, or the environmental quality outside of the Wilderness. Overland motorized equipment will not be used in restoration activities except in very special cases where it is justified by seriously threatened, high downstream values. New water-regulating structures, power installations, and related improvements within Wildernesses are subject to approval by the President—"upon his determination that such use or uses in the specific area will better serve the interests of the United States and the people thereof than will its denial . . ." (P.L. 88–577). Increasing storage capacity or replacing a reservoir not under a valid permit will be considered as a new water-regulating structure. Water prospecting, defined as drilling or digging to locate underground supplies, must also be approved by the President. If the storage capacity is not increased, reconstruction or change in the size or type of an existing installation merely requires the approval of the Chief of the Forest Service. Water will be utilized within Wildernesses for fishing, hunting, boating, swimming, wildlife, and other purposes compatible with management for preservation of the wilderness resource.

The Forest Service is managing 5.5 million acres in the 34 designated National Forest Primitive Areas to preserve their wilderness values. Water resources in Primitive Areas are managed under guidelines similar to those spelled out in the Wilderness Act. These Areas are being investigated for possible addition to the National Wilderness Preservation System.

The Fish and Wildlife Service manages National Wildlife Refuges for the preservation and restoration of wildlife environment in the national interest. Management results on some refuges are similar to those achieved in areas of the National Wilderness Preservation System inasmuch as the wild natural character of refuge areas is preserved. Usually, with refuge management, the natural runoff is preserved; although in some areas minor reductions occur due to the increased extent of wetlands or water-surface areas.

Historically, vast areas of the National Park System have been managed and administered by the National Park Service in line with the concepts expressed in the Wilderness Act. It is a fundamental tenet of national park management that where the past use of resources in an area has impaired wilderness qualities of that area, the national parks will discontinue such uses and restore the wilderness character. Thus, favorable conditions for natural, high water yield exist in many national parks and monuments. The National Park Service has developed wilderness management criteria which, among other things, do not permit water development projects within wild areas. Demographic, technologic, social, or economic changes or trends are not supposed to influence these Park System policies or the criteria. However, with the increase in pressures from these sources, there may be justification for supplemental protection of natural and historical land areas within the Park System

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from uses inconsistent with those for which they were originally reserved.

Water and related land resources development in wilderness areas within the public domain would be prescribed by proposed legislation before Congress. At the present time, no such lands have been designated; but should they be, the Bureau of Land Management will formulate wilderness management regulations unless overriding legislation is passed. It is expected that the objectives and practices designated by the Bureau will be similar to those designated by the Forest Service that pertain to National Forest lands in the Wilderness Preservation System.

In addition to Federal agencies, some States and localities manage small portions of their forest, public park, fish and game, and other conservation lands for purposes similar to those spelled out in the Wilderness Act.

FREE-FLOWING STREAMS

The Federal Interest

There is growing realization that the public interest is served by reserving some rivers or reaches of rivers in their free-flowing and unpolluted condition. Recreationists, such as fishermen and canoeists, look to free-flowing water for a unique kind of outdoor challenge. In 1962, the Outdoor Recreation Resource Review Commission recommended that certain rivers of unusual scientific, aesthetic, and recreation value be maintained in their free-flowing state and natural setting without man-made alterations. In 1964, the Wild Rivers Study identified certain rivers (fig. 5–8–1), that were considered to be valuable as essentially free-flowing rivers, and it proposed plans for the protection and management of these rivers and adjacent lands. Based on this study, legislation to establish a nationwide system of Scenic and Wild Rivers has been recently enacted (PL 90-542).

Scenic and Wild River designation would serve to protect the scenic and recreation qualities of a river area—both the streamflow and the adjoining lands. Normal rural activities along the river, such as farm and ranch operations, are compatible with the concept. So are timber-harvesting operations, water-use facilities, recreation development, and access construction where these activities are planned and conducted in a manner that does not substantially interfere with the free-flowing nature, water quality, or scenic value of the stream. Incompatible activities are those that would destroy these stream qualities, such as dam construction and channelization, and those that would disrupt the land related to the stream, such as residential or industrial development that would adversely affect the scenery as viewed from the river.

In 1964, the Congress established the Ozark Scenic Riverway (Current River, Missouri) and its related adjoining lands as a unit of the National Park System. Other Federal land management agencies are making the protection of scenic and recreation qualities of streams a policy in their planning and management programs. The Forest Service currently protects and manages over 84,000 miles of streams and streamsides, prescribing management suitable to the resource values involved. The Bureau of Land Management also has established scenic and recreation protection zones along streams. Several National Wildlife Refuges include river reaches having potential for inclusion in a system of free-flowing streams.

State and Private Efforts

Many States are actively engaged in efforts to safeguard the recreation and natural qualities of their rivers. The outdoor recreation plans of 21 States recognize the need to preserve segments of streams in their free-flowing condition; 14 States have recommended a total of 106 segments for preservation. Kentucky alone has identified 34 segments, totaling over 1,000 miles. The States of California, Maine, Missouri, Montana, New York, Oregon, Washington, and Wisconsin either have passed laws for stream preservation or have legislation under consideration. The Allagash Wilderness Waterway in Maine and a protection program for a 60-mile segment of the Wolf River in Wisconsin are two notable actions for scenic river preservation taken at the State level with Federal assistance in the form of grants from the contingency reserve of the Land and Water Conservation Fund.

A major share of efforts to protect rivers has necessarily been limited to government bodies because of the nature and complexity of the problems involved. Notwithstanding, a number of private landowners, especially utility companies and forest product industries, have maintained the scenic and wild character of streams as a matter of policy. Such groups have preserved segments of the St. Croix River in Minnesota and Wisconsin, and the Allagash River in Maine. Indian tribes are also supporting efforts to maintain the wild character of streams. The Pueblo Council, for example, is now considering

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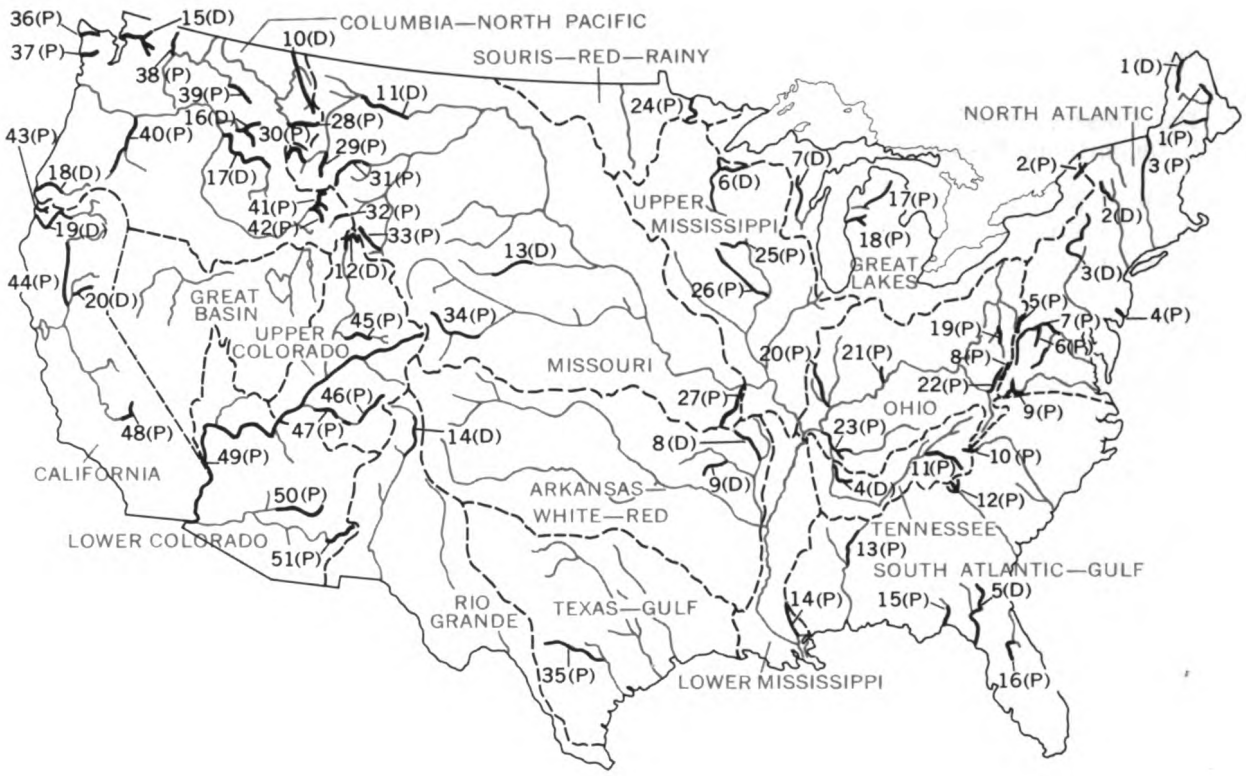

EXPLANATION

(P) Rivers receiving preliminary study;

1 Penobscot
2 Ausable
3 Connecticut
4 Mullica
5 Youghiogheny
6 Shenandoah
7 Potomac
8 Cacapon
9 James
10 Linville
11 French Broad
12 Savannah
13 Black Warrior
14 Tangipahoa
15 Wacissa
16 Oklawaha
17 Manistee
18 Pere Marquette
19 Cheat
20 Little Wabash
21 Blue
22 Greenbrier
23 Cumberland
24 Big Fork
25 Upper Iowa
26 Wapsipinicon
27 Gasconade
28 Blackfoot
29 Madison
30 Big Hole
31 Yellowstone
32 Gros Ventre
33 Wind
34 Cache La Poudre
35 Guadalupe
36 Hoh
37 Queets
38 Methow
39 St. Joe
40 Deschutes
41 Snake
42 Teton
43 Smith
44 Sacramento
45 White
46 Animas
47 San Juan
48 Kern
49 Colorado
50 Salt
51 Gila

(D) Rivers receiving detailed study;

1 Allagash
2 Hudson
3 Susquehanna
4 Buffalo
5 Suwannee
6 St Croix—Namekagon
7 Wolf
8 Eleven Point
9 Buffalo
10 Flathead
11 Missouri
12 Green
13 Niobrara
14 Rio Grande
15 Skagt
16 Clearwater
17 Salmon
18 Rogue
19 Klamath
20 Feather

FIGURE 5–8–1.—*Potential scenic rivers investigated in Wild Rivers Study, 1964.*

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the inclusion of the Taos Pueblo lands bordering the Rio Grande in a Scenic River proposal.

The Present Situation: A Diminishing Resource

Although it is estimated that there are more than 3 million miles of streams in the United States, most are too small to serve the primary objectives of the free-flowing stream concept. There are, for example, only about 725 streams with a total length of 100,000 miles that have a minimum flow of at least 550 cfs. This rate of flow is considered to be the minimum desirable rate for the expected types of scenic river recreation activities. This group includes over 90% of the rivers investigated in the Wild Rivers Study.

Competition for water use and development on these 725 streams is increasing. Most major water development projects are located on them, and many commercial developments are located on adjacent lands. Many of these rivers are subjected to daily deposition of large quantities of domestic and industrial wastes. As a result, only a limited number are still relatively free-flowing and with an otherwise pleasing environment. In most cases, only portions of rivers would still qualify for consideration as Scenic or Wild Rivers. Growing demands for water will require increased development of streams which in turn will reduce opportunities for preservation and management of rivers in their free-flowing state.

Outlook for the Future

Free-flowing rivers add an important dimension to the total outdoor recreation picture. They are often less accessible than other forms of recreation areas and appeal to those who seek enjoyment and relaxation in activities away from the usual crowds. However, the number of people who regard them as a primary source of enjoyment for boating, fishing, water-fowl hunting, and camping is increasing.

Streams must be studied before they can be considered for Scenic and Wild River or other protective status. These studies can both evaluate the potential of the river in its free-flowing condition, and compare this potential with those of alternative uses. In addition to providing the basis for possible future free-flowing river development and protection plans, these studies should be an integral part of comprehensive water and related land resources planning. In this connection, a better methodology is needed for comparison of the benefits of scenic river status with benefits of alternative resource development uses. Qualified streams must be identified and evaluated during early stages of river basin planning if they are to be successfully dedicated to this use.

Any adequate program for the protection of free-flowing rivers and streams must be a joint public-private effort. Federal efforts should be directed at those river segments that are sufficiently important to attract visitors from several States or the entire Nation. State and local governmental efforts should be directed toward those rivers that are of less than regional or national significance. The private sector is also capable of protecting valuable sections of certain streams and should be encouraged to do so when possible.

The Scenic and Wild Rivers program must be integrated into the overall national water use and development program so that a reasonable balance is struck between management which develops and controls the water resource, and management which preserves the free-flowing, scenic, and ecological qualities of the stream.

The management of an individual stream or segment of stream as a scenic river should take into account all the inherent qualities that make the resource valuable for recreation and aesthetic purposes. In some instances, general recreation use will be possible. In other instances, use will have to be controlled so as to guarantee the quality of the recreation experience. Management will vary from the type that permits a wide range of recreation uses to that which is designed to perpetuate the natural and scenic values associated with wild areas.

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CHAPTER 9

Institutional Arrangements

INTRODUCTION

It is apparent from the preceding chapters in this National Assessment that water and related land resources constitute a complex system which responds to the actions of both man and nature. Management is the process of controlling this system and includes the planning, development, and operation of water and related land resources projects and programs. Any significant water use or water or land management program affects one or more uses or water problems and in turn is affected by them. Upstream activities determine the limits within which downstream activities may be carried out. Atmospheric, surface, and underground waters are continuously interrelated in the hydrologic cycle. The quality of water is inseparably conditioned upon quantity, and quantity cannot be divorced from quality for purposes of any meaningful beneficial use. Actions taken in one river basin may affect the water situation in other basins, either directly by the physical transfer of water or indirectly through the allocation of economic resources or the stimulation of political concerns. The following figure 5–9–1 constitutes one portrayal of a water resources system including many of these interrelationships in schematic form.

No assessment of the national water situation is complete without some discussion of the institutional processes by or through which water management functions. This chart primarily describes physical or hydrologic relationships, although it also suggests the important mutual interdependence of physical results with regional and national economic activity. No attempt is made in the chart to portray the all-important human dimension of the system. In addition to hydrologic, technical, and economic factors, the factor of human beings working through human institutions is also determinative in the water equation. These institutional considerations include such diverse matters as Federal, State, and local law; the form and powers of water organizations; financial arrangements; public attitudes; political traditions; and the like.

It is not possible within the scope of this chapter to describe and assess all of the institutional arrangements that bear upon water management. Nor could the task be undertaken with any assurance of accuracy and completeness even if time and space allowed, because the study, evaluation, and development of institutional arrangements has not kept pace with our national progress in understanding the technical aspects of water development. It is the purpose of this chapter, therefore, to discuss briefly several of the important topics and current developments in the institutional dimension of water management. It is expected that this subject will be given much fuller treatment in subsequent national assessments.

OPERATIONAL ORGANIZATIONS

It is helpful to begin a discussion of institutional arrangements in water management by describing briefly those existing organizations and entities which actually develop and administer operational programs—as distinguished from regulatory, planning, research, advisory, and financial assistance functions—and to indicate their relative contribution in the national water picture. It is these bodies that today largely determine the physical availability, quantity, quality, location, and price of water for beneficial use. Changing objectives in national water policy can be implemented either through them by changing their roles or their powers or through new organizational arrangements.

The Public Sector

Water management operations are carried out by all levels of Government and by private enterprise. At the Federal level, the U.S. Army Corps of Engineers constructs, operates, and maintains single-purpose and multiple-purpose dams and other facilities on most of the Nation's navigable rivers for flood control, navigation, hydropower, water supply and other purposes; harbor im-

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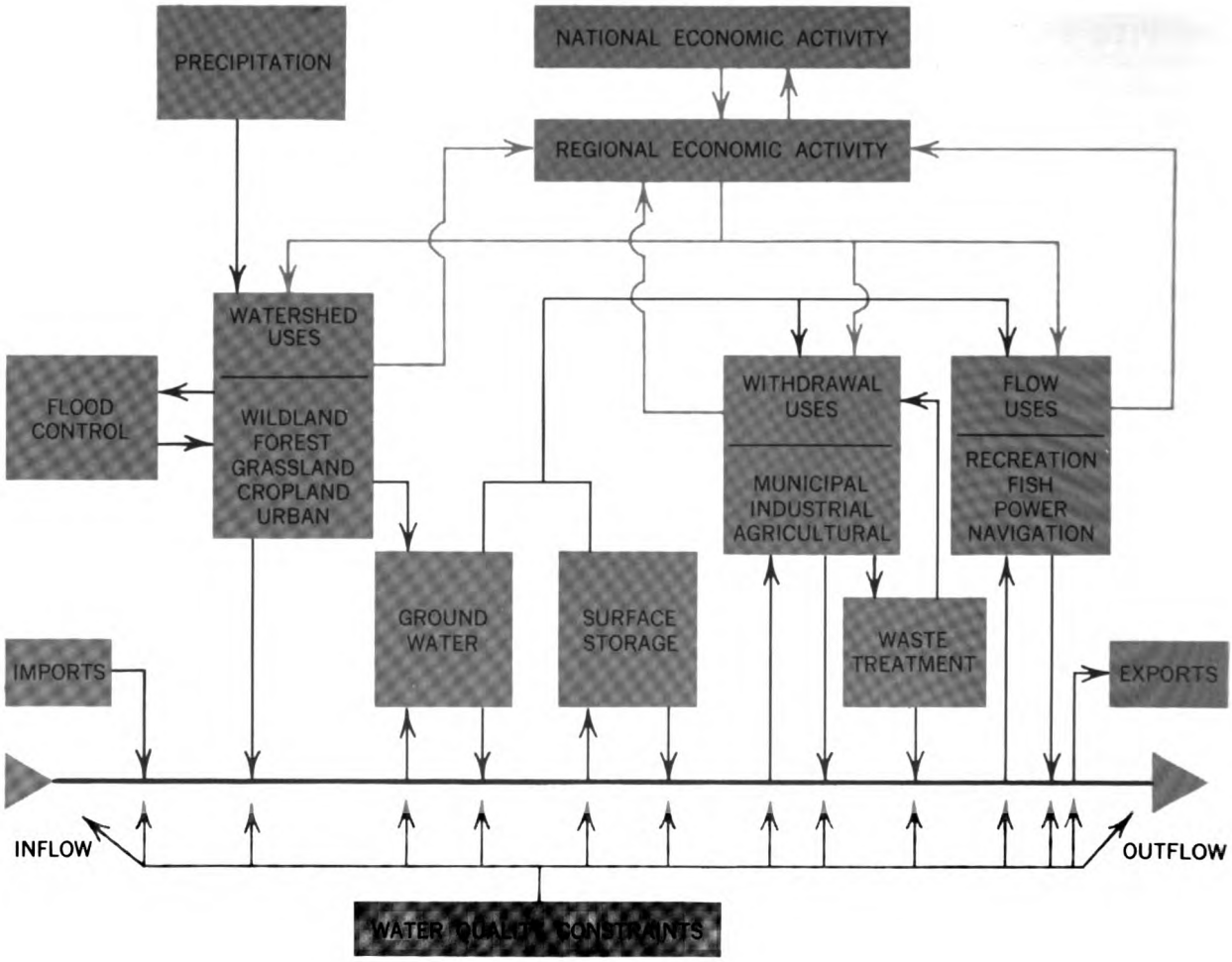

FIGURE 5–9–1.—*Schematic diagram of a water resources system.*

provements, including dredging; and shore erosion, hurricane protection, and other works on the coastal and major inland shorelines. The Bureau of Reclamation in the Department of the Interior constructs, operates and maintains multiple-purpose dams and irrigation distribution and drainage systems in the 17 Western States. The Soil Conservation Service of the Department of Agriculture constructs structural works of improvement, which are operated and maintained by cooperating non-Federal organizations, in 11 watersheds and assists such organizations in similar watershed improvements elsewhere. Watershed lands owned by the United States are administered by the Federal land management agencies, which include the Forest Service (national forest system) of the U.S. Departament of Agriculture; the Bureau of Land Management (public domain), National Park Service (national park system), and Bureau of Sport Fisheries and Wildlife (wildlife refuges and games reserves) of the U.S. Department of the Interior; and the Department of Defense (military reservations). The Bureau of Indian Affairs of Interior assists the various Indian tribes in the management of Indian reservations. The Tennessee Valley Authority, an independent Federal corporation, manages an extensive system of dams and other structures in the Tennessee River valley and continues to develop water-related programs. Other Federal agencies are involved in a variety of water management operations of lesser impact.

At the State level, all of the States carry out watershed management operations through the administration of State forests, parks, and other conservation lands. Most of them have also developed water facilities for recreation and fish and wildlife enhancement. A few States have undertaken the construction and operation of facilities for the storage, conveyance, or treatment of water. One notable example is the multibillion dollar California Water Plan under which water rising in the northwestern por-

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tion of the State will be stored and transported more than 400 miles to the large metropolitan markets in the arid southwestern area. Other States have entered the field in a more limited way or are making plans to do so.

At the level of local government, municipalities have played the dominant role in village and urban areas in providing water supply and in the removal and treatment of sewage and storm runoff. In many cases they have constructed single-purpose or dual-purpose reservoirs, often at a considerable distance from their corporate boundaries, to provide hydroelectric generation and/or municipal water supply.

In addition to the operational activities of individual municipalities, there are more than 10,000 special districts established under State law and authorized to plan, build, and operate local projects of one or more types. Their boundaries may be coterminous with a county, be smaller than a county, or include all or parts of several counties. The 1967 Census of Governments reported single-function districts as follows: drainage, 2,193; flood control, 656; irrigation, 896; sewage, 1,220; and water supply, 2,112. There are about 3,000 soil and water conservation districts. Some of the more notable early works in flood control and multiple-purpose water development were carried out by conservancy districts such as the Miami and the Muskingum Watershed Conservancy Districts in Ohio. Multiple-function districts include 292 that deal with both sewage and water supply and 44 that have both natural resources and water supply functions.

A number of organizations have been created by interstate compact, which in varying degrees have operational programs relating directly to water and related land resources. The Federal-interstate compact creating the Delaware River Basin Commission involves, potentially, the most far-reaching operational responsibility.

At the international level, the International Boundary and Water Commission, United States and Mexico, has built or is building two major dams on the Rio Grande. The Commission is also building a new sewage treatment plant for Nogales, Arizona, and expanding the plant at Douglas, Arizona. The St. Lawrence Seaway Corporation operates the international navigation facilities on the St. Lawrence River.

The Private Sector

Water management activities in the private section exhibit considerable diversity in scope and purpose. They range from the drilling of a single well by a rural or suburban homeowner to provide a water supply for household needs to the installation of expensive ground- and surface-water production, conveyance and treatment facilities to serve a large industrial complex; from the bulldozing of a small farm pond for livestock watering to the construction of a large dam for the generation of hydroelectric power and other purposes. Any activity in the private sector which alters or affects the surface of the land will also affect in some degree the land-water relationship, and such activities span the gamut of human enterprise. All construction activities, for example, influence seepage and runoff patterns to some extent. All agricultural operations, from the simple steps of clearing, cultivating, fertilizing, and harvesting, to the installation of elaborate irrigation and drainage systems, affect the quantity and quality of water withdrawn, consumed, and discharged.

The Relative Contribution

It is extremely difficult to determine the relative impact on water resources management attributable to the various groupings of operational organizations, and only the broadest generalizations are possible. One source of the difficulty is the problem of drawing an agreed-upon line between water management operations and other economic activities. Another is that no systematic efforts have been made heretofore to relate organizational category to such a criterion.

One such test is the amount of money that is expended annually for water resources programs. Although accurate figures are not available for the reasons mentioned, preliminary estimates indicate that the Federal sector makes about 30% of the total national expenditures for water and related land resources development; the non-Federal public sector, about 30%; and the private sector, the remaining 40%.

These rough estimates apply on a gross national basis. The pattern will vary considerably when water management is viewed in terms of separate uses of water or separate management programs. For example, the single greatest consumptive use of water is for agriculture. Most of this water is supplied to the land by precipitation, but of that supplied by irrigation, about 20% is attributable to Federal development, and individual and corporate farm operators and water users associations account for all but a small portion of the remainder. The second greatest consumptive use is for industrial purposes, most of which is provided by industry

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itself. Water supply for municipal and domestic use in urban areas is provided largely by municipalities, although there are several relatively large cities supplied by private companies. Domestic use in rural areas is supplied primarily by the private sector. As to instream uses, most inland waterways are improved and maintained by the Federal Government, as well as most of the flood control works. Well over half of the water-related recreation opportunities are provided by the public sector. Of the installed capacity at hydroelectric projects, about 40% is Federal, and about 60% is State, local, and private.

REGULATORY INSTITUTIONS

Assuming that an operational organization has determined upon a need or objective in water management, and has the technical knowledge to design a program adequate to fulfill the objective or meet the need, its ability to execute the program will be circumscribed by various institutional constraints. Broadly speaking, the operation of such constraints might be defined as regulation, and it is in this sense that the subject is dealt with in the following discussion.

Each operating level is subject to regulatory institutions of one kind or another. For the private sector, these are State and Federal laws and regulatory bodies. The powers of local governmental units and State agencies are defined and limited by State law and are, also, subject to Federal regulation. Similarly, the powers of Federal agencies are defined and limited by Federal law. All must operate within the framework of constitutional doctrine. Taken together, the combination or totality of operational levels and regulatory institutions constitutes a matrix which determines the end results of water management. The discussion that follows attempts to isolate and describe some of the regulatory institutions which affect the operations of each level and the interrelationships among levels.

State and Local Regulation

Regulation of water activities at the State and local level takes a number of diverse forms. One important function of State law is to establish the procedures under which private and public rights to the use of water are determined. As to surface waters, some 31 Eastern and Midwestern States generally follow the English common law doctrines of riparian rights, under which each owner of property bordering upon a watercourse may take what he needs for his reasonable use, while allowing the flow to continue otherwise undisturbed. The early settlers in the more arid Western States found that riparian principles were not workable in areas where demand obviously could exceed supply. As a consequence, there evolved a new doctrine to govern water rights within a State based on the concept of "first in time, first in right." Known as the law of prior appropriation, these rules protect the right of the first person to use a known quantity of water to continue to use this amount as against any subsequent upstream or downstream user. Today, the law of 18 States is based either solely on the prior appropriation doctrine or on some combination of it and riparian rights. The fiftieth State—Hawaii—has a unique system based on ancient custom, legislation, the partial adoption of riparian doctrine, and the rejection of prior appropriation.

In appropriation States, a sophisticated legal structure exists. Typically, it consists of a water code enacted by the State legislature that governs the acquisition and transfer of rights to the use of water and the accommodation of public and private interests; an administrative system to facilitate the measurement and recording of these rights and the management of the public interests in water; and an adjudicatory system to resolve disputes.

In regard to underground waters, beginning in the 19th century a number of States rejected the English common law doctrine that the owner of land has an absolute ownership of all groundwaters located beneath the surface and substituted what has come to be known as the American doctrine of reasonable use. Usually a legal distinction is made between percolating waters and underground streams. Some appropriation States extend the appropriation doctrine to all underground waters; others do not. With the increase of scientific knowledge of groundwater and its relation to surface water, and with the rising demands upon water supplies from both sources, new legal refinements are evolving both through the courts and through legislation.

A number of State and local regulatory bodies have been established to control private water activities in the public interest. The water pollution control function has been assigned to existing State agencies or to new agencies created for this specific purpose. State permit or licensing requirements have been established for water-related structures such as dams, navigation facilities, and the like. State and local agencies supervise the public health aspects of

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wells and other water supply facilities, of sewage and other waste disposal installations, and of recreational use of water areas. Building and other construction permits issued by local bodies affect land-water relationships. Land use regulation through such measures as zoning ordinances is winning increased recognition as an important public tool in water management.

Federal Regulation

The Federal Government regulates other operating organizations through direct limitations or licensing requirements. Under the Federal Water Power Act of 1920 (now called Part I of the Federal Power Act) no State, municipality, or private entity may build a structure for hydroelectric power generation on navigable waters, or on any stream over which Congress has jurisdiction where the project affects interstate commerce, or on the public lands or reservations of the United States without a license from the Federal Power Commission. Licenses may also be issued to these non-Federal interests for utilization of the surplus water or water power from a government dam. The Commission has broad powers to impose terms and conditions in its licenses to assure that the project is best adapted to a comprehensive plan for improving or developing the waterway for commerce, power, and other beneficial uses. No dredging or other activity affecting navigable waters may be carried out without a permit from the Chief of Engineers, U.S. Army, and in some cases structures affecting navigable waters may not be built unless authorized by an Act of Congress. The Public Health Service promulgates drinking water standards which, although technically relevant only to interstate water supplies, have been widely followed for local application.

Joint State-Federal Regulation

In the realm of joint State-Federal regulation, the most important recent development is enactment by Congress of the Clean Water Restoration Act of 1966 which establishes a joint State-Federal procedure for the establishment of water quality standards for all interstate waters. Under the legislation, the States are given the first opportunity to establish such standards, subject to review and approval by the Secretary of the Interior. Enforcement procedures are available to obtain compliance with the standards in the event that voluntary cooperation is not successful. The promulgation of these standards and the process of adherence to them will have a major impact at all operational levels. They represent a deliberate choice by Congress to advance instream uses such as recreation, fisheries, and environmental quality in relation to the instream use of waterways for waste disposal; they will, among other consequences, affect the uses of riparian lands and tend to shift the costs of water treatment.

Interstate Regulation

There are some 40 interstate compacts relating to water resources which have been consented to by Congress pursuant to Article I, section 10, clause 3, of the Constitution, and 15 more are under negotiation. These arrangements are largely a twentieth century phenomenon, developed as the result of mutual recognition that a single State no longer could ignore the conflicting interests of other States in shared interstate waters. One of the principal purposes of many of these compacts is to allocate the use of the waters of an interstate river between or among the participating States. Two of them—New York Harbor (Tri-State) Interstate Sanitation Compact, 1935; and the Ohio River Valley Water Sanitation Compact, 1939—establish interstate commissions vested with authority to establish and enforce certain water quality standards for the covered waters.

The Delaware River Basin Compact of 1961, one of the most recent of the group, is unique in many ways. It is the only one to which the United States is a signatory party. The Delaware River Basin Commission, composed of representatives of the four basin States and the Federal Government, is vested with extremely broad powers to manage and control the water and related land resources of the entire Delaware basin. Perhaps its most significant activities to date have been the successful handling of the interstate conflicts created by the recent sustained drought, its leadership in the development of water quality standards within the basin, and the careful review and approval of hundreds of individual water facilities, including wells, industrial installations, and municipal water supply and sewage systems to help assure coordinated development. Although the Commission is empowered to construct and operate water projects, it has not as yet undertaken to do so.

FINANCIAL AND TECHNICAL ASSISTANCE

A major institutional arrangement is for financial and technical assistance between levels

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of Federal, State, and local governments and private entities. The conditions which are attached to the Federal assistance have an important influence upon the program carried out by the recipient. Federal financial aid in the form of loans and grants for water resource development and technical assistance amounts to well over $1 billion annually. This includes programs for small watersheds, soil conservation, rural and community facilities, open space acquisition, recreation, water supply, and sewage treatment.

SUPPORT FUNCTIONS

In addition to organizational arrangements, the successful planning and management of water programs requires adequate research, data, and manpower.

Research

Recognition of the necessity for intensive and comprehensive water resources planning and management has been accompanied by an awareness of the need to maintain a vigorous and coordinated water resources research program. To advance such a program, the Federal Council for Science and Technology maintains a Committee on Water Resources Research with membership from all concerned Federal research agencies to identify needs and priorities in various research categories, to recommend programs to meet these needs, and to facilitate coordination and communication throughout the research field. To provide a general program guide, the Committee developed the "Ten-Year Program for Federal Water Resources Research." This program anticipates that Federal expenditures for research will increase from $70 million in 1965 to about $200 million in 1971. Obligations of the several Federal agencies for water research for fiscal year 1968 are estimated at $136 million. In addition, very sizable expenditures for demonstration project work are being contracted to non-Federal entities.

A large portion of the Federal program involves use of non-Federal entities through research contracts and grants. The Water Resources Research Act of 1964 provided for establishment of a water resources research institute in each of the 50 States and Puerto Rico. Funds are made available to these institutes in the form of allotments and matching grants. Considerable research is also contracted to educational institutions and other research and industrial organizations. Independent of Federal financing, private enterprise maintains large investments in water-related research, primarily in the development of equipment and hardware required for water management.

Exchange of scientific information is a vital need in any research program. The Science Information Exchange of the Smithsonian Institution collects information on current water resources research projects. An annual catalogue is published by the Department of the Interior. To further coordinate Federal interagency efforts in this field, a Water Resources Scientific Information Center has been established in the Department of the Interior to store and disseminate the results of research on water resource problems.

Water Resource Data

The collection of basic hydrologic data in the United States by the Federal Government is centered in the Departments of Commerce and the Interior. The Department of Commerce is the principal collector of hydrometeorological data, and it operates nationwide networks which provide data on such things as precipitation, snow depth, water equivalent of snow on the ground, evaporation, river ice, and humidity. It also operates a network of river-stage stations as a part of its flood-forecasting activity. The Department of the Interior is the principal source of hydrologic data and is responsible for coordinating Federal water-data acquisition activities, much of which is carried out in cooperation with the States. It operates nationwide networks for the collection of data on surface water, quality of water, and groundwater, and conducts a continuing program of special investigations which generate water resources information. Other Federal Departments also collect hydrologic data, notably the Department of Agriculture's snow and soil moisture surveys. All Departments routinely publish or otherwise make generally available most of the data they collect which is of national interest; however, some which is collected primarily in support of their own missions is available only on request. In addition, many State and local agencies either acquire data directly or support cooperatively the hydrologic data collection activities of other agencies.

Hydrologic data are collected periodically by Federal agencies at about 20,000 surface-water stations having 3 or more years of record, at about 6,000 water-quality stations having 3 or more years of record, at about 15,000 precipita-

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tion stations, at several thousand observation wells, and at hundreds of snow courses. In addition, large volumes of data continue to be amassed as a part of project-type water resources investigations by Federal, State, and local agencies. It is estimated that expenditures for water-data collection by Federal agencies and by State agencies in cooperation with the Federal Government exceed $50 million annually. Other expenditures by State, local, and private interests are also substantial.

Plans for future hydrologic data collection are emphasizing coordinated programs, balanced to meet the needs of water resource planners and managers, with particular attention to data for describing and evaluating hydrologic systems, for predicting the response of these systems to development, and for an accounting of the quality and quantity of water moving through them.

The situation with respect to data on the use of water resources is not nearly as good. It is becoming increasingly clear that a severe limitation is being placed on the comprehensive planning program, the national assessment, the planning-programing-budgeting systems, and other considerations of water resources because of inadequate water use data.

The First National Assessment has been limited to problems for which data are readily available. Even these data are quite inadequate and have given rise to many misunderstandings and problems in consideration of the situation in the various regions and subbasins. The Water Resources Council and the Committee on Water Resources Research are making a special study to outline the needs for data on the use of water resources, to review the present data collection and analysis systems, and to prepare recommendations for improvement.

Manpower Development

Many thousands of people are employed in water resource related activities throughout the United States of which in excess of 20,000 are professional people. Many different professionals are engaged in planning, designing, constructing, and operating water facilities. A broad array of other sciences is represented in such fields as water quality management and pollution abatement, fish and waterfowl conservation, water-based recreation, soil and water conservation, and public health activities. Research involves scientists, engineers, and economists, covering the entire field of water resources from institutional management to the search for new water supplies through desalination and weather modification. Legal and public administration activities also engage a number of specialists in the field of water resource related activities. Federal, State, and local governments are the principal employers. Industry utilizes a substantial but undetermined number of professionals by direct employment and through consulting and contract arrangements. University faculty members substantially involved in water resources research and training number several thousand.

There is presently a significant unfilled need for professionally qualified personnel in water and related land resources development. More and better trained technicians are required with the increasing numbers of sophisticated systems for water quantity and quality management. Future requirements for qualified personnel are expected to increase substantially. In consequence, water-related professional education and training are receiving high priority attention in many universities, and this is assisted through special provisions of several programs of Federal and State agencies. The Federal budget, for instance, included $7 million in 1968 for education programs in water resources both within the Federal Government and in universities for graduate and post-graduate studies for continuing education of its employees. It is anticipated that by 1971 this Federal program will increase to $12 million.

COMPREHENSIVE, COORDINATED, JOINT PLANNING

In the Water Resources Planning Act of 1965 Congress declared its policy "to encourage the conservation, development, and utilization of water and related land resources of the United States on a comprehensive and coordinated basis by the Federal Government, States, localities, and private enterprise with the cooperation of all affected Federal agencies, States, local governments, individuals, corporations, business enterprises, and others concerned."

In view of the complex interrelationships among technical, economic and institutional factors involved in successful water management, the fulfillment of this policy requires, on a continuing basis, comprehensive, coordinated, and cooperative or joint planning: comprehensive, because all relevant factors must be studied, all reasonable alternatives evaluated, and present needs related to future demands; coordinated, because the operational program of each man-

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agement organization must be meshed with the programs of all others affected; and joint, because that planning is most effective which is participated in by those agencies responsible for or affected by its implementation.

River Basin Commissions

Title II of the Water Resources Planning Act provides for establishment of river basin commissions for river basins, groups of related river basins or other areas, composed of a chairman appointed by the President, one member appointed from each of the Federal Departments or agencies having a substantial interest in the work to be undertaken, one member from each of the States which lies wholly or partially within the jurisdictional area of the commission, and one member from each appropriate interstate compact agency. The vice-chairman is elected by the State members. River basin commissions are authorized to coordinate Federal, State, local, and private planning; to prepare and keep up to date a comprehensive, coordinated, joint plan for water and related land resources development; to recommend priorities for data collection, investigation, planning, and construction of projects; and to submit to the Water Resources Council with its comprehensive plan recommendations for implementing the plan. Commissions do not have authority to construct or operate projects. To date, four river basin commissions have been established. These are the Pacific Northwest River Basins Commission, Great Lakes Basin Commission, Souris-Red-Rainy River Basins Commission, and New England River Basins Commission.

Interagency Committees

In a number of regions where river basin commissions are not established, interagency committes function under the aegis of the Water Resources Council. These bodies, composed of representatives of Federal and State agencies, coordinate planning activities and operational policies of the participants. At the present time interagency committees are in existence for the Pacific Southwest, the Arkansas-White-Red basins, the Missouri basin, and the Southeast basins.

The Water Resources Council Planning Program

One of the major recommendations of the 1961 report of the Senate Select Committee on National Water Resources was that the Federal Government, in cooperation with the States, should prepare and keep up-to-date plans for comprehensive water development and management for all major river basins of the United States. The plans were to take account of all prospective demands served by water development and all practical means of meeting such demands. To carry out this recommendation, in keeping with the policy of the Water Resources Planning Act, the Council is undertaking a program of planning studies for 20 regions encompassing the Nation (fig. 5–9–2).

Framework Studies (Type 1)

Framework studies, which are conducted by a river basin commission or other Federal interagency-State organization of a region, provide long-run economic projections of economic development; translation of such projections into demands for water and related land resource uses; hydrologic projections of water availability, both as to quantity and quality; projections of related land resource availability so as to outline the characteristics of projected water and related land resource problems; and the general approaches that appear appropriate for their solution. While potential sites may be identified, project formulation studies are not included in framework plans.

The framework studies will provide general guides to future water resource development. The plans will indicate which regions or subbasins within them have water problems calling for prompt detailed planning efforts as well as those where no such problems are current or looming. In addition, these studies will provide a substantial contribution of fact and analyses to subsequent detailed plan formulation.

Normally, framework plans are the first phase of the comprehensive plan to be prepared by river basin commissions established under the Water Resources Planning Act.

Comprehensive River Basin Studies (Type 2)

These are comprehensive studies by a river basin commission or other Federal interagency-State coordinating organization that extend the scope beyond the type 1 studies to define and evaluate projects in sufficient detail, including project formulation, to comprise a basis for authorization of those Federal and Federally assisted projects to be initiated in the next 10 to 15 years.

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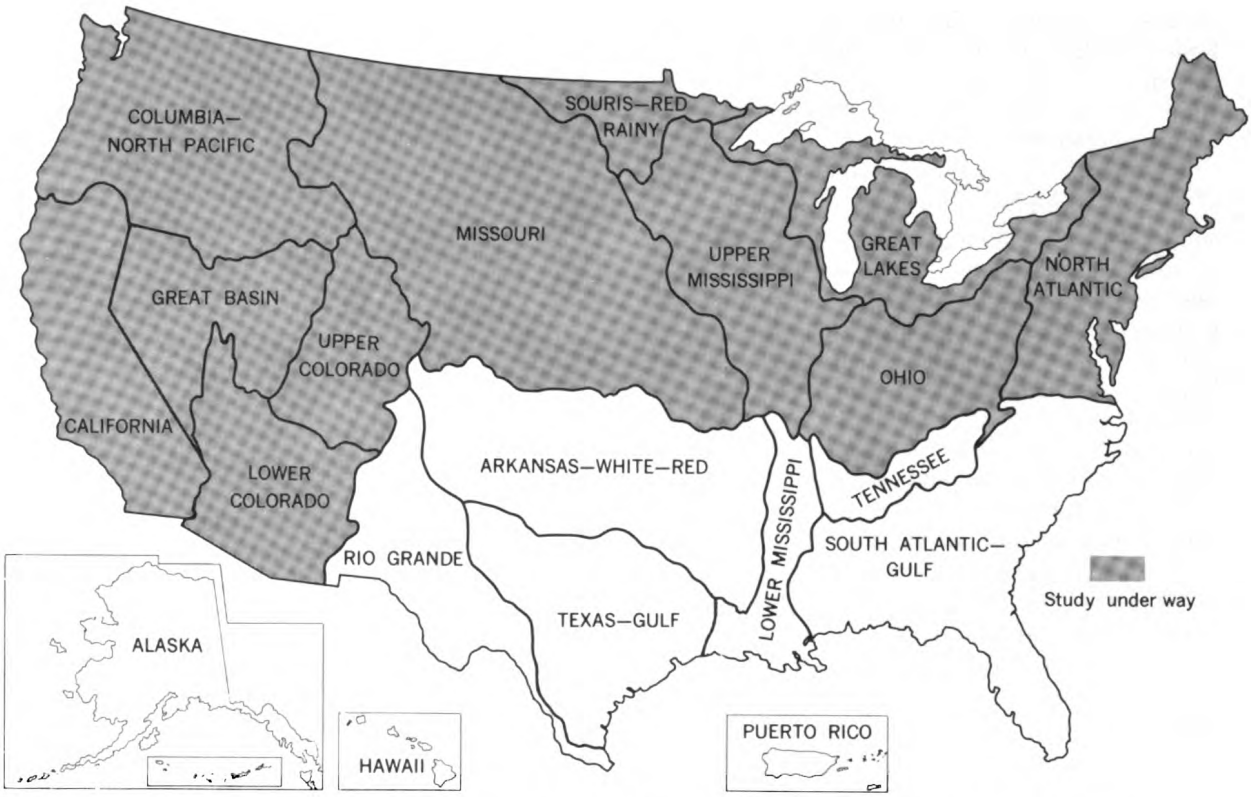

FIGURE 5–9–2.—*Regions in which Water Resources Council's type 1 framework studies are under way.*

Project or Single-Purpose Studies (Type 3)

These are studies of narrower geographic or analytic compass or by a single agency that usually relate to one project or purpose or a proposal for preservation or improvement of water and related land resources. The studies indicate the relationship of the proposed programs and projects to the comprehensive plan for the river basin or region or, if no comprehensive plan has been completed, the relationship to probable later development needed or to be undertaken in the basin or region.

Cooperative Studies (Type 4)

These are State-sponsored studies of water resources for all or a part of a State in which one or more Federal agencies are participating.

Assistance to the States for Comprehensive Planning

In recognition of the need for increased participation by the States in water and related land resources planning, the Water Resources Council is authorized under Title III of the Water Resources Planning Act to make grants to States to assist them in the development of comprehensive water and related land resource plans. State programs are to provide for comprehensive planning with respect to intrastate or interstate water resources, or both, to meet the needs for water and water-related activities, taking into account prospective demands for all purposes served through or affected by water and related land resources development, with adequate provision for coordination with all Federal, State, and local agencies and nongovernmental entities having responsibilities in affected fields. In fiscal year 1968, $2.25 million was appropriated for planning grants. Forty-nine States, Puerto Rico, and the District of Columbia are participating.

MANAGEMENT OF RIVER BASIN OPERATIONS

The river basin—or a major tributary basin or a group of smaller related river basins—is generally regarded as the desirable unit for managing water operations. This follows, of course, from the fact that the principal source of water is surface water, and the principal hydrologic and land-water relationships involve the natural

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surface watershed. The area chosen should be large enough to be meaningful and small enough to be workable in terms of the institutional arrangements selected to conduct management operations.

Nonetheless, a word of caution is appropriate as to the limitations of focusing solely on a single basin. Underground aquifers do not necessarily correspond with surface watershed boundaries. Likewise, air movements do not respect watershed boundaries, a fact which is important to the extent that weather modification becomes a management tool. The normal patterns of economic development do not usually conform to river basin configurations, nor do political boundaries and cultural ties. Last, regional and national considerations often transcend watershed boundaries and, thus, militate against confining attention only to the in-basin problems of matching demand with supply. Increasing attention will need to be given to larger regional needs.

Criteria

Any successful institutional arrangement for managing river basins should be able to carry out certain objectives and meet certain criteria. Without attempting to exhaust the list, these include:

1. Responsiveness to local wants;
2. Competency in planning, coordination, and research;
3. Allocation of available resources among uses and areas;
4. Control over both water quality and quantity;
5. Ability to decide and to act;
6. Ability to provide financial support; and
7. Flexibility to respond to changing situations and to meet future needs.

Alternative Institutional Patterns

Institutional arrangements in the United States for managing river basin operations in terms of full multiple use of their resources are, by and large, in the early stages of development. Institutional evolution tends to respond to felt demand, and although this river basin approach has antecedents reaching far back into our history of water and related land resource development it has been only in recent years that economic pressures on regional resources and economic and political pressures in favor of their multiple use have reached sufficient intensity to begin to force dramatic institutional growth and innovation. The publication "Alternative Institutional Arrangements for Managing River Basin Operations," by the Water Resources Council, gives a detailed discussion of this subject.

The two polarities of river basin institutions attempting to provide overall basin management can be stated as the unified approach and the coordinated approach (beyond the latter, of course, is no coordination at all, or a state of institutional anarchy, in which each operating organization or area stakes out its own claim without any sense of responsibility toward its competitors).

Unified Approach

There are at the present time three institutional arrangements for managing river basin operations that tend strongly toward the unified approach and even these include important attributes of coordination. One is the Tennessee Valley Authority—an independent agency of the Federal Government. Although the State and local governments have no legal powers in formulating or executing TVA policies or programs, TVA seeks and receives the cooperation of State and local governments and nongovernmental agencies as advisors and collaborators. It should also be noted that TVA does not exercise exclusive Federal jurisdiction within the Tennessee River basin: the Corps of Engineers operates the locks in TVA dams for navigation purposes; the Soil Conservation Service plans and constructs small watershed projects; and the Secretary of the Interior exercises Federal responsibilities under the Federal Water Pollution Control Act, as amended, including the Water Quality Act of 1965.

Another type of institutional arrangement is the administration of the Colorado River by the Secretary of the Interior pursuant to the Boulder Canyon Project Act of 1928, as amended and supplemented. The Act incorporated provisions of the Colorado River Compact negotiated by the States in 1922, and also provides for the establishment of State advisory commissions. However, it should be noted that the degree of unification of Federal responsibility achieved by the Boulder Canyon Act of 1928 does not preclude the exercise of the responsibilities of several other Federal departments and agencies within the Colorado River basin.

Both the Tennessee and Colorado arrangements were born of apparently unique political circumstances and came about at a time when each river system was relatively undeveloped

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and the Federal Government appeared to be the only body with the capability of acting on the scale and in the manner required.

The third type of institutional arrangement is the compact approach. The solely interstate compact arrangements that have been adopted in the interests of unification thus far have been limited largely to single-purpose aspects of river basin management. The experience of three interstate compact organizations dealing with water pollution control indicates the potential for unified regulation of water quality standards. There is nothing inherent in this arrangement, however, to prevent the broadening of the powers of the compact commission to cover all the aspects of water management within the competence of the participating States. The Delaware River Basin Commission, a Federal-interstate compact commission, is endowed with broad powers relating to multiple-use management of the basin. Currently, there is a substantial interest in this institutional arrangement and similar Federal-interstate compacts are being considered for the Susquehanna, Potomac, and Hudson River basins.

Coordinated Approach

Also, there are at the present time three institutional arrangements expressive of the coordinated approach.

The ad hoc coordinating committee is one approach that is now utilized in the coordination in the preparation of specific comprehensive water and related land resources studies. Several such committees, under the chairmanship of the representatives of a specified Federal or State agency and composed of representatives of Federal and State agencies participating in the study, are in operation at the present time. This same device can be used for exchanging information regarding river operations.

Several river basin interagency committees have been established by Federal interagency agreement in which State agencies have agreed to participate. These are being continued under the Water Resources Council. While the initial mission has been to coordinate planning, there has been some evolution on an informal and continuing basis for coordination and review of subsequent programs. The committee itself cannot undertake either the construction of projects or their operation but can seek consensus on investigations and priorities for further attention. For example, experience in the Missouri River basin indicates the potentialities for effective coordination of reservoir operation to achieve desired streamflow regulation. Six dams on the main stem of the Missouri River and 46 on the tributaries provide regulation for flood control, navigation, irrigation, water supply, hydroelectric power generation, recreation, water quality control, and fish and wildlife enhancement. A coordinating committee for the past 15 years has developed an annual operating plan to maximize overall benefits through the integrated operation of the main stem system.

River basin commissions authorized to be established under Title II of the Water Resources Planning Act do not have any authority to construct projects or operate them. They do, however, recommend priorities for investigations, planning, and construction of projects. They also must make recommendations for implementing the program. The participation by many agencies and States in joint comprehensive planning in itself produces, as a by-product, a great deal of coordination in management and administration.

THE ROLE OF PUBLIC OPINION

In recent years there has been a marked increase in public awareness of water and related land resources problems. As droughts lead to the imposition of water use restrictions, as normally full reservoirs are depleted and groundwater tables drop, as favorite water recreation sites disappear or become more and more crowded, and as water pollution becomes more offensive, water is no longer taken for granted. To unprecedented degree, water has become recognized in the public mind as a general concern. Through individual action and through civic, conservation, and other groups, the citizenry demands more governmental action—either to develop resources or to preserve them for enjoyment in their natural state—and elected representatives at all levels of government endeavor to appropriately respond to these demands. Concerned, informed, and organized public opinion thus functions as an important and desirable institutional factor in all aspects of water and related land resources.

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PART 6

Regional Water Supplies and Requirements

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Regional Water Supplies and Requirements

INTRODUCTION

The level of geographic detail adopted for this Assessment was dictated by readily available data and consists essentially of the same 20 water resources regions presently being used in the framework planning program (fig. 6–1) and 110 subregions. While the broad areas used in the regional chapters mask many local problems, they do reveal striking contrasts in water problems.

The regional chapters were prepared by field committees composed of Federal and State experts (fig. 6–2). These committees were asked to prepare statements about current and future water problems in their regions. Thus, field personnel of the 20 regions, who are intimately involved in water resources activities, were asked to assess the adequacy of present levels of water and related land resources use and development in each subregion, to discuss present institutional and management problems, to project regional water requirements and emerging water problems, and to present near-future development needs. Because these chapters reflect regional goals as well as national and regional requirements for water resources development, the Water Resources Council does not necessarily endorse all of their findings, conclusions, or projections.

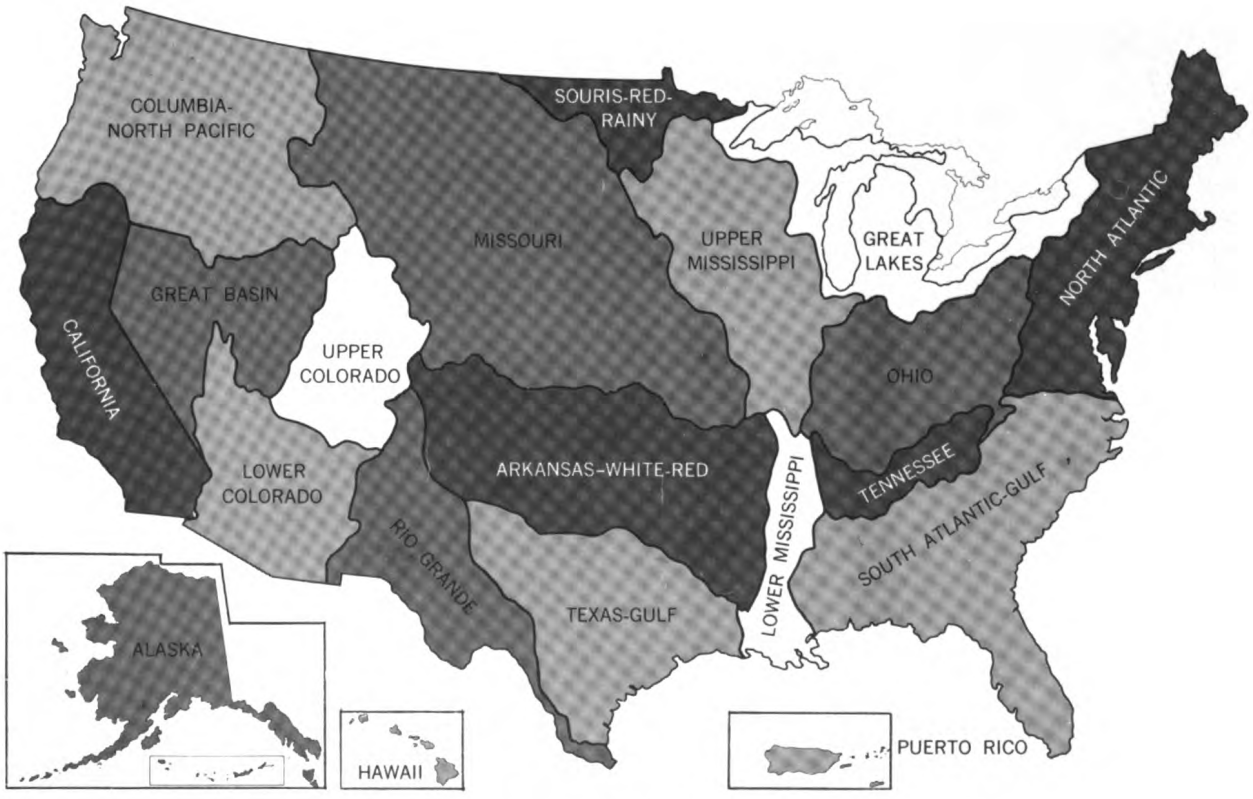

FIGURE 6–1.—*Water resources regions used in the first National Assessment.*

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CHAPTER	REGION	LEAD FIELD COMMITTEE
1	North Atlantic	North Atlantic Framework Study Coordinating Committee
2	South Atlantic-Gulf	Southeast Basins Inter-Agency Committee
3	Great Lakes	Great Lakes Basin Commission[1]
4	Ohio	Ohio Framework Study Coordinating Committee
5	Tennessee	Tennessee Valley Authority
6	Upper Mississippi	Upper Mississippi Framework Study Coordinating Committee
7	Lower Mississippi	Mississippi River Commission
8	Souris-Red-Rainy	Souris-Red-Rainy River Basins Commission[2]
9	Missouri	Missouri Basin Inter-Agency Committee
10	Arkansas-White-Red	Arkansas-White-Red Basins Inter-Agency Committee
11	Texas-Gulf	Texas Water Development Board
12	Rio Grande	Ad hoc group under the leadership of the Department of the Interior
13	Upper Colorado	Pacific Southwest Inter-Agency Committee (Upper Colorado State-Federal Inter-Agency Group)
14	Lower Colorado	PSIAC (Lower Colorado SFIG)
15	Great Basin	PSIAC (Ad hoc Great Basin SFIG)
16	Columbia-North Pacific	Pacific Northwest River Basins Commission[3]
17	California	PSIAC (California SFIG)
18	Alaska	Federal Field Committee for Development Planning in Alaska
19	Hawaii	Hawaii Department of Land and Natural Resources
20	Puerto Rico	Puerto Rico Aqueduct and Sewer Authority

[1] Chapter initially prepared by an ad hoc group under the leadership of the Department of the Army.
[2] Chapter initially prepared by an ad hoc group under the leadership of the Department of Agriculture.
[3] Chapter initially prepared by the Columbia Basin Inter-Agency Committee.

FIGURE 6–2.—*Field contributors to the first National Assessment.*

The Council's projections of regional water requirements are shown in table 6–1 and in some cases they differ from those presented in the regional chapters. In addition, the reader should be aware that the data include use of mined groundwater and use of saline water by self-supplied industries and steam-electric power utilities, and do not include phreatophyte and other channel losses nor requirements for in-stream uses. These items are discussed in each chapter.

Comparisons of the projections of water requirements with those of water availability indicate that the Rio Grande, Upper Colorado, Lower Colorado, and Great Basin Regions and significant portions of the Missouri, Arkansas-White-Red, Texas-Gulf, and California Regions are expected to have severe water shortages by 2020. In addition to the foregoing Regions, the Great Lakes, Ohio, and Upper Mississippi Regions and significant portions of the North Atlantic and South Atlantic Regions are expected to have severe water quality problems resulting from high degrees of use and reuse.

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TABLE 6–1.—*Estimated water use and projected requirements, United States*

(Million gallons daily)

Region	Used 1965	Projected requirements			Used 1965	Projected requirements		
		1980	2000	2020		1980	2000	2020
	Withdrawals				*Consumptive use*			
North Atlantic	37,467	54,920	113,860	236,290	2,023	2,870	4,960	8,490
South Atlantic-Gulf	20,560	53,180	87,440	130,190	2,695	3,395	5,655	8,265
Great Lakes	25,119	47,893	96,594	190,960	1,199	1,881	3,183	5,484
Ohio	28,255	41,749	65,109	90,163	1,134	1,619	2,539	3,623
Tennessee	5,767	12,252	13,877	18,106	331	572	834	1,132
Upper Mississippi	8,179	14,800	30,587	41,266	770	1,103	1,778	2,624
Lower Mississippi	5,571	12,816	27,967	39,442	1,470	3,012	4,453	6,251
Souris-Red-Rainy	391	936	2,002	2,758	77	215	494	544
Missouri	19,344	23,264	27,876	31,572	10,554	13,160	14,979	16,378
Arkansas-White-Red	9,410	17,279	25,336	31,589	5,874	8,482	10,587	12,329
Texas-Gulf	16,410	29,080	57,330	92,640	7,289	9,435	10,890	12,300
Rio Grande	7,289	8,330	9,510	11,680	4,403	4,676	4,991	5,466
Upper Colorado	4,017	5,675	6,575	6,725	1,982	2,700	3,100	3,140
Lower Colorado	6,913	8,497	8,428	8,889	3,448	4,075	4,645	5,310
Great Basin	5,115	7,055	7,550	7,800	2,253	3,299	3,562	3,776
Columbia-North Pacific	29,631	41,407	90,135	156,735	10,521	13,581	17,325	21,616
California	37,300	56,290	120,510	244,760	20,944	29,205	32,660	38,190
Alaska	162	535	901	4,206	12	50	96	184
Hawaii	1,597	2,658	4,698	8,587	533	728	1,000	1,368
Puerto Rico	1,120	4,010	8,325	13,730	270	360	475	615
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

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CHAPTER 1

North Atlantic Region

SUMMARY

The North Atlantic Region covers an area of about 172,000 square miles and includes all or portions of 13 States and the District of Columbia. Although it contains only 5% of the Nation's land area, it accounts for 25% of the national population total and generates close to 30% of the national personal income and manufacturing employment.

Considering the entire Region and average availability, water is abundant, but its usefulness is limited by uneven geographic distribution, large fluctuations in supply, and seriously degraded quality in some locations. The adjacent ocean greatly supplements the resource.

Present withdrawals of fresh surface water for all purposes total only 12% of the average annual natural runoff. This percentage varies significantly, however, between major areas. Consumptive use is very low, totaling slightly more than 1% of average annual runoff.

The Region contains the largest urbanized complex in the Nation—a complex that can be expected eventually to form a strip city that will extend from north of Boston to south of Washington. By 2020, the Region's population is expected to exceed 100 million, more than double the present figure. Economic activity is expected to increase by more than seven times, with a commensurate increase in water requirements. Large quantities of water will be needed for municipal and industrial use, steam-electric power, waste dilution, agriculture, and recreation. This may well involve transfer of water from areas of abundant supply to areas of need.

To meet the urgent water-related problems that have already emerged and those that will be posed in the near future by the expected increases in population and economic activity, it is first of all essential in an early stage of the planning process (1) to define the objectives of water resources development in this highly urbanized Region as a whole and (2) to evaluate relative importance of the objectives in terms of public preference for them, in various parts of the Region.

Among the important matters that still need technical and managerial solution are (1) long-range and emergency planning for municipal water supply; (2) water quality management; (3) flood control and flood-plain management; (4) protection of wetlands, estuaries, and anadromous fish habitats; (5) improvement of techniques and lowering of costs for exploration, development, and management of groundwater resources; (6) provision of cooling water for steam-electric power generation and control of its associated thermal pollution; (7) facilities for deep-draft navigation; (8) sand for maintenance of beaches; and (9) expansion of roles for regional coordination agencies.

The most urgent problems requiring immediate attention are water supply for the large metropolitan areas, improvement of water quality, flood control on several major rivers, greater utilization of nonstructural measures for the reduction of flood damages, and preservation of coastal and estuarine areas.

Integration of effort is greatly needed in all phases of water-related development. If future problems are to be solved, or at least minimized, high priority should be given to (1) continuation of present Federal water resource programs at a rate commensurate with normal increased needs; (2) provision of institutional arrangements to permit earlier acquisition of reservoir sites; (3) coordination of basin studies in such a manner as to yield optimal and timely development; (4) coordination between Federal, State, interstate, and local activities and programs; (5) incorporation of watershed land management as a basic and integral function of water resources planning and development; and (6) regionalization, where appropriate, of water supply and waste treatment services.

DESCRIPTION OF THE REGION

The North Atlantic Region includes all river basins, as well as adjacent estuarine and coastal waters, within the United States draining into

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the Atlantic Ocean at points north of the Virginia-North Carolina border and those basins draining into the St. Lawrence River east of its junction with the international border (fig. 6–1–1). Extending approximately 1,000 miles along the Atlantic Coast—from the southernmost boundary of the James River Basin in Virginia to the northernmost tip of Maine—and inland from the Coast an average of some 200 miles, the Region covers about 172,000 square

FIGURE 6–1–1.—*Map of the North Atlantic Region.*

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miles. The area encompasses all of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, and the District of Columia, and portions of New York, Pennsylvania, Maryland, West Virginia, and Virginia.

This aggregation of States and parts of States represents only 5% of the Nation's land area, yet it contains 25% of the national population total and generates some 30% of national personal income and manufacturing employment. These percentages reflect the high degree of the Region's economic development. The extreme concentration of urban development is indicated by the fact that almost 87% of the land area is occupied by cropland, pasture, or forest, while 82% of the regional population resides in the remaining 13%. The usage and utility of the preponderant nonurban areas vary greatly in different parts of the Region. In the regional portions of Pennsylvania, Maryland, and Virginia, for example, about half of the land is put to agricultural use, yet less than half of that land is suitable, or used, specifically for crop production. The proportion of land occupied by forests is generally highest in northern New York State and northern New England.

Most of the Region's terrain is either mountainous, with altitudes ranging up to more than 4,000 feet above sea level, or hilly upland. The major economic development has occurred in lowlands along the coast and along the streams. Of the 47 standard metropolitan areas, 22 are on the coast or on estuaries, 13 are inland on large rivers, and 12 are inland on small rivers. Only 2 have altitudes exceeding 1,000 feet above sea level. The density of valley occupancy increases the possibility of serious damage from floods. The relatively steep gradients of the river channels discourage inland navigation.

About 25,000 square miles of the Region lie in the coastal plain, which includes Long Island and that part of the mainland east of the fall line which passes through Philadelphia, Baltimore, Washington, and Richmond. The coastal plain is an area of low relief with underlying beds of sedimentary rock, many of which are excellent sources of large quantities of groundwater.

Glaciers, which covered all of New England, most of New York, and parts of New Jersey and Pennsylvania, left many depressions that became lakes and ponds, many of which are used as sources of water supply and also constitute a valuable recreational asset. Many glacially filled valleys provide groundwater supplies. The glaciers also altered river courses and gradients, producing the rapids and waterfalls that contributed to the early industrialization of the Region and still provide considerable hydroelectric power.

The climate in the Region is humid, with four distinct seasons, and generally characterized by frequent weather changes. Climate along the coast is tempered in both winter and summer by the Atlantic Ocean and large bays. Inland, the mountain ranges have marked effects—lowering temperatures, shortening frost-free seasons, and increasing the amount of rain and snow. Average annual temperature has a range of about 20°, varying from slightly less than 40° in northern New England to approximately 60° in southern Virginia. Winters in the northern part of the Region are long and rather severe, and growing seasons average less than 100 days in some areas; farther south, growing seasons average up to 200 frost-free days and summers are long and hot. Precipitation averages about 41 inches annually, and is fairly evenly distributed throughout the year. Runoff averages about 50% of precipitation, but usually exhibits considerable seasonal and geographical variations; one-half or more of the annual volume often occurs in two or three spring months, and the runoff proportion of annual precipitation is much higher in the northern part of the Region than in the southern part.

THE WATER RESOURCE

If the average availability of water in the entire North Atlantic Region is considered, the resource is blessedly abundant. However, uneven geographic distribution, large fluctuations of supply, and seriously degraded quality in some localities combine to limit the usefulness of the abundance. (Table 6–1–1 summarizes the annual natural runoff in the Region.) In addition to the surface waters, large sources of groundwater are available. Those in the sands of the coastal plain from Long Island southward, for example, are capable of sustained yields of about 3 to 5 bgd. The gravels of ice-age deposits in the northern part of the Region and the limestones of the Shenandoah and Cumberland Valleys also yield significant quantities.

Much of the runoff in northern New England (subregion 1) occurs during the late winter and spring, and the many natural lakes appreciably moderate high flows. Flood problems are infrequent on the major rivers, but some small rivers and streams frequently create localized

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TABLE 6–1–1.—*Annual natural runoff, North Atlantic Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	30,900	34.39	23.37	34.4	25.1	22.5
2	28,700	32.81	24.01	32.8	24.0	21.5
3	27,300	27.63	21.25	27.6	21.2	19.4
4	17,500	17.88	21.46	17.4	13.1	12.0
5	35,800	30.50	17.89	30.5	21.9	19.5
6	31,400	19.75	13.21	19.7	12.9	10.9
Regional value	171,600	163.0	19.95	163.0	123.2	112.0

flood problems. Drought problems are infrequent and minor. Pollution problems exist on many of the main stems of the major rivers, as well as on some tributaries and lakes. Although not in large supply, groundwater occurs in both bedrock and glacial drift; the most productive aquifers are beds of permeable sand and gravel incorporated in stratified glacial drift, and occurring mostly in southern parts of the subregion. Groundwater is generally of good quality but in various areas may be hard, corrosive, or high in iron, chloride, nitrate, or radioactive elements.

In comparison with subregion 1, southern New England (subregion 2) has generally much less natural storage, and seasonal variations and extremes are more pronounced. Although floods are relatively short in duration, peak flows are among the highest in the Region. The whole area is vulnerable to hurricane-related storms, which cause serious fluvial and tidal flooding. Surface water is generally of good to excellent quality; however, many of the major streams are polluted by municipal and industrial wastes. Groundwater, although somewhat harder and more mineralized than surface water, is generally suitable for most domestic, agricultural, and industrial uses. The most productive aquifers are in the lowlands, where deposits of stratified drift are traversed by streams which can recharge the aquifers.

The seasonal variation of runoff in the Hudson-St. Lawrence subregion (No. 3) is similar to that of subregion 2, with 50% or more generally occurring in the spring. This variation is considerably less pronounced in coastal areas where sizable portions of streamflow are derived from groundwater sources and snowmelt is not a significant factor. Except for hurricane-related floods, which can affect the southern portions in late summer and fall, highest flows generally occur in March and April, and the lowest in August and September. The quality of surface water is generally good in the small tributaries and headwaters, but serious municipal and industrial waste pollution problems exist in the major streams near metropolitan centers—for example, in sections of the Hudson River from Albany to the mouth and in some of its tributaries draining other urbanized and industrial zones. The most productive groundwater area is Long Island. Upstate New York also has productive areas along the glacial spillway that carried the outflow of the glacial ancestor of Lake Erie into the lower Mohawk and Hudson River valleys. Groundwater contamination in heavily populated areas is a problem, especially on Long Island where the supply is vulnerable to encroachment of salt water, pollution by wastes from the surface, and significant reduction in recharge due to urbanization.

Normally, the highest runoff in subregion 4 (Delaware River basin-coastal New Jersey) occurs in March and April and the lowest in August and September. The entire subregion is affected by hurricanes and extratropical storms sometimes associated with these disturbances. Serious municipal and industrial waste pollution problems exist in sections of the Delaware River, some of the tributaries draining urbanized and industrial zones, many of the streams in northern New Jersey, and in Raritan Bay. A further critical problem is caused by saline water intrusion in the estuary near Philadelphia during drought conditions in the Delaware River basin. Acid mine drainage degrades the headwaters of the Schuylkill River and, to a somewhat lesser extent, the Lehigh River. Groundwater is mainly found in the coastal plain in New Jersey and southeasternmost

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Pennsylvania, and is of generally good quality, although salt water encroachment is a problem. Limestone areas are also important sources of groundwater; the water is hard but otherwise of good quality. Contamination by sewage and industrial wastes is rather common in the cavernous limestone in southeastern Pennsylvania.

The seasonal variation in runoff of the Susquehanna-eastern Chesapeake subregion (subregion 5) is similar to that of the northern subregions, although in the southern portion the season of highest flows generally occurs somewhat earlier—in February and March. Floods related to hurricanes and northeasters are exceptions to this rule. The quality of surface water has been degraded in many areas by industrial and municipal wastes and acid mine drainage. Serious mine drainage pollution occurs in the Susquehanna River and its tributaries from the mouth of the Lackawanna River to about Bloomsburg, the upper West Branch Susquehanna River and its tributaries, and the upper Juniata River. The best aquifers lie in the coastal plain in Maryland and Delaware, with the highest yields of wells occurring on the eastern shore of Chesapeake Bay where rates as high as 1,700 gpm are known. This groundwater is high in iron content and in various localities is subject to saline water intrusion and other contamination.

In the Potomac River basin, the largest basin in subregion 6 (western Chesapeake), about 43% of the annual runoff occurs from March through May, while only 12% occurs from July through September. Variations from season to season and year to year are especially severe in this basin, where the ratio between the lowest and highest observed flow is about 1 to 660. Fluvial and tidal floods resulting from extratropical storms, tropical storms, thunderstorms, and combinations of these can occur in any season of the year throughout the subregion. With some notable exceptions, the quality of surface water is generally good. One exception is acid mine pollution in the North Branch of the Potomac River; another is pollution from municipal sources in the Potomac estuary. In addition, the quality of many local reaches of streams is degraded by municipal and industrial pollution. The most productive aquifers are in the coastal plain and the Shenandoah Valley. In general, the groundwater is of good quality; however, saline intrusion has been reported in coastal areas, contamination occurs in some localities, and hardness is a problem in limestone areas.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Total withdrawal for all purposes and from all sources in the North Atlantic Region is 37.5 bgd, of which 2.0 bgd, or a little over 5%, is consumed (table 6–1–2). Over 90% of the withdrawal is from surface sources, about evenly divided between fresh and saline water. Instream uses and other development functions in each subregion are discussed briefly below.

Lakes, ponds, and streams in subregion 1 are extensively used for fishing and boating, and as focal points for camping and vacation homes. Streams are developed on a very substantial scale for hydroelectric power; average instream use for this purpose amounts to about 55 bgd. Commercial navigation is limited to the lower reaches of a few of the larger rivers. There are more than 30 large—i.e., of greater than 1.6 billion gallons usable capacity—reservoirs or controlled natural lakes with a total usable storage capacity of about 2,100 billion gallons. These impoundments are mainly put to use for power production, log driving, and recreation.

Streams throughout subregion 2 are developed for hydroelectric power, flood control, and recreation. Average instream use for hydroelectric power is about 59 bgd. There are about 80 large reservoirs, with total usable storage capacity of about 1,300 billion gallons. Almost 100 federally assisted small dams are in operation in upstream watersheds. Flood control measures provide a high degree of protection for many of the larger urban areas. Commercial navigation is confined to the lower reaches of the major rivers, and there are a number of harbors along the coast.

In subregion 3, widespread lake areas in the upper Hudson River basin provide natural storage for reducing flood flows and are much valued for recreation. Lake Champlain is widely used by commercial shipping and pleasure boats, although ice conditions during the winter limit the navigation season to about 8 months of the year. Commercial navigation also moves through the Hudson River basin via the Hudson River and the New York State Barge Canal. Principal streams throughout the area contain reservoir developments for hydroelectric power, flood control, flow augmentation, municipal water supply, navigation, and recreation. The more than 50 large reservoirs total to a usable capacity of over 1,500 billion gallons. Average instream use for hydroelectric power is about 41 bgd. Extensive deep-draft navigation and hydroelectric power developments exist on the

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TABLE 6–1–2.—*Present water use, 1965, North Atlantic Region*

(Millions of gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation	Livestock	
			Water withdrawn				
1	9	70	445	100	2	3	629
2	91	1,134	1,121	3,120	24	8	5,498
3	85	1,435	2,192	5,790	28	15	9,545
4	71	1,664	3,094	6,350	66	10	11,255
5	80	636	1,820	2,880	9	27	5,452
6	54	507	827	3,660	22	18	5,088
Total	390	5,446	9,499	21,900	151	81	37,467
From:							
Groundwater	(383)	(1,158)	(874)	(8)	(92)	(47)	(2,562)
Saline	.....	.....	(8,980)	(11,400)	..	..	(15,380)
Wastewater	.....	.....	(130)	.....	(1)	..	(131)
			Water consumed				
1	3	14	26	1	2	3	49
2	81	124	53	22	24	8	312
3	21	289	130	42	28	13	523
4	13	301	175	46	66	4	605
5	36	60	134	21	9	25	285
6	32	117	37	26	21	16	249
Total	186	905	555	158	150	69	2,023

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 40,404,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).

St. Lawrence River, which is adjacent to this subregion.

Streams and lakes throughout subregion 4 are extensively used for recreation, particularly in the Pocono Mountains. The total usable storage of large reservoirs is about 500 billion gallons; over 50% of this is contained in Pepacton, Cannonsville, and Neversink Reservoirs, which are designed primarily to provide water for New York City. Average instream use for hydroelectric power amounts to only about 1 bgd. Commercial navigation on the Delaware River extends upstream as far as Trenton.

Chesapeake Bay and other tidal areas of subregion 5 are utilized extensively for recreation, particularly pleasure boating and sport fishing. Water-related recreation activities are also widespread in upper portions of the subregion, although limited in some localities by degraded water quality. Commercial navigation is essentially limited to Chesapeake Bay, which also is extensively used by the commercial fishing industry. Hydroelectric power development is concentrated in the lower Susquehanna River, and the average instream use in the subregion is about 48 bgd. The total usable capacity of large reservoir developments is about 300 billion gallons and is used mostly for flood control, conservation, and power. In upstream watersheds, nearly 100 federally assisted small dams are in operation. Streams are used widely for waste disposal and assimilation. The upper Susquehanna basin receives both treated and untreated wastes from municipalities and from industries, including mining operations. The tidal waters receive large quantities of wastes in the Baltimore area.

In subregion 6, instream use is fairly limited, except for some navigation improvements in the lower Potomac, Rappahannock, York, and James Rivers. The average use for hydroelectric power is about 13 bgd. Recreation activities are widespread but are limited in some areas by the scarcity of fresh water lakes and by poor water quality. Large reservoir development is nominal, total usable storage amounting to less than

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33 billion gallons. However, more than 70 federally assisted small dams are in operation in upstream watersheds.

ADEQUACY OF PRESENT DEVELOPMENT

While the water resources of the Region are ample for present use, their development is inadequate in many areas and for many purposes. Overall, withdrawals of fresh surface water average only 12% of the total available, but this percentage varies significantly within the Region.

Development inadequacies in subregion 1 pertain principally to improvement of water quality and to use competition. Serious water quality problems exist on many of the lower reaches of major rivers and also on some tributaries. Many lakes are deteriorating rapidly because of the large increase of recreation activity. Streams are developed mainly for hydroelectric power, and storage of water to meet peaking requirements interrupts flow in downstream reaches, adversely affecting water usage there for municipal, industrial, waste dilution, and recreation purposes. Wider acceptance of multiple use development and of provisions for carryover storage is necessary. In general, flood problems are relatively infrequent, but do occur on some of the smaller rivers and streams.

Development inadequacies related to water quality, flood control, and municipal, industrial, and recreation uses are found throughout subregion 2. During the 1961–66 drought many localities experienced problems concerning the quantity and quality of municipal water supplies and their treatment, conveyance, and distribution. More flood control storage is required, particularly where the effective height of existing dikes and walls in lower valleys was predicated on a degree of upstream reservoir control which has not materialized, and there is also a continuing need for nonstructural measures for reducing flood losses. Additional measures for reduction of losses due to tidal flooding also appear warranted. The supplies of water for recreation use are in general not commensurate with the needs of the large population. Fresh water developments are often not available for public use, lack access, or are not suitable because of pollution. The prevailing practice of weekend water storage, which prevents flow in reaches immediately below hydroelectric plants, not only creates an unaesthetic condition but also adversely affects recreation and other uses downstream. Supplemental storage or a revised operating procedure that would allow release of water on weekends is required.

Severe water shortages developed in subregion 3 during the 1961–66 drought. Emergency water sources were established and conservation measures put into effect in many areas. Although New York City's water supply had been indicated by planners as adequate until 2000, it had to be supplemented temporarily from the Hudson River at one period during the drought. Actually, sufficient water for the city is available in the Hudson River basin, but increased storage is needed to offset the effects of large variations in runoff. Improvements in water quality are needed throughout the subregion, particularly in regard to the lower Hudson River and to groundwater conditions on Long Island. Development for navigation above tidewater from Troy to Buffalo and from Troy through Lake Champlain to the St. Lawrence River is believed to be reasonably adequate. However, traffic is occasionally hampered by flood conditions at the start of navigation in the spring, and minor delays occur during low water periods that result from weekend shutdown of hydroelectric power facilities. Significant inadequacies have been reported regarding flood loss reduction, water supplies for recreation use, and beach preservation.

In subregion 4, serious development inadequacies were revealed by the widespread drought-engendered problems concerning municipal and industrial water quantity and quality in the Delaware River basin and the adjacent northern New Jersey basins. Municipal, industrial, and marine wastes, acid mine drainage, thermal pollution, land erosion, and salt water intrusion all contribute to the poor quality conditions, particularly in the lower Delaware River and estuary. Many localities experience high flood losses, and in some cases it appears that emphasis should be placed on locally oriented projects involving nonstructural and less conventional structural measures. Major drainage projects may be warranted at a few locations. One such location in the Hackensack River basin, for example, is unique because of its proximity to New York City and its strategic location with respect to major transportation networks. There is strong conservationist support, however, for preservation of coastal swamps.

The upper portion of subregion 5 is in general characterized by a surplus of water over present requirements. Development needs pertain to improvement of water quality, reduction of flood losses, and provision of multipurpose storage for municipal and recreation uses. In

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the lower portion of the subregion, there is need for expansion of metropolitan water systems, improvement of water quality, and maintenance of desired ecological conditions in Chesapeake Bay. Development needs in rural areas are not significant on the western shore of the Bay because of the ever-expanding metropolitan service areas. On the eastern shore, however, local needs for flood control and drainage persist. In view of rising average annual flood losses, additional flood control and flood-plain zoning and other nonstructural measures are necessary.

Development needs in subregion 6 relate primarily to water quality control, low-flow augmentation, recreation, and reduction of flood losses. Municipal, industrial, and marine wastes, thermal pollution, acid mine drainage, and land erosion are among the factors contributing to the generally inadequate water quality conditions, particularly in lower river reaches and estuaries. The needed water quality improvement goes beyond levels that can presently be achieved even with effective waste treatment programs, which include high-efficiency treatment plants and appropriate standards, policies, and enforcement. Such programs must be complemented with streamflow regulation. The drought of the past few years has clearly demonstrated significant inadequacies in development for municipal uses. For example, the flow of the Potomac River fell to about intake rate for the municipal systems serving the Washington area. Throughout the subregion there is a general scarcity of fresh-water areas for recreation use, and, near urban centers, overcrowding and pollution restrict full enjoyment of available fresh and salt water areas.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

There is a need for integration of effort in all phases of water-related development. This would include planning, financing, constructing, managing, and operating these developments as well as coordinating private, public, and government views and interests. In the interest of developing and implementing better water resources programs, compatible and coordinated planning, programming, and budgeting systems must be instituted at the Federal level. A necessary complement to this process is the development of similar capabilities in the States.

Also needed are institutional arrangements that allow for freer exchange of sophisticated skills, in view of the intense competition in Federal, State, and local agencies, as well as in private agencies and industries, for trained personnel. There is a shortage of professionals in practically all fields related to water resources. Thus, even where fiscal restrictions are not a factor, it is very difficult to meet staffing requirements.

Reservoir sites, which constitute another scarce resource, are being lost to other land-use developments. Arrangements to preserve sites might involve zoning or other land-use regulation; changes in Federal laws to permit earlier acquisition; or State acquisition, with costs to be considered toward the non-Federal share of Federal projects.

The scarcity of reservoir sites and the need to integrate development efforts indicate that the full potential at each site must be considered. Institutional and functional limitations of the various agencies should not result in less than optimal development in terms of purposes served and the scale of development.

Satisfying water-related recreation demands involves both institutional and management problems. The competition for land creates problems in acquiring sites suitable for development and in providing guaranteed access to established recreation areas. In New England, Maryland, and a few other parts of the Region, some of the water supply reservoirs are suitable for recreation use, but problems arise because of incompatibility with the primary use, or because of problems entailed in assessing respective costs and in managing and policing recreation areas.

As pointed up by the effects of the recent drought throughout the North Atlantic Region, and perhaps most conspicuously in the New York City metropolitan area, continued study and evaluation is needed of the extent, degree, and significance of municipal water supply inadequacies. Regionalization of water supply services, where appropriate, especially the distribution and transportation of water, constitutes a major problem. An expanded role for interstate compacts might be one way to alleviate this problem.

Despite foreseen implementation problems, it appears that water quality improvement can be achieved to a large extent by increased funding, provided that research is continued concurrently. This possibility is especially relevant to pollution control techniques in tidal estuaries and in areas receiving mine waste discharges. The machinery for putting the results of the research to work in a combined government and private effort toward water quality control must be set up as soon as possible. More flexibility is needed in

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making decisions between utilizing low-flow augmentation for water quality control and providing advanced waste treatment.

There is need for increased knowledge about effective flood-plain management, taking into consideration a variety of structural and nonstructural techniques, and there is also the need to overcome lack of local awareness and participation. In connection with zoning, the establishment of consistent ordinances still leaves much to be desired. This is evidenced by the mixed reaction of the courts to various attempts throughout the Region to formulate zoning laws.

The Region must consider means of preserving natural beauty, open spaces, and the aesthetic values of river basins and rural areas. This will require the combined efforts of Federal, State, and local interests.

There is a need for broad action in developing more effective public information programs. Although public information subcommittees composed of Federal and State members are operating in connection with all comprehensive studies in the North Atlantic Region, it seems to be difficult to sustain the interest of the public and their legislative representatives in water resources planning and development unless such efforts are dramatized by emergency situations.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The North Atlantic Region contains the largest urbanized complex in the United States, a complex that can be expected to continue to grow toward the consolidation of a strip city from north of Boston to south of Washington. In 1960, the population of the Region was nearly 44 million, of which almost 25 million were living in the strip city commonly referred to as Megalopolis. By 2020, a regional population of almost 102 million is expected, with over 76 million in Megalopolis. This population increase of 130% is expected to be accompanied by increases of 730% in total personal income and 260% in per capita income. Table 6–1–3 illustrates the anticipated growth according to preliminary economic and agricultural projections. It should be noted that a substantial reduction in agricultural employment is foreseen, but a lesser reduction in productive croplands. Timber-based industries also show a marked drop in employment after 1980, with continuing increases in production resulting from technological advancements and employee skills.

The projection of water use is an essential part of water resources planning. Data are now

TABLE 6–1–3.—*Economic and agricultural projections, North Atlantic Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou	43,896	56,693	74,993	101,726
Per capita personal income	1954 dol.	2,282	3,525	5,300	8,150
Employment, total [2]	thou.	17,621	23,066	30,106	40,437
Agriculture	do.	406	242	191	180
Manufacturing	do.	5,589	6,356	7,259	8,857
Other commodity producing	do.	1,464	1,908	2,402	3,216
Distributive industries	do.	4,394	5,280	6,709	8,662
Service industries	do.	5,768	9,279	13,545	19,521
Land base	thou. ac.	106,254	106,254	106,254	106,254
Agricultural	do.	92,319	88,419	82,299	73,569
Cropland total [3]	do.	17,599	15,723	14,634	13,080
Used for crops	do.	15,377	11,957	11,944	12,826
Idle and fallow	do.	2,222	3,766	2,690	254
Pasture-permanent	do.	7,980	8,776	8,170	7,306
Forest and woodland	do.	66,740	63,920	59,495	53,183
Nonagricultural	do.	13,935	17,835	23,955	32,685
Irrigated land [4]	do.	[5] 240	380	550	700

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965, irrigated land amounted to 310 thousand acres.

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being developed in the North Atlantic Region type 1 framework planning study for such projections. For the purpose of this Assessment, preliminary gross projections were estimated based on readily available data (table 6–1–4). Cooling water withdrawals for steam-electric powerplants are expected to grow from the 22 bgd of 1965 to 184 bgd by 2020, or from about 60% to about 80% of total withdrawals. Saline water sources are expected to supply most of this increase.

Instream uses will all continue to increase, but by widely diverging rates. Water use for conventional hydroelectric power will increase very slightly if at all, but for pumped-storage installations the increase is likely to be sharp. The increase in inland navigation uses will probably be slow and occur mainly in the Lake Champlain-Hudson, Delaware, and, to a lesser degree, Chesapeake Bay areas. Instream water uses are likely to increase most in relation to recreation, fish and wildlife habitat, water quality control, and visual enjoyment, but not necessarily in that order.

EMERGING PROBLEMS

The North Atlantic Region's major water problem has already emerged; it is the race to keep up with a rapidly growing urbanized society and supply it with water from a resource having not only a fixed total quantity but also large variations in temporal and areal distribution. Coupled with this is the steady upgrading and shifting of objectives among a growing and affluent society. It is not enough to merely supply the water; it must be supplied in a manner that maintains a quality environment wherein aesthetic and cultural values are highly considered.

This most important problem requires that the objectives of water resource development in the Region as a whole and the relative importance of these objectives in various parts of the Region be defined. In a highly urbanized area, investment objectives other than those of increasing national income through counting of primary benefits are very relevant to planning. For example, the quality of urban environment in relation to water resources development becomes important, as well as the regional distribution of income and economic development. It is also important to identify these objectives and public preferences early in the planning process so that they can be taken into account in the choices that must be made to arrive at the final plan. Because of the expected increases in population and production in the Region, the importance of focusing clearly on the objectives of water resource development will become increasingly evident.

That local water supply agencies' need to plan for emergency situations as well as for long-range resource development was underscored by the 1961–66 drought. The possibilities of unexpected breakdown, power loss, natural disaster, and the recurrence of unusually severe drought conditions should be anticipated.

Greatly increased and improved efforts in research, development, and analysis of all aspects of water quality management will be needed to cope with the problem of more people and more waste versus an improved environment. These studies must not only address themselves to better methods of pollution control but also to such problems as the effect of water quality on the human environment, including public health aspects; institutional arrangements; the social forces controlling change; public understanding of the problem; and financing. As urban areas grow there will be increased pressures to develop lands within flood plains. Thus, improved flood control measures as well as comprehensive floodplain management, including zoning, floodproofing, insurance, and warning systems, will be required.

In northern areas, both coastal and inland wetlands are increasingly being lost to other uses. The need to protect these lands is becoming acute. Wildlife that thrives in such environments will be lost to future generations unless public control of these lands can be assured. The need to preserve estuaries, particularly as ecologic units, is also becoming more and more apparent. Basic and applied research programs should be intensified, to insure intelligent management, optimum use, and enjoyment of estuary areas extending along the entire coastal area of the Region. In addition, expanded programs will be required for the maintenance and restoration of once-abundant species of anadromous fish.

Improvement of techniques and lowered costs of exploration, development, and management of groundwater resources are also needed. It is anticipated that groundwater will continue to be relied upon to augment surface water. Interest in the possibilities of managed underground storage is increasing.

Steam-electric power generation, whether by fossil fuel or nuclear power, calls for enormous

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TABLE 6–1–4.—*Projected water requirements, North Atlantic Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	390	400	400	400
Municipal (public-supplied)	5,446	7,100	10,000	14,200
Industrial (self-supplied)	9,499	14,100	22,800	37,200
Steam-electric power (fresh)	10,500	10,900	11,300	14,700
(saline)	11,400	22,100	68,900	169,200
Agriculture:				
Irrigation	151	230	330	420
Livestock	81	90	130	170
Total	37,467	54,920	113,860	236,290
Consumptive use				
Rural domestic	186	200	200	200
Municipal	905	1,210	1,750	2,550
Industrial	555	850	1,500	2,600
Steam-electric power (fresh)	75	120	320	580
(saline)	83	180	750	2,000
Agriculture:				
Irrigation	150	230	330	420
Livestock	69	80	110	140
Total	2,023	2,870	4,960	8,490

quantities of water. Under present technology, future withdrawal requirements would be huge, plants and cooling towers could be of tremendous size, and considerable thermal pollution would occur. Unless planning for this type of development is deliberated with great care, it could seriously unbalance water resources programs for years.

The location of steam-electric powerplants in tidal estuaries is also an increasing concern. Studies in Maryland have indicated that heated discharges may upset the delicate environmental balance of these highly productive ecological areas. Further research is needed on the effects of the addition of heat on stream ecology and on means of making beneficial use of waste heat. Thermal pollution should be considered in the licensing of power generation plants.

Problems of major magnitude will develop in connection with depths, maneuvering spaces, and docking facilities as oceangoing vessels approach 500,000 tons. Regional port areas which will be involved include Portland, Boston, New York, Philadelphia, Baltimore, and Norfolk.

The need for sand for proper maintenance of beaches used by the expanding population along the Atlantic Coast will cause large problems, particularly in such present high-use areas as the shore areas of Long Island, New Jersey, Maryland, and Virginia. Use of sand generally available in areas nearby the beaches disturbs the local ecology. The recovery of sand from areas in the Atlantic Ocean requires much further research.

Expanded roles are emerging for commissions on water and related land resources development, regional organizations, and inter-governmental coordination agencies. These bodies must be well organized to handle complex regional problems in the distribution and transportation of waters, the intimate relationship between water supply and waste disposal, basin diversion, the complications of local versus metropolitan interests, and water rights. The New England River Basins Commission, which replaced the Northeastern Resources Committee, is a step in this direction. The Delaware River Basin Commission is also working along these lines, and proposals are now under way which may eventually result in Federal-State organizations for the Susquehanna, Potomac, and Hudson River basins. On the international front, there have been numerous studies under the International Joint Commission on the regulation of the Region's water areas which are contiguous to Canada.

Problems could arise between coordinating bodies such as the river basin commissions and

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the States that are party to such bodies. The regulation of water resources utilization involving the conservation, marketing, and distribution of water should be thoroughly investigated and clearly defined. Water resources management at this stage must be supported by increased water resources research and management planning.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

To provide sufficient water for the Region's large metropolitan areas, and especially the New York metropolitan area, in the event of another period of serious drought, additional sources of supply are urgently needed. The overall problem of municipal water supply is presently being investigated in connection with the Northeastern Water Supply (NEWS) study, looking toward development of plans to assure adequate water supplies for the metropolitan centers of the Region.

There is an immediate general need for water quality control throughout the Region. Such control, as contemplated in the Water Pollution Control Act, may be derived from low-flow augmentation as well as from advanced waste treatment. This would also result in enhancement of recreational and aesthetic values, fish and wildlife habitats, and municipal water supplies. Studies of water quality conditions in New England, the Hudson River basin, the Lake Champlain basin, metropolitan coastal areas of New York and New Jersey, and the Chesapeake-Susquehanna area are currently under way.

Regionalization of water supply and waste treatment services and increased roles for interstate organizations are measures essential to meeting water supply and water quality needs.

Flood control is vital throughout the Region, both in upstream and downstream areas. However, the area that has the greatest flood potential lies along the Passaic River in subregion 4; the problem has been under study since 1936, but to date no project has been approved. Other areas with extremely high flood potential that could, to a large extent, be reduced by construction of authorized projects, are in the Connecticut and the Housatonic basins in subregion 2 and in the Susquehanna basin in subregion 5. A considerable portion of flood damage in the Delaware River basin also could be eliminated by such construction, but about half of the total flood potential would still remain. To reduce flood damage in the Region as a whole greater use of nonstructural measures, including flood-warning systems, flood-plain information, zoning, and improved watershed management, would be essential to supplement present and future structural programs.

Increasing beach use and development require shore preservation and improvement. These problems need immediate attention in the vicinity of the metropolitan areas of New York and New Jersey. Since Federal participation in beach erosion control improvements is limited to publicly owned and publicly used shores, and the costs of such improvements are relatively high, it is anticipated that by 1980 the shore preservation problem will have become even more urgent. Protection against tidal flooding due to hurricanes and other storms or zoning areas subject to such flooding is one of the immediate needs. Concerted effort is also needed to protect estuaries that are particularly of value in relation to fish and wildlife, recreation, and aesthetics.

Because of the increasing size of tankers, there is an immediate need for deeper channels. This need applies to most of the deep-draft harbors in the Region, but especially to New York harbor, which handles the greatest petroleum tonnage.

Institutional arrangements are needed to identify and to preserve potential reservoir sites throughout the Region. These may involve zoning or other land-use regulations, changes in Federal laws to permit earlier acquisition, or State acquisition with costs to be considered toward the non-Federal share of Federal projects.

The various basin studies that have been completed (Delaware and Potomac Rivers) and those still under way (Susquehanna, St. John, Connecticut, Passaic, Raritan, and James Rivers and NEWS) should be coordinated with the North Atlantic Region type 1 study in such a manner as to yield optimal and timely development. Moreover, watershed land management must be incorporated as a basic and integral function of water resources development.

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CHAPTER 2

South Atlantic-Gulf Region

SUMMARY

The South Atlantic-Gulf Region encompasses 24 distinct river systems and numerous minor systems, totaling 276,000 square miles. Its average annual natural runoff of 197 bgd is the third highest in the United States. Despite this large quantity of available water, anticipated regional growth will place increasing demands on the management of water and related land resources.

The population of the Region was 19.7 million in 1960; by 2020 it is expected to be 61.4 million. Although total employment is expected to increase almost 230% during that period, agricultural employment will decline by 75%. Agricultural land is also expected to decrease 8.6%, from 155 million acres in 1960 to 142 million acres in 2020.

Economic growth is expected to be slightly below the national average. As this economic growth takes place, however, the demand for water will increase. Water withdrawals are expected to increase from 21 bgd in 1965 to 130 bgd in 2020, and consumption to increase from 2.7 to 8.3 bgd during the same period. By 1980, water supply storage needs for municipal and industrial uses will have increased by 240 billion gallons and for water quality control by 320 billion gallons. Recreation and lowland flood protection needs will double.

DESCRIPTION OF THE REGION

The South Atlantic-Gulf Region encompasses the drainage area from the point where the Virginia-North Carolina boundary meets the Atlantic Ocean to the mouth of Lake Pontchartrain on the Gulf of Mexico in Louisiana (fig. 6–2–1). Its 276,000 square miles includes parts of Virginia, North Carolina, Georgia, Alabama, Louisiana, and Mississippi and all of South Carolina and Florida. There are 24 distinct river systems, with numerous minor drainage areas. The terrain ranges from rugged, densely wooded mountains having conspicuous relief and well-defined narrow valleys through rolling plains with well-drained soils to flatlands, wetlands, and marshes adjacent to the coasts.

Most of the coastal plain is underlain by highly productive aquifers. Local streams are typically unreliable for water supply, although streams above the fall line can usually be developed by storage facilities. The Florida subregion has few such streams and few efficient reservoir sites. It also has the least promise of effective improvement of surface water resources, but groundwater is extensive and of usable quality. Springs having relatively uniform annual flows abound in the coastal plain in Florida and southern Georgia, Alabama, and Mississippi.

Twenty-eight metropolitan areas serve primarily as regional distribution points and centers of major financial and economic activities. Population of the Region in 1960 was 19.7 million, evenly divided between rural and urban, with 90% of the urban population living in the 28 metropolitan areas. Estimated per capita income in 1960 was about $1,430, about 72% of the national average.

Primarily agricultural prior to World War II, the regional economy has become rather widely diversified. However, agriculture is still a major industry; products include cotton, tobacco, peanuts, poultry, beef, pork, apples, peaches, pecans, citrus fruits, and dairy and forest products. Other important industries include textiles, apparel, metals, food processing, chemicals, transportation, and tourism. The Birmingham, Alabama, area is especially notable for its heavy industry. Tourism is rapidly growing throughout the Region because of mild weather conditions and the development of vacation resorts along the coasts and in the mountain areas.

The climate is characterized by well-distributed rainfall, mild winters, and warm-to-hot humid summers. Average annual rainfall ranges from over 80 inches in the mountains to about 44 inches in central Georgia. Freezing tempera-

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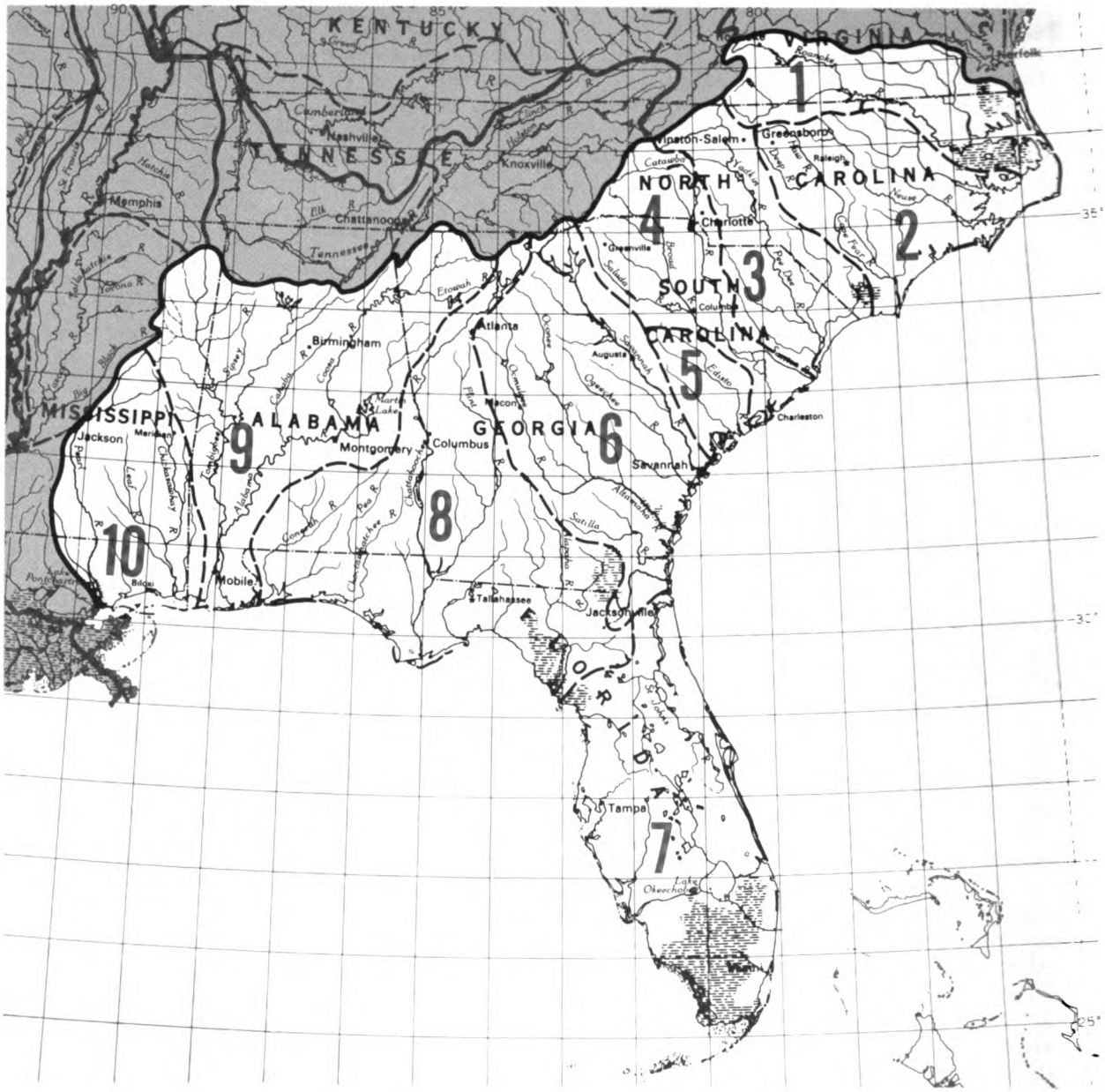

FIGURE 6–2–1.—*Map of the South Atlantic-Gulf Region.*

tures are rare in south Florida, but usually occur about 40 times per year along the fall line and 70 or more times in the mountain area.

Thunderstorms may occur any time of the year but are most common during summer afternoons. Hurricanes and lesser tropical storms cause varying amounts of wind, tide, and flood damage along the coast. General freedom from snow and frozen soil permits economical construction and year-round outdoor activity. Livestock commonly graze 9 months or more per year and require little winter housing. Prolonged droughts are rare, yet short dry spells are common enough to make supplemental irrigation a part of many farming operations.

THE WATER RESOURCE

Annual natural runoff ranges from 10.5 inches in subregion 5 to 20.8 inches in subregion 10 (table 6–2–1). However, runoff of individual basins ranges between 5 and 40 inches per year. Significant differences are apparent among the

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TABLE 6–2–1.—*Annual natural runoff, South Atlantic-Gulf Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	18,100	11.12	12.90	11.12	6.96	5.83
2	21,600	14.50	14.10	13.57	8.70	7.42
3	19,000	11.65	12.88	10.90	6.99	5.96
4	17,900	11.40	13.37	10.99	7.91	7.11
5	6,000	3.01	10.54	2.78	1.70	1.44
6	37,000	22.31	12.66	20.95	13.59	11.65
7	38,300	19.84	10.88	19.15	8.37	6.15
8	50,700	40.10	16.61	37.89	25.18	21.77
9	47,800	43.98	19.32	42.40	30.52	27.44
10	19,100	18.95	20.84	17.96	12.07	10.50
Regional value	275,500	196.9	15.01	188.4	131	116

subregions when average runoff is compared with runoff exceeded 95% of the time. Subregion 7 in the Florida peninsula has an average annual runoff of 19.84 bgd, while the annual runoff exceeded 95% of the time is 6.15 bgd. At the other extreme, subregion 4 in parts of North and South Carolina has an average annual runoff of 11.40 bgd and a runoff of 7.11 bgd exceeded 95% of the time.

The quality of streams is generally excellent. Most of the water is soft but that from limestone areas, particularly in subregion 7, is somewhat harder. Turbidity and color impair stream physical quality in parts of the coastal plain, and moderate to high sediment loads are prevalent.

The yield of groundwater varies greatly throughout the Region. The mountainous areas have well yields of 50 gpm in sandstone aquifers, 200 gpm in carbonate aquifers, and little or none in shales. Well yields in the Piedmont range from 0 to 400 gpm, with the sustained yield of most wells ranging from 10 to 40 gpm. The coastal plain has some of the most productive aquifers in the country. Wells in sand and gravel aquifers in Virginia, North Carolina, Alabama, Mississippi, and in the upper coastal plain in Georgia and South Carolina are capable of yielding 50 to 400 gpm of fresh water. Wells in limestone aquifers in southern South Carolina, southern Georgia, southeast Alabama, and all of Florida, commonly yield 1,000 gpm, with some wells yielding several times that amount.

The quality of groundwater is suitable for most uses; however, water from carbonate rocks is hard and many of the shallow aquifers contain corrosive water with a high iron ore content. Some deep lying groundwater in the coastal plain, especially near the coast, contains salt water. Salt water contamination will occur in these coastal wells if overpumped.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Urban populations are generally served by publicly owned water-supply systems. Municipal domestic use averages 110 gcd but is 140 gcd in subregion 7. Total municipal withdrawals vary considerably and this is caused largely by industrial uses. Table 6–2–2 presents the 1965 water use by subregions.

Most of the municipal water uses in the coastal plain are supplied from groundwater. Subregions 7 and 10, located entirely within the coastal plain, take 90% of their water for municipal use from wells. In contrast, municipal uses in subregions 2 and 3 pump only 14% and 8%, respectively, of their withdrawals.

Self-supplied industries withdraw more water than municipalities and average about 3.36 bgd for the Region. The largest withdrawals are in subregions 6 and 9. The large industrial withdrawals in subregion 6 are caused by "wet" industries in the lower coastal plain where groundwater supplies are plentiful. Much of this water is used in making pulp, paper, and related products from pine. The large withdrawals in subregion 9 reflect use in the Birmingham-Chattanooga industrial corridor and in the Montgomery and Mobile metropolitan areas.

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TABLE 6–2–2.—*Present water use, 1965, South Atlantic-Gulf Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
1	43	50	161	280	12	8	554
2	105	143	102	220	14	19	603
3	64	84	151	390	15	15	719
4	54	267	145	1,680	13	9	2,168
5	6	18	10	110	2	2	148
6	39	158	773	470	19	14	1,473
7	53	645	604	5,230	3,154	16	9,702
8	76	290	483	1,230	32	21	2,132
9	50	269	777	1,400	8	24	2,528
10	14	56	154	290	1	18	533
Total	504	1,980	3,360	11,300	3,270	146	20,560
From:							
Groundwater	(504)	(991)	(1,308)	(100)	(1,240)	(78)	(4,221)
Saline	.....	.....	(432)	(3,700)	.....	....	(4,132)
			Water consumed				
1	35	5	8	0	12	7	67
2	105	13	7	0	14	19	158
3	64	7	12	0	15	15	113
4	54	33	18	2	13	8	128
5	6	3	1	0	2	2	14
6	37	39	22	1	19	13	131
7	46	140	52	48	1,287	14	1,587
8	63	37	34	6	30	20	190
9	49	62	69	0	7	23	210
10	13	24	37	4	1	18	97
Total	472	363	260	61	1,400	139	2,695

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 13,402,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric power plants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

Practically all of the water used by steam-electric powerplants is for condenser cooling. Average withdrawals are 7.6 bgd of fresh water and 3.7 bgd of saline water.

Rural domestic and livestock uses are relatively small. Irrigation uses are small except in subregion 7, where over 3 bgd were withdrawn. Over 60% of irrigation withdrawals in the Region are supplied from surface water. About 1.5 million acres were irrigated in 1965.

Total withdrawals of fresh water were about 16.4 bgd in 1965. Of this, surface water withdrawals were about 12.2 bgd and groundwater withdrawals were about 4.2 bgd. Consumptive use is low regionally, but it may become seriously high in portions of subregion 7. Although the low year runoff is 6.2 bgd and present withdrawals and consumption are 9.7 and 1.6 bgd, respectively, the highly productive Floridan aquifer tends to even out hydrologic variations in most of the subregion.

Instream water use for hydroelectric power production in 1965 was about 200 bgd, and withdrawals for cooling purposes at steam-electric plants were about 11 bgd. The water used for hydroelectric power is about 55% of its estimated water use potential.

Natural lakes and springs used mainly for recreation are found in Florida and some adjacent areas in Alabama and Georgia. Elsewhere, farm ponds and large power reservoirs provide water-based recreation.

In 1965, residents of the Region spent about 90 million user-days in fresh water fishing and

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20 million user-days hunting. Commercial fish landings totaled about 79.3 million pounds, valued at nearly $55 million.

Floods cause occasional damage to a few communities and industries, but damage to cropland from flooding is common. Few people live and work in the flood plains because of frequent flooding.

Some pollution is attributed to location of cities on interstream ridges, distant from large rivers. Nine of the 28 metropolitan areas are so located. There has been a recent trend to more factories in rural areas and small towns, bringing the threat of pollution to more localities.

Table 6–2–3 gives an idea of the present level of water resources development in the Region.

TABLE 6–2–3.—*Water resources developments, 1965, South Atlantic-Gulf Region*

Item	Unit	Quantity
Reservoir storage uses:		
Municipal and industrial ..	bil. gal.	160
Agriculture	do.	260
Hydroelectric power	do.	[1]
Flood control	do.	[1]
Water quality control	do.	[2] 1,080
Instream uses:		
Hydroelectric power	mw	[3] 4,500
Navigation—harbors	thou. tons	85,895
—waterways	mil. ton-miles	4,642
Recreation	thou. user-days	[4] 160,000
Fish and wildlife	do.	118,000
Land management:		
Flood protection	thou. ac.	1,400
Irrigation	do.	1,500
Drainage	do.	739
Beach protection	miles	37
Hurricane protection	acres	300

[1] Information not readily available.
[2] Includes water stored for other purposes which augments existing river flows and improves water quality.
[3] 1,086 mw Federal.
[4] Total recreation use (land and water).

ADEQUACY OF PRESENT DEVELOPMENT

Ground and surface water sources are in general adequate for present water needs, and current development of the sources is keeping pace. However, developments are inadequate to meet present water-based recreation needs; for several large urban areas this shortage has become critical.

Watershed land management is needed on 1,141 small watersheds comprising 141 million acres. The need includes protection from floodwater on 7 million acres, drainage on 34 million acres, and supplemental irrigation on 2.9 million acres. When the watershed projects already developed are augmented by the completion of presently authorized projects, 555,000 acres of flood plain land in tributary watersheds will be protected.

Existing navigation needs in the Warrior and Alabama-Coosa System will be met mostly by presently authorized construction. Other basins in the Region have only a portion of these needs authorized.

Flood control needs in subregions 6 and 8 will be largely satisfied by construction of authorized projects.

Most of the regional needs for water resource development are not critical, and there are few shortages of water for municipal, industrial, power, or navigation uses. However, pollution control and water for low-flow augmentation is critical in localized areas. These problems are being aggravated by the construction of reservoirs which considerably reduce assimilative capacities in some reaches of the streams. There is little widespread, disastrous flooding. Improved flood and low-flow forecasting would assist in reducing flood damages and help operators of water supply works, irrigators, and others in need of forecast of streamflow information.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Water-associated problems are generally of secondary importance within the South Atlantic-Gulf Region. However, as population and economic activity increase, such problems will become more important. Few States have established effective agencies or provided significant funds for water resources planning or development. A lack of defined responsibilities in some State agencies causes planning and management difficulties. Most States do not have adequate organizational structure and staff to deal with emerging water problems.

Owing to the generally adequate supply of water, water laws and rights are not clearly defined. Florida is experiencing problems in regard to ownership of river and lake bottoms. North Carolina has legal problems concerning ownership of coastal marsh areas. Alabama has two research projects under way which are ex-

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pected to identify inadequacies in present water use laws and indicate solutions.

In 1958, the Congress established a United States Study Commission, with an independent chairman and members from six Federal agencies and four States, which studied the water and related land resources of a large portion of the Region. Since the completion of the Study Commission report in 1963, the States of Alabama, Florida, Georgia, and South Carolina have organized a Resources Advisory Board to assist in coordinating further planning and to monitor and assist in the implementation of the planned developments.

Although great strides have been made in recent years in reducing water problems, old incipient problems still remain. The growth of cities and industry, has magnified many of these, and changes in stream regulation and in public attitudes toward pollution control measures are slow in developing. Releases of water for water quality control are not clearly specified in most existing Federal reservoirs. Conflicting interests among preservationists, sportsmen, and regulatory agencies are complicating formulation of water quality standards by the States for interstate streams. The general need for efficient operation and maintenance of elaborate sewage treatment plants continues to increase, because properly trained and certified operators are in short supply. The relative roles of in-plant control of industrial wastes versus treatment by public agencies are being questioned. Urbanization, industrialization, and more intensive agricultural practices are expected to require major adjustments in institutional arrangements for pollution control.

The recreation potential is limited by a general lack of public access to streams and lakes. This problem is being partially solved through greater landowner permissiveness and through the acquisition of lands for public use. However, State and county governments need to give this matter more attention.

All States in the Region need to enact cost-sharing laws to match Federal and municipal funds for installing waste collection and treatment facilities. The States have difficulty in providing matching funds for agencies responsible for the preparation of State water plans under the provisions of Title III of the Water Resources Planning Act. Investment capital from within the Region is not readily available for promoting water resource developments; unless innovative local institutional arrangements can be evolved, outside assistance will become necessary for some of the more costly developments.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Region's economic growth will exceed the Nation's; however, per capita income is not expected to catch up with the rest of the Nation by 2020. The level of education and training is improving, and industrial development will be greatly enhanced by further emphasis on higher education, vocational training, and research facilities.

Certain resource-oriented manufacturing groups, such as lumber and wood, pulp and paper, and stone, clay, and glass industries, are expected to grow as raw material production increases and as markets are developed. Industries located in rural areas, such as textiles, apparel, lumber, food processing, and stone, are typically low-wage, slow-growth industries. This situation, plus the generally low farm incomes and the lack of rural job opportunities are manifestations of economic problems facing the Region.

Development of the water and related land resources of the Region for industrial and leisure-time use will contribute substantially to increased economic activity in services, trades, and construction. These and other categories of nonagricultural and nonmanufacturing activity are expected to grow in line with expansion of the basic manufacturing industries. Projections of population, economic activity, and land use are shown in table 6–2–4.

The total population is expected to increase over 200% between 1960 and 2020, with urban population increasing from 13.6 million, 62% of the total in 1965, to 55.9 million, 91% of the total in 2020. Agricultural employment will decrease 75%, the number of farms, 60%, and total agricultural lands and croplands, 10%.

Regional water withdrawals are projected to increase from 20.6 bgd in 1965 to 130.2 bgd in 2020 (table 6–2–5). Fresh water sources will be required for about 85 bgd of the 2020 withdrawal requirement. Consumptive use is expected to increase from 2.7 bgd in 1965 to 8.3 bgd in 2020.

Municipal water withdrawals are expected to increase from 2.0 bgd in 1965 to 8.3 bgd in 2020. Self-supplied industrial withdrawals will increase from 3.4 bgd in 1965 to 12.2 bgd in 2020, an increase of over 250%.

Estimated fresh water withdrawals for steam-electric power will increase from 7.6 bgd in 1965 to 56 bgd in 2020 and saline water withdrawals from 3.7 to 45 bgd. Many future powerplants are expected to be located near load centers.

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TABLE 6–2–4.—*Economic and agricultural projections, South Atlantic-Gulf Region*

Item	Unit	Projections			
		1960 [1]	1980	2000	2020
Population, total	thou.	19,727	29,099	42,602	61,438
Per capita personal income	1954 dol.	1,429	2,525	4,300	7,150
Employment, total [2]	thou.	7,232	11,142	16,354	23,639
Agriculture	do.	724	315	209	180
Manufacturing	do.	1,748	2,588	3,621	4,922
Other commodity producing	do.	873	1,156	1,563	2,135
Distributive industries	do.	1,699	2,883	4,064	5,622
Service industries	do.	2,187	4,200	6,898	10,780
Land base	thou. ac.	167,196	167,196	167,196	167,196
Agricultural	do.	155,178	151,028	146,588	141,908
Cropland total [3]	do.	29,587	27,880	27,063	26,202
Used for crops	do.	24,256	19,316	19,451	22,428
Idle and fallow	do.	5,331	8,564	7,612	3,774
Pasture-permanent	do.	16,707	17,177	16,671	16,137
Forest and woodland	do.	108,884	105,971	102,854	99,569
Nonagricultural	do.	12,018	16,168	20,608	25,288
Irrigated land [4]	do.	[5] 850	1,800	2,750	3,750

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture land.
[5] In 1965, irrigated land amounted to 1,500 thousand acres.

TABLE 6–2–5.—*Projected water requirements, South Atlantic-Gulf Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	504	380	340	310
Municipal (public-supplied)	1,980	3,300	5,400	8,300
Industrial (self-supplied) [1]	3,360	4,900	8,000	12,200
Steam-electric power (fresh)	7,600	28,500	39,800	56,000
(saline)	3,700	12,000	27,600	44,800
Agriculture:				
Irrigation	3,270	3,900	6,000	8,200
Livestock	146	200	300	380
Total	20,560	53,180	87,440	130,190
Consumptive use				
Rural domestic	472	355	320	290
Municipal	363	600	1,000	1,500
Industrial	260	380	620	940
Steam-electric power (fresh)	42	190	765	1,440
(saline)	19	80	215	385
Agriculture:				
Irrigation	1,400	1,600	2,450	3,350
Livestock	139	190	285	360
Total	2,695	3,395	5,655	8,265

[1] Includes 432 mgd saline water withdrawn in 1965. Saline water use is not projected for other than steam-electric power use.

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This trend, while reducing the cost of transmission, will increase demands for fresh water.

EMERGING WATER PROBLEMS

The problem of local financing for water and related land resources development is expected to continue to be greater in the South Atlantic-Gulf Region than in most of the other Regions of the Nation.

Anticipated urban and industrial growth will cause increased demands for water and will necessitate careful, comprehensive water and land management. Much recent growth has occurred on the headwater streams of North Carolina, South Carolina, and Virginia. The spectacular growth and limited water availability of the North Carolina Piedmont Crescent has reached the point where transfer of water between river basins is being considered. During the 1980-2000 period, water shortages are expected to occur in the populous St. Johns basin and Okeechobee-Everglades areas in Florida.

There is a growing need for water resource management to have accurate, timely, and organized information about water resources that are increasingly being altered by man's activities. A thorough knowledge of aquifer systems, per se, and of their prudent management and control is necessary to optimal use of groundwater supplies. Improper well spacing and overpumpage has created groundwater quality difficulties in several localities along the Atlantic and Gulf Coasts. Early action is necessary to prevent heavy industrial withdrawals from damaging the groundwater resource in Beaufort County, North Carolina. Several isolated cases of salt water intrusion, attributable to high withdrawal rates, have also been noted. Bacteriological contamination is beginning to be significant in some areas.

It is becoming increasingly difficult to meet the demand for high-quality recreation areas. Surface runoff from farm, forest, and urban developments contributes bacteriological contamination which severely restricts recreation use of small downstream impoundments and arms of some large impoundments. There is a great need for recreation activity zoning and for the application of sound public health standards to recreation water quality.

Comprehensive flood-plain management and zoning are needed. In some areas a marked reluctance to enact or enforce local zoning laws is a problem that must be overcome.

Conversion of agricultural and forested lands to urban and industrial uses has intensified flood potential, magnified silt pollution and other water quality problems, and reduced fish and wildlife resources.

Pesticides and other man-made chemicals are being used in ever increasing quantities. The use of aquatic herbicides to control noxious aquatic plant infestation requires careful surveillance. Ultimately, some exotic chemicals reach groundwater aquifers and watercourses. Their impact on man's health and on the aquatic environment requires study.

Overdrainage in some areas of Florida may create future water shortages. Moreover, the drainage and urban development of Florida swampland may not be compatible with water conservation.

Intrusion of fresh water into estuaries, causing changes in the salt water ecosystem of fish and bird life and their supporting aquatic species, is a growing problem in some Florida areas. On the other hand, invasion of salt water threatens the maintenance of fresh-water habitats on the Outer Banks of North Carolina.

Future industrial and urban growth will increase the need for more complete waste treatment and flow regulation to control water quality. Flow regulation is not feasible in all headwater streams, however, and other means of waste disposal and/or treatment must be devised for these areas. Extensive eutrophication of estuaries, lakes, and streams is an emerging problem. Present municipal waste treatment does not sufficiently remove phosphorous and nitrogen compounds, which cause excessive aquatic vegetation and algal growth. Agricultural runoff and industrial wastes also contribute to the problem. In Florida, recreation has already been restricted on several lakes because of aquatic growths, and eutrophication has been encountered in east coast estuaries.

There is a real need for water quality and waste treatment criteria that would be compatible with the cultural, economic, political, social, and technical conditions of the Region. The standards now being established by each State in cooperation with the Federal Government hold promise of meeting this need.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Water resources are adequate and available to meet the projected demand through 1980—but not all of them are developed. Surface water reservoir storage needs for municipal use are

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projected to be 400 billion gallons by 1980, or an increase of about 240 billion. Existing Federal programs should supply about 180 billion gallons of this storage, leaving about 60 billion to be developed by State, local, and private enterprise.

About 1,080 billion gallons of storage in 8 of the 24 major basins of the Region augment existing river flows and improve water quality. Additional storage requirements for 1980 are estimated to be 320 billion gallons. Two projects scheduled for completion before 1975 will provide 55 billion gallons of this additional storage. Several other projects are under study, but it is doubtful whether they can be developed by 1980.

Potential developments indicate that complete reuse of water in textile, paper, and other industries may be feasible in the near future. Research is needed to make this an earlier reality. Research is also needed concerning the use of deep wells or ocean outfalls for waste disposal.

By 1980, 190 additional small watershed projects should be operational, and many should include regulatory storage. About 210 multiple-purpose structures could be developed with public recreation facilities included that would provide 16.8 million recreation activity-occasions annually. Added storage for fish and wildlife and other purposes could be included as needed. About 877,000 acres of critical silt-producing land areas will need extensive conservation treatment by 1980 to reduce harmful effects of erosion. Existing programs may be able to install the needed measures. Of some 34 million acres in the Region having a drainage problem, 8.5 million are feasible to protect under existing criteria. By 1980, drainage improvements will be provided for about 3.75 million acres.

There is a need for flood protection of 3.3 million acres by 1980. Authorized Federal projects expected to be completed before 1980 will provide protection to 1.25 million, but continuing Federal programs can provide protection to only one-half of the remaining 2 million. Of 56,000 acres of lowlands subject to tidal flooding and needing protection from hurricanes, less than 500 are adequately protected. Four projects scheduled for completion by 1975 will protect 35,000 acres. Flood-warning services for riverine, estuarine, and coastal communities need expanding, and the development of community emergency plans to cope with flood disasters should be encouraged.

Beach erosion occurs on much of the 2,035 miles of coastline. By 1980, several hundred miles of beach will need protection. Six authorized projects provide about 91 miles of improvements and could be completed within the next 10 years. Recommendations emanating from 16 authorized beach erosion control studies may satisfy the remaining needs. Increased participation by local interests is needed.

By 1980, about 1,800,000 acres of agricultural land are expected to be irrigated, and increased technical assistance should be provided to landowners to insure efficient use of land and water.

Deep draft navigation requirements will increase to about 150 million tons annually by 1980. This increase can be met by increasing channel depths and widths at existing harbors, providing better maintenance at existing projects, improving existing terminal facilities, and developing newly authorized projects. Navigation survey studies scheduled for completion within the next 5 years may recommend improvements to provide for these needs. By 1980, commerce via waterways will be about 9 billion ton-miles annually. The Cross Florida Barge Canal, now under construction, and the authorized Tennessee-Tombigbee Waterway are expected to be completed before 1980 and will meet most of the 1980 requirements.

With the increasing population, demands for commercial fish products will grow. The need for developments to protect and improve the quality and accessibility of high-value natural habitats is emphasized by the projected commercial and sport fishing uses. Habitats suitable for the propagation and survival of diverse species are needed to meet the demand for 52 million more user-days for fishing and 15 million more for hunting by 1980.

Outdoor recreation use is expected to increase to 380 million annual user-days (land and water) by 1980. Only about half of these recreation demands can be met by existing Federal water resources development programs. Single-purpose recreation developments located near metropolitan areas should be considered in meeting high-density use requirements. Reexamination of existing water resources projects and examination of streams, bays, estuaries, islands, and shorelines need to be undertaken to determine the amount of additional recreation use that can be accommodated. Improved public access to ocean and other shoreline areas is also required. Quantitative and qualitative planning is needed to provide for adequate development, preservation, and maintenance of natural areas.

Federal hydroelectric projects currently under construction will provide 715,000 kw of installed capacity, non-Federal projects, about 1 million

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kw. Four other federally authorized projects on which construction has not been initiated are likely to be completed before 1980 and will provide 580,000 kw of hydropower. Non-Federal facilities may be developed that will provide 800,000 kw.

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CHAPTER 3

Great Lakes Region

SUMMARY

The Great Lakes Region has a moderate climate with an average annual precipitation of about 31 inches which yields 8.5 to 18.3 inches of runoff, depending on the subregion. In 1965, the population was 28 million; by 2020, it is expected to climb to 58 million. An urban-industrial corridor crossing the southern portion of the Region is expected to experience the greatest economic growth. Regional water withdrawals are estimated to increase more than six-fold between 1965 and 2020.

The predominantly rural northern part of the Region should continue to have abundant supplies of good quality water through 2020. The highly urban southern part of the Region, however, uses water in some areas in excess of that available on a long-term basis from local ground and surface sources. Both portions of the region obtain part of their requirements from the Great Lakes; in the southern portion, this use trend is expected to increase as the industrial corridor's economic growth continues.

Future developments will be needed for additional or improved municipal water supplies; waste treatment and flow augmentation for water quality control; flood-plain management; urban and agricultural drainage; water-oriented recreation; fish and wildlife habitat enhancement; irrigation; erosion and sediment control; and navigation facilities.

The Great Lakes themselves will need projects to minimize water level fluctuations or the effects thereof, enhance water quality, and improve facilities and waterways to accommodate the expanding commercial and recreation uses.

Proper coordination in planning, development, and management of water and related land resources is essential in the Region. The problems relating to control of the Great Lakes are both international and interstate in character, while the problems relating to the major urban-industrial centers often affect multicounty areas and more than one State. The newly established Great Lakes Basin Commission should provide such planning coordination within the United States. Coordination of the international aspects of the Great Lakes water level and flow problems are a Treaty function of the International Joint Commission.

DESCRIPTION OF THE REGION

The Great Lakes Region is defined by the drainage areas within the United States of Lakes Superior, Michigan, Huron, Erie, and Ontario, and the St. Lawrence River upstream from the point where it enters Canada (fig. 6–3–1). It includes a land and water area of about 175,000 square miles; an additional 120,000 square miles of land and water area in Canada contribute to the drainage basin. The Great Lakes system is about 2,000 miles long and has a total water surface area of about 95,000 square miles. The portion of the system included in the Region has a water surface area of about 61,000 square miles, with 4,000 miles of mainland shores and 1,500 miles of island shores. The Great Lakes are connected by the following rivers: the St. Marys from Lake Superior to Lake Huron; the St. Clair and the Detroit from Lake Huron to Lake Erie; and the Niagara from Lake Erie to Lake Ontario. The St. Lawrence River connects Lake Ontario to the Atlantic Ocean. Lake Michigan is connected to Lake Huron by the wide and deep Straits of Mackinac.

The basin was formed by glaciation and weathering processes and is characterized by low relief and fairly thick overburden. With the exception of the Adirondack range on its eastern boundary, there are no mountains of significance.

The land area (by whole counties) of the Region is about 82.3 million acres, of which about 71.1 million are agricultural land generally in private ownership. Forest and woodland make up 48% of the total land base. Mainly concentrated in northern Minnesota, Michigan,

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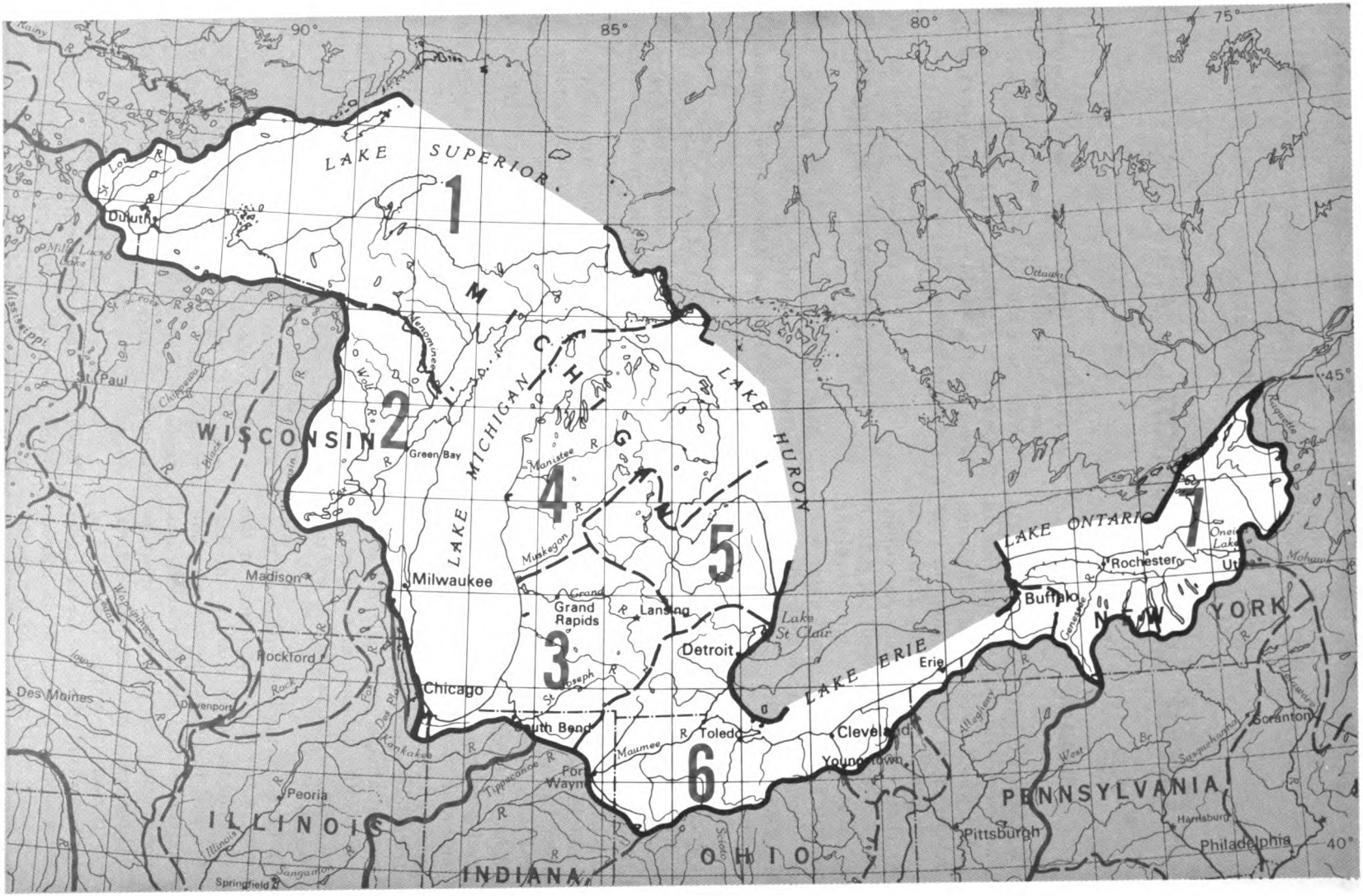

FIGURE 6–3–1.—*Map of the Great Lakes Region.*

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Wisconsin and New York, these forests represent a wide range of types, both hardwood and coniferous. The cropland and pasture, respectively, 33% and 6% of the total land, are primarily located in eastern Wisconsin, northern Indiana, northern Ohio, and southern Michigan. The remaining 13% of the land area, or 11.2 million acres, is nonagricultural and includes urban, commercial, transportation, and industrial developments, as well as farmsteads, idle lands (not idle cropland), and wildlife and small water areas.

The Region occupies about 4% of the United States land area and has 14.4% of the national population total. The 1960 population was about 25.5 million, 19.4 million of which were classified as urban area residents.

The southern portion of the Region specializes in manufacturing and is heavily urbanized. Durable goods industries, especially those involving the production and utilization of steel, are preeminently important. About 50% of the Nation's steel is produced in the Region, most of it in this southern area.

How significant the area's concentration of various types of United States manufacturing industries is can be shown by the percentage of the Nation's employment each of the following industries represents: primary metals, 42; instruments, 36; nonelectrical machinery, 31; fabricated metal products, 30; transportation equipment, 29; and electrical machinery, 26. Most of the industries serve national or major subnational markets.

Coal and limestone, water for manufacturing processing, and waterborne transport have provided the bases for the area's growth; continental land transport by rail and truck is also excellent. Chicago is the rail, retail, wholesale, service, and financial hub of the central United States. Its manufacturing includes basic steel, machinery, and food products. Other major industrial centers are Detroit (automobiles), Cleveland (basic steel, machine tools, and electrical equipment), Milwaukee (beer and heavy machinery), and the Calumet area in northwestern Indiana (basic steel, oil refining, and cement).

The eastern portion of the Region contains three diversified industrial cities (Buffalo, Rochester, and Syracuse), dairy farms, fruit orchards, and vacation resorts. The western portion—northern parts of Minnesota, Wisconsin, and Michigan—is thinly populated. It is not well-suited to farming and also has had difficulty in attracting diversified industry. However, it does have important lumbering, mining, and recreation industries.

The regional climate is moderated considerably by the presence of the Lakes, with average annual temperatures ranging from 39° on Lake Superior to 49° on Lake Erie. The mean annual precipitation is about 31 inches, varying from 26 inches in 1930 to 37 inches in 1950. The mean annual snowfall varies over the subregions from about 40 to 120 inches.

THE WATER RESOURCE

The average annual natural runoff (exclusive of the surfaces of the Great Lakes) is about 63.2 bgd or 11.6 inches (table 6–3–1). Little yearly and monthly variation in precipitation is ob-

TABLE 6–3–1.—*Annual natural runoff, Great Lakes Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	25,800	15.60	12.70	15.16	11.43	10.47
2	14,700	5.93	8.47	5.93	3.71	3.11
3	12,900	6.44	10.48	6.44	4.12	3.47
4	19,000	9.85	10.88	9.85	7.96	7.42
5	6,100	2.44	8.40	2.28	1.46	1.25
6	20,800	10.04	10.14	10.04	5.79	4.59
7	15,200	12.89	17.81	12.61	9.83	9.11
Regional value	[1] 114,500	63.2	11.59	61.4	46.3	42.4

[1] Does not include water area of Great Lakes.

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served. The influence of the Great Lakes is responsible for the fact that the climate is more moderate than that of other areas of the same latitude. The rather wide variations in runoff among the subregions are due to differences in glacial geology and land use, rather than to differences in annual precipitation.

The lake surface and land drainage areas of the Great Lakes system are shown in table 6–3–2, along with other hydrologic data. The average annual precipitation on the lakes is from 29 to 34 inches, whereas the average annual evaporation is only 21 to 33 inches; the result is an average net water gain from the lake surfaces. However, the margin of difference between precipitation and evaporation is relatively small and in dry years the lake evaporation may exceed rainfall, resulting in a net water loss.

The average natural water gain is a measure of the water available directly from each Lake for various water uses. This natural water gain to a given lake represents the algebraic sum of the contribution from precipitation on the lake surface, natural runoff from the land area, groundwater inflow, and evaporation from the lake surface. It approximates natural flow conditions without the effects of manmade imports or exports.

The level of each of the Great Lakes depends upon the balance between inflow and outflow. If the water supply to Lake Michigan were reduced by 6.5 bgd and this continued for a period of 3 years, as might occur during a period of reduced precipitation, the Lake level would be lowered about 0.5 foot at the end of the period. This would also result in lowered levels for Lakes Erie and Ontario of about 0.3 foot each after 39 and 42 months, respectively. These same lowered levels would also occur if the consumption of water in the Lake Michigan basin were increased by 6.5 bgd for 3 years. A variation of 6.5 bgd from the Lake Michigan water supply represents a variation of about 25% from the normal for that Lake, but only

TABLE 6–3–2.—*Hydrologic data for the Great Lakes system*

Item	Unit	Lake Superior	Lake Michigan	Lake Huron	Lake St. Clair	Lake Erie	Lake Ontario
Areas							
Water surface, United States	sq. mi.	[1] 20,700	[2] 22,300	[3] 9,100	[4] 198	4,980	[5] 3,600
Water surface, Canada	do.	[1] 11,100	—	[3] 13,900	[4] 292	4,930	[5] 4,000
Drainage basin land, United States	do.	[1] 16,700	[2] 45,600	[3] 16,200	[4] 2,850	18,000	[5] 15,200
Drainage basin land, Canada	do.	[1] 31,500	—	[3] 33,400	[4] 4,080	4,720	[5] 12,000
Drainage basin land, Total	do.	[1] 48,200	[2] 45,600	[3] 49,600	[4] 6,930	22,700	[5] 27,200
Drainage basin (land and water) Total	do.	[1] 80,000	[2] 67,900	[3] 72,600	[4] 7,420	32,600	[5] 34,800
General hydrologic data							
Average annual precipitation [6]	inches	29.45	31.08	31.14	[7]	33.69	34.10
Average annual evaporation [6]	do.	21	[8]	[8] 26	[7]	33	28
Average annual natural outflow [9]	cfs	71,000	[8]	181,000	[7]	203,000	237,000
Average annual natural outflow [9]	bgd	46	[8]	117	[7]	131	153
Average annual natural gain [9]	bgd	46	[8]	[8] 71	[7]	14	22
Highest monthly mean elevation [6]	ft. IGLD [10]	602.06	581.94	581.94	[11] 575.70	572.76	248.06
Lowest monthly mean elevation [6]	do.	598.23	575.35	575.35	[11] 569.86	567.49	241.45
Mean elevation [6]	do.	600.37	578.69	578.69	[11] 573.00	570.36	244.77
Average seasonal fluctuation	feet	1.0	1.0	1.0	1.7	1.2	1.5

[1] Including St. Marys River above Falls.
[2] Lake Michigan including Green Bay.
[3] Including St. Marys River below Falls, North Channel, and Georgian Bay.
[4] Lake St. Clair and St. Clair and Detroit Rivers.
[5] Lake Ontario including Niagara River and St. Lawrence River to Iroquois Dam.
[6] Period 1860-1966.
[7] Included as part of Lake Erie.
[8] Lakes Michigan-Huron as single unit because of common outlet.
[9] Period 1900-1964.
[10] International Great Lakes Datum.
[11] Period 1898-1966.

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about 5% from the normal available to that Lake from Lakes Superior and Huron, as well as itself.

Interregional water transfers affect the available water supply of the Great Lakes Region. The Long Lake and Ogoki projects in Canada, which began in 1939 and 1943, respectively, import water to Lake Superior from the Albany River basin, a tributary of Hudson Bay. These projects have imported an average of 3.2 bgd since 1945. Exports of water from Lake Michigan at Chicago to the Upper Mississippi Region began as early as 1848; since 1938, the diversion has been at an average rate of about 2.0 bgd. The New York State Barge Canal exports very minor amounts of water to the North Atlantic Region. There is presently no apparent basis for expecting additional diversions into or out of the Great Lakes Region in the foreseeable future, and it is reasonable to assume that the existing diversions will continue at their present average rates.

The quality of the surface waters of Lakes Superior, Michigan. Huron, and Ontario is generally high. However, serious local pollution problems exist in the vicinity of the many highly developed industrial centers, originating from both municipal and industrial water discharges. Water quality problems are evident in specific locations in the following subregions: 1 (Duluth-Superior harbor); 2 (lower Fox River and Green Bay harbor, and the lower Milwaukee River and harbor); 3 (Indiana harbor, St. Joseph and Grand Rivers); 5 (Saginaw River and Bay); and 6 (Detroit and Clinton Rivers).

Lake Erie and its tributaries in subregion 6 are polluted by municipal sewage, industrial wastes, oil, silt, floating solids, and nutrients (phosphates and nitrates). The major portion of the soluble phosphates reaching Lake Erie is discharged in municipal wastes. Overfertilization of Lake Erie has stimulated algal growths, which are responsible for taste and odor problems, damage to recreation water use, and creation of large areas in the lake having very low dissolved oxygen concentrations.

The availability and distribution of groundwater in the Region is good, although in subregion 7 quantity and quality vary considerably.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Total water withdrawn for use in the Region in 1965 averaged about 25.1 bgd (table 6–3–3). Of this total, 1.2 bgd, or less than 5%, is consumed.

Withdrawals for steam-electric powerplants, mainly for condenser cooling, amounted to 48% of total withdrawals, but consumption for these uses came to only 8% of total consumption. Industrial and municipal uses account for the next highest withdrawals and together exceed the steam-electric power withdrawals. Rural domestic and agricultural uses account for less than 2% of withdrawals, and for 20% of consumption.

Consumption of water by instream uses has not been estimated, but might be expected to have a direct relationship to land use practices and amounts of exposed wetlands or water surface in the Region. Major instream uses are for hydroelectric power, commercial navigation, fish and wildlife habitat maintenance, recreation boating, and general outdoor recreation. Inland lakes provide a large portion of the waters available for water-based recreation and for fish and wildlife habitat in the western part of the Region and in southern Michigan. Streams predominate in the eastern portion. The shoal waters of the Great Lakes provide additional opportunity for sport fishing and hunting. There are eight national wildlife refuges and four national fish hatcheries in the Region.

Historically, navigation has played a major role in the growth of the Region. The Great Lakes, with their connecting natural and navigation channels, form a deep-draft navigation chain with a controlling depth of 27 feet, extending from the west end of Lake Superior to the south end of Lake Michigan and to the east end of Lake Ontario at the head of the St. Lawrence River. A 27-foot navigation project is available on the St. Lawrence River from Lake Ontario to Montreal, and there is a 35-foot navigation channel from Montreal to the Atlantic Ocean. Navigation in much of the Region is closed about 4 months each winter due to ice conditions.

ADEQUACY OF PRESENT DEVELOPMENT

The Great Lakes and their connecting channels are major sources of water-related problems. As the Region developed, the water-oriented industries migrated to the shores of the lakes and of the connecting rivers. Extensive water transfer systems have been or are being developed to supply fresh water to and remove the waste water from the interior of the Region.

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TABLE 6–3–3.—*Present water use, 1965, Great Lakes Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
1	9	58	977	220	1	3	1,268
2	56	1,469	1,070	3,460	16	20	6,091
3	49	277	2,380	1,580	26	14	4,326
4	14	35	243	220	4	4	520
5	15	81	281	1,110	3	8	1,498
6	91	1,416	3,659	4,230	14	16	9,426
7	40	286	459	1,180	11	14	1,990
Total	274	3,622	9,069	12,000	75	79	25,119
From:							
Groundwater	(100)	(387)	(386)	—	(32)	(58)	(963)
Saline	—	—	(25)	—	—	—	(25)
			Water consumed				
1	4	6	75	2	1	3	91
2	21	147	40	27	10	20	265
3	14	61	100	12	26	12	225
4	3	5	7	2	4	3	24
5	3	16	8	9	2	7	45
6	51	218	114	34	14	15	446
7	4	49	18	9	11	12	103
Total	100	502	362	95	68	72	1,199

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 21,079,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes mining and military establishments.
[4] Public utility uses by steam-electric power plants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

As water uses increase from the expected increase of both population and industrial development, more of the existing interior water systems will supplement their stream sources by seeking additional supply from the Great Lakes. However, all available groundwater sources are probably not being effectively developed or utilized.

In the southern half of the Region, withdrawal uses exceed the available supply from interior streams. These uses are supplied primarily from the Great Lakes themselves, which in turn draw their water essentially from the entire Great Lakes basin.

The Great Lakes are used for commercial and recreational navigation, general outdoor recreation, fish and wildlife maintenance, and municipal, industrial, and steam-electric power water supply. Water quality in the Great Lakes, and not quantity, will be a major constraint in water resource development.

Control of stream water quality is a major need in the Region. Adequate treatment of all wastes, including necessary disinfection, should have high priority. Municipal wastes represent the largest source of pollution, but industrial wastes, combined sewer overflows, and vessel wastes are other contributors. Pollution control has not kept pace with urban growth.

Water resources developments on interior streams, excluding waste treatment facilities, are limited and usually single-purpose. During the 1920's, numerous small power dams were developed in the Region. Power generation of these dams is declining, but the impoundments are used for industrial and municipal water supplies. In other places, dams are being maintained or constructed to maintain impoundments and natural lake levels for beautification and recreation purposes. Small impoundments are being developed for recreation use and beautification effects in real estate developments. Also, Federal and State agencies and private groups are giving serious consideration to constructing reservoirs for water quality control.

The availability of water for recreation is

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adequate, but lack of public access to recreation areas is a major problem. More water-related recreation developments are needed closer to major population centers. Lands and waters available for the development of fish and wildlife resources are also adequate, especially in the relatively unpopulated areas in the northern part of the Region. Nevertheless, increased urbanization, industrial expansion, and pollution could operate to destroy the quantity and quality of fish and wildlife habitat.

Erosion control measures throughout the Region are needed. Land and streambank erosion is prevalent on many streams, and beach erosion is damaging 1,200 miles of Great Lakes shoreline as a recreation resource. In addition, the American Falls at Niagara are progressively deteriorating. Flood-damage control measures are insufficient, and it is estimated that 556,000 acres are now subject to flooding. Consideration must also be given to further regulation of the levels of the Great Lakes to reduce the adverse effects of extreme highs and lows.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

The international boundary between the United States and Canada divides four of the Great Lakes and their connecting channels. Only Lake Michigan is entirely within the United States. The International Joint Commission, United States and Canada, was established by treaty between Great Britain and the United States to deal with questions or problems that affect boundary waters. The Commission normally makes its investigations through engineering advisory boards composed of specially qualified personnel of technical agencies in the two countries. It receives the views of interested parties through public hearings and its boards coordinate their studies and activities with State, Province, and local government units on a continuing basis. Recommendations submitted by the Commission with respect to projects are subject to legislative processes in both countries. The Commission has been effective in dealing with major water problems on the Great Lakes, and this effectiveness is expected to continue.

The Great Lakes Basin Commission, established by President Johnson under the provisions of the Water Resources Planning Act of 1965, is committed to conduct water and related land resource planning within the Great Lakes Region. It is to be the principal coordinating agency for Federal, State, interstate, local, and nongovernment plans for development of water and related land resources. It will consider problems relating to water levels, pollution, navigation, shoreline development, flood control, erosion, fish and wildlife, and recreation, as well as the various withdrawal and consumptive uses of water.

The States in the Region are responsible for establishing and enforcing water quality standards under the Water Pollution Control Act of 1965. Joint Federal-State conferences have been held to consider pollution abatement in the Indiana harbor area, the Huron and Raisin River basins in southeast Michigan, and the Lake Erie basin. Schedules for construction of treatment facilities are being established in accordance with recommendations and conclusions of the conferees.

Present legal processes surrounding land and water rights are complex and require careful consideration in connection with planning for long-range development. There is also an apparent need for regulatory bodies with adequate legal power to enforce required controls. Furthermore, water management groups should be established to foster greater cooperation among water users. Proper functioning of these organizational measures is especially critical because many of the existing water problems are interstate or international in scope. Such changes will be needed to facilitate future development of the Region's resources.

Competition and conflict among the uses of water resource developments is a growing problem. Uses which provide the greatest monetary benefits are often given preference before a careful assessment of all water requirements has been made.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

In 1960, about 76% of the Region's population was classified as urban; by 2000, this percentage is projected to increase to 85%. The trend toward a high degree of urbanization is viewed primarily as expansion of the 27 major metropolitan areas. Projections shown in table 6–3–4 indicate that the regional growth rate for population, employment, and total personal income is slightly less than the Nation's, but this only means that the rest of the Nation is finally catching up with the historical growth of the Region.

There are major concentrations of industries

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TABLE 6–3–4.—*Economic and agricultural projections, Great Lakes Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	25,474	33,171	43,293	57,640
Per capita personal income	1954 dol.	2,218	3,450	5,325	8,075
Employment, total [2]	thou.	9,664	12,944	16,836	22,379
Agriculture	do.	299	164	124	115
Manufacturing	do.	3,699	4,660	5,303	6,475
Other commodity producing	do.	573	802	1,048	1,449
Distributive industries	do.	2,463	3,164	4,184	5,156
Service industries	do.	2,630	4,155	6,178	9,183
Land base	thou. ac.	82,302	82,302	82,302	82,302
Agricultural	do.	71,113	65,913	60,313	54,373
Cropland total [3]	do.	26,761	24,877	23,344	21,176
Used for crops	do.	22,555	23,144	22,824	21,055
Idle and fallow	do.	4,206	1,733	520	121
Pasture-permanent	do.	4,769	5,116	4,679	8,584
Forest and woodland	do.	39,583	35,920	32,290	24,613
Nonagricultural	do.	11,189	16,389	21,989	27,929
Irrigated land [4]	do.	[5] 100	230	350	470

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965, irrigated land amounted to 140 thousand acres.

in the Region that require large amounts of water, among them primary metals, fabricated metal products, food, chemicals, coal products, and paper and allied products. Most of these serve national or major subnational markets and are expected to exand as the Nation expands.

As projected in table 6–3–5, the principal withdrawals of water in 1980, 2000, and 2020

TABLE 6–3–5.—*Projected water requirements, Great Lakes Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	274	257	292	347
Municipal (public-supplied)	3,622	5,030	6,900	9,500
Industrial (self-supplied)	9,069	16,700	33,000	66,000
Steam-electric power (fresh)	12,000	25,700	56,100	114,700
Agriculture:				
Irrigation	75	110	170	230
Livestock	79	96	132	183
Total	25,119	47,893	96,594	190,960
Consumptive use				
Rural domestic	100	85	103	125
Municipal	502	702	953	1,304
Industrial	362	728	1,400	2,800
Steam-electric power (fresh)	95	184	467	898
Agriculture:				
Irrigation	68	95	140	190
Livestock	72	87	120	167
Total	1,199	1,881	3,183	5,484

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will be for steam-electric power and manufacturing industries. Consumption of water will be mostly for municipal, industrial, and steam-electric power uses.

From a summary viewpoint of economic development and water requirements, the Region's outstanding features are the large bodies of fresh water in the Great Lakes, its location within the highly industrialized north central United States, and the presence of valuable natural resources, among them iron ore, limestone, other minerals, and timber. The Great Lakes system, with its 95,000 square miles of water surface is the world's largest body of fresh water. The Region benefits from the system's provision of water for industry, municipalities, and recreation, as well as for transport of more than 100 billion ton-miles of waterborne freight per year.

EMERGING WATER PROBLEMS

The water problems of the Region are divided between the Great Lakes proper and the interior basins and are discussed separately below.

Great Lakes

Significant water resource problems of the Great Lakes fall generally into three categories: (1) lake level fluctuations, with accompanying discharge variations; (2) water pollution, resulting primarily from inadequacies of treatment; and (3) inadequacy of facilities and waterways to accommodate expanding commercial and recreational navigation.

1. Long-term water level fluctuations of the lakes are primarily caused by variations in precipitation over the basin. In the case of the two Lakes under control—Superior and Ontario—the variation effects are minimized by regulation. Abnormally high levels cause flooding and erosion damage to shorelines and structures; during the 1951-52 highwater level period, damage was estimated at $105 million (in 1964 dollars). Other kinds of damages and losses occur during abnormally low levels, such as those of 1964-65. The losses due to low levels range widely in character: less draft available to commercial navigation results in higher costs per ton shipped; decreased flows in connecting river channels decrease hydroelectric power generation; exposure of fish and waterfowl habitat threatens wildlife existence; exclusion of numerous canals and waterway areas to navigation discourages many recreation craft; and shoreline alterations and low water reduce recreation values in general. Numerous estimates of portions of such losses have been made, but an accurate total has so far not been compiled.

2. Quality control problems are becoming serious in Lake Erie and in the southern portion of Lake Michigan. Lake Erie, in particular, is experiencing large amounts of algal blooms supported by nutrient additions from waste discharges. Damages to fishery and waterfowl habitat have been immediate and evident, and the loss of recreation use of the Lakes is evident in the closing of some beaches. The problem may be alleviated as a result of Federal-State enforcement actions. The quality of tributary streams and the Great Lakes should be further improved by the establishment of water-quality standards now being developed for all interstate streams. From a fisheries standpoint, however, there is need for acceleration of research on the critical role of bottom sediments in the long-range oxygen problem of the Great Lakes.

3. Problems concerning the scarcity and inadequate size of facilities and waterways to accommodate increased commercial and recreational navigation uses of the Lake are expected to multiply rapidly as the full effect of improved harbors, the St. Lawrence Seaway, and connecting channels projects is felt. The trend toward larger commercial ships, which draw more water, will probably require the enlargement and deepening of existing projects and extending the navigation season. The rapid growth of the recreation fleet and its similar trend toward larger boats with deeper drafts will create problems of overcrowding and inadequate depths in existing facilities and waterways.

Interior Basins

Water resources problems of the interior basins are related to the Lakes, and it is not possible to make precise comparisons between subregional supplies and projected demands. It is safe to expect that an adequate quantity of water will be available for most needs. This would include supplying Great Lakes water to some places now using local sources.

1. Return water will have to be treated to remove pollutants, and, in some cases, new treatment methods must be developed as new products or processes change the character of wastes. Some solution must be found for the rise in temperature caused by water use for condensing or cooling. Increased use of cooling towers may be necessary.

2. While the quantity of water available in

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inland areas may be increased by provision of new reservoirs or by modification of existing regulating structures, the lack of good sites will lead to higher costs. At some points, it may be advisable to consider pumping from the Great Lakes as an alternative to regulation of inland streams. Water supply problems will tend to concentrate industries with high water use near the Lakes.

3. There has been a gradual development of supplemental irrigation by individual farmers to improve quality and yield of crops. The principal source has been groundwater, although some streams have been used. It is possible that withdrawals may increase in the future to the point of damage to downstream users or of lowering the water table locally. It may become necessary to provide additional supplies.

4. A major instream use of water is for recreation. Present demands are rapidly occupying available shoreline areas, and individual private developments are being taken over either for public recreation or for industry. The large demand for shoreline cottage sites is still mainly unsatisfied, but to a limited extent is being met by private construction of ponds. Demands for public facilities are expected to exceed the space that will be available at proposed multiple-purpose reservoirs, and it may become necessary to consider single-purpose reservoirs for recreation. Construction of artificial islands in shoal portions of large bodies of water may provide additional shoreline.

5. Effects of water resource development projects on fish and wildlife environment will have to be considered in planning for the future.

6. The Region contains 556,000 acres of flood plains subject to flood damages. Most of these plains are at higher elevations than the lakes, and their damages are not related to the fluctuations of the lakes. Increased development in the flood plains is expected to increase damages in the future and will require improved measures for flood control and flood-plain management. In addition, flooding and inadequate drainage create problems on flat upland areas, most of which are used for agriculture.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Development Needs

Development needs fall into two categories—those pertaining to the Great Lakes proper and those pertaining to the interior basins.

1. Great Lakes

An implementing program to raise the degree of waste treatment and to insure better control of all polluting materials from both land-based and waterborne sources will be needed if the water quality of the Lakes is not to be debased. Extensive surveillance and enforcement activities will also be needed.

Studies are needed to determine the feasibility of stabilizing the levels of Lakes Erie and Michigan-Huron. The economic feasibility of deepening channels and harbors to permit greater vessel draft for commercial navigation and extending the navigation season should be reexamined. Local beach erosion and damage control projects will be needed.

As other types of recreation facilities become more crowded because of growing population and increased leisure time, the need for closer spacing of harbors and additional harbor facilities to provide for anticipated increases in recreation boating will become necessary.

2. The Interior Basins

The major immediate need, that of eliminating restrictions now placed on water use by poor water quality, can be met by programs now under way. As population and waste production increase, it will be necessary to continue and expand such programs, and probably to require higher degrees of treatment.

Steam-electric power generation and its associated water use for cooling purposes will increase rapidly. Consideration must be given to the effect that returning large quantities of water at higher temperatures will have on desirable and undesirable plant and animal life. To prevent damage, such returns must be limited and may require supplemental cooling procedures.

With additional regulation of inland streams and pumping from the Great Lakes as alternative methods of supplying many water uses, studies should be made, in advance of growth of demand, to determine which source would be more economical. Another alternative to be considered in some areas will be recharge of groundwater.

Solutions to flooding and water management problems in flat upland areas are required to maintain an efficient and productive agricultural economy.

A continuing program for provision of additional shoreline and water areas for recreation would be desirable, particularly near the major urban centers.

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Management Needs

Management of water and related land resources is the concern of every citizen residing in the Great Lakes Region. There is need for a unified attack on the most pressing problems. A type 1 comprehensive framework study of both immediate and long-range water and related land resource needs of the Region by representatives of Federal agencies and each of the States involved was initiated in 1967 under the leadership of the Great Lakes Basin Commission. When the report on this study is completed, a management organization will be needed to carry out the recommended long-range coordination between the various levels of government and the private landowner or water user. Coordination will also be needed to go beyond the planning stage in the design, construction, and operation of water resource developments.

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CHAPTER 4

Ohio Region

SUMMARY

The Ohio Region produces more than 10% of the gross national product on 6% of the land area of the conterminous United States. Economic activity is expected to increase more than 6 times by 2020, requiring ever increasing quantities of water for municipal, industrial, steam-electric power, quality control, agricultural, and recreation uses. Water withdrawals currently amount to 17.4 bgd for steam-electric cooling and 11.2 bgd for other purposes, and consumptive use is about 1.4 bgd. Although the average annual natural runoff is 125 bgd, inconsistencies of availability and need occur each year. A number of smaller tributaries go dry in summer, and flow deficiencies in lower reaches restrict water uses. At other times, excess flows cause extensive flood damages.

If adequately managed, the water available is sufficient to provide for future needs. Groundwater aquifers are extensive and can supply water of satisfactory quality in many areas, particularly for smaller communities and light industry. Total withdrawal from all sources by 2020 is expected to be 61 bgd for steam-electric cooling and 30 bgd for other uses. Water reuse will increase and consumptive use will approach 5 bgd.

The total surface reservoir storage capacity is expected to increase from 7,600 billion gallons in 1965 to about 19,200 billion gallons in 2020. Large reservoir sites are scarce in some parts of the Region, but upstream storage sites of less than 3.3 billion gallons capacity are generally plentiful. However, under present criteria, the economic feasibility of either kind of reservoir is a matter for concern. Large storage sites are especially limited in subregions 3 and 4, which include large parts of Ohio and Indiana and a portion of Illinois, but groundwater aquifers in these areas generally have high yields.

Estimates of water and related land resource investments needed by 2020 are control of high and low flows, $11.5 billion; basic outdoor recreation facilities, including fish and wildlife environments, $3.1 billion; agricultural land treatment, irrigation, and drainage, $2.2 billion; and navigation, $3.0 billion. Also urgently needed are major investments in municipal and industrial water systems, waste collection and treatment facilities, and corrective measures applicable to dispersed sources of pollution including acid mine drainage.

Water is vital to economic growth in the Region. Industrial expansion and related demands for housing and for commercial and recreational facilities, and increased needs for minerals, food, and fiber will require the use of vast amounts of water. Forty-nine percent of the Region is in Appalachia, an economically underdeveloped area. Proper development and management of water resources and related lands and the control of flows can help to improve the economic situation for Appalachian residents.

The following items merit priority attention in the Ohio Region (the order of listing is not intended to indicate relative priority):

1. Formation of plans to make available to Federal, State, regional, and local officials and private interests the results of (1) the Region's type 1 comprehensive framework study and (2) the Ohio River Basin Comprehensive Water Quality Survey being conducted by the Federal Water Pollution Control Administration.

2. Establishment of effective and continuing institutional and public educational arrangements designed to encourage participation of Federal, State, regional, local, and private interests in coordinated planning, development, and operation of projects so as to best serve both public and private interests in all water and related land resource uses.

3. Allocation of more Federal and State funds for water resource development in areas of critical need to implement and expedite authorized programs.

4. Implementation of action to improve waste treatment, abate existing pollution, including

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mine drainage, and conserve good quality water in streams and aquifers.

5. Development of rules for project operation that are sufficiently flexible to allow reallocation of storage capacity or other modification of initial project purposes consistent with economic development or technological advances.

6. Identification and acquisition (or reservation by other means) of reservoir sites needed for future development.

7. Exploration and research (particularly regarding groundwater availability and water quality control) to identify alternatives and support efficient action programs.

DESCRIPTION OF THE REGION

Historic

Many of the pioneer settlers of the area that would become the Ohio Region followed the natural water routes taken earlier by exploration parties from the Atlantic Coast, Great Lakes, and the Gulf of Mexico to the interior. The abundant water supply, extensive fertile soils, and evidence of mineral resources the pioneers found gave impetus to dreams of economic development. Before long immigrants from overseas who were seeking communities in which to practice their skills and invest their savings were attracted to the area. Agriculture soon flourished on the fertile soils of the glaciated plains of central Illinois, Indiana, and Ohio, as well as in the bluegrass area of Kentucky. The overland routes traveled by settlers on horseback or in covered wagons soon became established roads, along which canals were sometimes developed, and later the trackbeds of the young railroads.

The first effort at planned water management was in the Wabash River area, where in 1808 private landowners built levees to protect their lands from flooding. Federal participation began in 1824 with the removal of sandbars to improve navigation on the Ohio River. Aided by abundant water supplies, small manufacturing and commercial centers began to grow into cities, as increasing water resource development provided water power and navigation facilities.

Demographic

In 1965, the Ohio Region contained 20 million people (nearly 11% of the Nation's total), with an average density of 116 people per square mile. The population is concentrated in the eastern and northern portions, reaching a density of 2,200 people per square mile in Allegheny County of the Pittsburgh area.

Columbus, Dayton-Hamilton, Cincinnati, Indianapolis, Louisville, and Evansville are all large population centers. The mountainous regions of West Virginia, Kentucky, and Tennessee are sparsely settled; but Charleston-Huntington, Lexington-Frankfort, and Nashville are important centers of growth and economic activity.

Economic

The Region contains one of the major concentrations of economic activity in the Nation. Situated between the populous East and the Upper Mississippi Valley-Great Lakes area, it serves as a transportation corridor as well as a source of raw materials and manufactured products. The labor force is over 7 million, which is 10% of the Nation's civilian labor force. In 1960, the gross regional product (or value added) was $51 billion. Of this, noncommodity industries, services, trade, etc., accounted for 42%; manufacturing, 33%; government, 12%; construction, 5%; mining, 4%; and agriculture, 4%. The Region accounts for 12% of the Nation's mining income, including more than 75% of its bituminous coal production. Mineral production also includes clay, sandstone, limestone, petroleum, natural gas, sand, gravel, and salt.

Geographic

The 163,000 square miles of the Region include major portions of Ohio, Indiana, Kentucky, and West Virginia; the western third of Pennsylvania; the eastern half of Illinois; parts of Tennessee; and small areas of New York, Maryland, Virginia, and North Carolina (fig. 6–4–1). The Ohio River flows through the center of the Region for 981 miles from Pittsburgh, Pennsylvania, to Cairo, Illinois. Much of the northern portion is a glaciated plain of minor relief. The unglaciated portion north of the Ohio River and all of the area south of it are hilly to mountainous. The geology is sedimentary except for a small section of the Blue Ridge in North Carolina and Virginia.

Of the 104 million acres in the Region, more than 1 million are under water. Nearly 5 million are in urban areas and some 94 million are privately owned. Over 50 million are in cropland and pasture, and extensive stands of hardwood timber are found in some 40 million acres of forest.

The eight subregions of the Ohio Region

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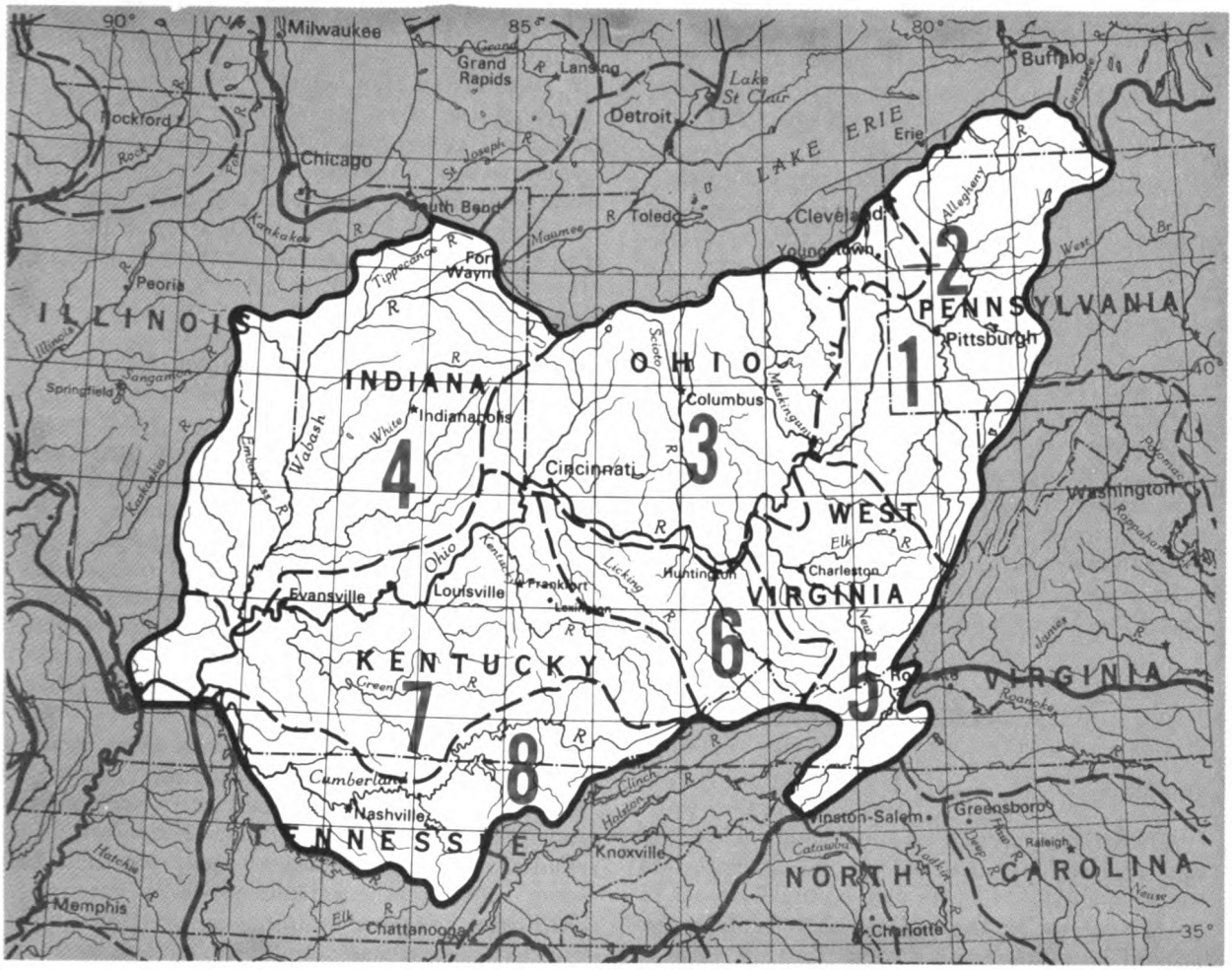

FIGURE 6–4–1.—*Map of the Ohio Region.*

form distinct geographic areas. These are shown in figure 6–4–1 and their characteristics are briefly outlined below:

1. Allegheny - Monongahela: Mountainous, forested; mining, heavy industrial complex in lower reaches.
2. Beaver: Heavily industrial.
3. Muskingum-Scioto-Miami: Part glacial plain; agriculture, manufacturing, commerce.
4. Wabash: Glacial plain; agriculture, industry.
5. Kanawha: Upper reaches rugged; mainly underdeveloped, but vast chemical complex along lower Kanawha.
6. Guyandotte-Licking: Rugged; mainly underdeveloped, but coal mining.
7. Kentucky-Green: Underdeveloped, but manufacturing, agriculture, coal mining.
8. Cumberland: Underdeveloped, but agriculture, light manufacturing, hydropower.

Climate

Summers are moderately warm and humid with favorable conditions for at least one harvest. Average July temperatures vary from 70° to 80° from northeast to southwest. Several days with temperatures above 90° can be expected each year, and extremes have been over 100°. Winters have several days of subzero temperatures, but average January temperatures range from 40° in the south to 26° in the north.

Flood occurrences vary. Ice jamming in water may cause floods in tributaries and interruption of navigation. Major flood-producing storms occur most frequently from December to April when soils are saturated or frozen, but they seldom cover the entire Region. Upstream flooding is often associated with high intensity local storms occurring during the summer months.

The growing season normally varies from 200 days in the south to 120 days in the northeast,

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although extremes of 247 in the former to 73 in the latter have been recorded. Prevailing winds are from the south or southwest, averaging 6 to 12 mph; maximum velocities have exceeded 80 mph.

Average annual precipitation is 44.8 inches. Average monthly precipitation is greatest in June or July and least in October. Snowfalls may be heavy, but are usually followed by thawing periods leaving no large accumulation for melting in the spring. Hurricane-associated rains occasionally spill over the Appalachians into the Region, causing floods. Widespread drought occurs on the average of once every 6 or 7 years but seldom results in complete crop failure, although it causes severe economic loss. Low streamflow and the drying up of ponds and shallow wells are annual problems. Potential evapotranspiration is 28 to 36 inches and results in peak demand for supplementary irrigation from June through August.

THE WATER RESOURCE

Quantity

The average annual natural runoff is 125 bgd and represents about 36% of the precipitation (table 6–4–1). It varies geographically from 21 to 12 inches. In the period 1928 to 1960, the annual regional runoff varied from 29.7 inches to 8 inches. The maximum was 32 inches for subregion 1, and the minimum was 2.9 inches in subregion 4.

Groundwater is usually replenished annually. The best aquifers are in the alluvial material along the Ohio River and in the lower reaches of tributaries. The glacial sediments to the north of the river are a mixture of clay, silt, sand, and gravel containing a large volume of groundwater. The bedrock produces good yields from wells in the sandstone and limestone, but there are areas of shale through the center of the Region where obtaining a supply is difficult.

Quality

In general, surface waters in the Region are of good chemical quality. Dissolved solids vary from less than 100 ppm to over 1,000 ppm. Principal water quality problems are associated with residual organics and nutrients, sediment loads, acid drainage from coal producing areas, and chlorides from industrial operations. Taste and odor due to organic chemical compounds and heat added by steam-electric plants create local problems. Hardness varies roughly from 60 to 240 ppm (soft to moderately hard) depending upon location, being highest in Ohio, Indiana, and Illinois.

Two-thirds of the Nation's acid mine drainage problem occurs in the Region. Approximately 2,900 miles of streams carry acid waste that is estimated at more than 2 million tons residual per year. Sediment loads are high in some subregions, particularly where extensive cultivation or strip mining is practiced and during construction activities. Average annual sediment rates per square mile have varied from 26 to 1,700 tons.

The chemical content of groundwater is generally higher than that of surface water and

TABLE 6–4–1.—*Annual natural runoff, Ohio Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	24,500	24.1	20.7	23.42	17.66	16.17
2	3,100	2.4	16.0	2.36	1.45	1.20
3	26,800	16.2	12.7	16.19	9.13	7.14
4	33,100	19.2	12.2	18.63	8.49	6.32
5	14,500	12.9	18.7	12.91	8.78	7.60
6	13,200	9.6	15.3	9.62	5.02	3.81
7	29,900	23.2	16.3	22.81	11.45	8.85
8	17,900	17.6	20.6	17.59	10.78	8.95
Regional value	163,000	125.2	16.13	125.2	80.0	67.5

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much more constant. During periods of low flow, the discharge of groundwater into streams grows in significance and the relative chemical content of the stream rises. Temperatures of groundwater range from 48° to 60°.

Extremes

Major water availability problems are associated with seasonal weather changes and concentrations of demand in particular locations and at particular times of year. The greatest flow of record at Metropolis, Illinois, near the mouth of the Ohio, was 1.9 million cfs during the January-February 1937 flood. The lowest estimated discharge at the same point was 10,000 cfs in 1930.

Seasonal Variation

Runoff is usually greatest in the winter and spring, averaging close to 50% of the annual flows during the 4 months from December through March and reaching a low in early fall. Many small streams are dry during the summer and fall. Base streamflow is from groundwater discharge. Groundwater levels are generally highest in the spring and lowest in September and October.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Present water withdrawal and consumption are 28.6 and 1.4 bgd, respectively (table 6–4–2). Cooling water for steam-electric power accounts for 61% of the withdrawals, but only 1% of the consumption. On the other hand, agricultural uses, including rural domestic, accounted for less than 3% of the withdrawals but 43% of the consumption.

The Region has about 46,000 miles of fishable

TABLE 6–4–2.—*Present water use, 1965, Ohio Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation	Livestock	
			Water withdrawn				
1	33	545	4,160	4,730	2	13	9,483
2	12	81	1,247	350	0	2	1,692
3	57	480	1,329	3,480	7	28	5,381
4	74	266	350	1,420	5	33	2,148
5	22	52	1,182	1,530	1	7	2,794
6	23	57	158	60	1	6	305
7	52	214	124	5,340	7	31	5,768
8	27	96	56	490	1	14	684
Total	300	1,791	8,606	17,400	24	134	28,255
From:							
Groundwater	(242)	(507)	(915)	(35)	(7)	(54)	(1,760)
Saline	—	—	(27)	—	—	—	(27)
			Water consumed				
1	12	54	185	38	2	13	304
2	6	8	43	3	0	2	62
3	48	50	41	28	7	27	201
4	49	61	7	11	5	32	165
5	18	3	77	12	1	7	118
6	17	5	15	0	1	6	44
7	27	28	31	42	7	31	166
8	23	21	11	4	1	14	74
Total	200	230	410	138	24	132	1,134

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 13,543,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric power plants (predominantly for cooling).

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streams, 36,000 acres of natural lakes, and 442,000 acres of impounded waters. These provide over 25 million angler-days. Hunting provided 23 million sportsman-days in 1965. The commercial fish harvest totaled nearly 8 million pounds. Water resources projects supported 41 million visitor-days of recreation. This includes associated State and local parks and nearly 1 million days of recreation at upstream watershed projects. Hunting and fishing accounted for about 20% of attendance.

Instream water use of 67 bgd produced more than 3 billion kwh of electricity at hydroelectric plants in 1965. Hydroelectric power is generated not only at storage dams but also at several navigation dams utilizing run-of-the-river flow. An additional 172 billion kwh were produced at steam-electric plants. Cooling towers are presently being constructed at steam-electric plants in several subregions. Fifty-two percent of the present population of the Region is served by combined sanitary and storm sewer systems. The 2,026 miles of navigable waterways in the Region carried 27.3 billion ton-miles of freight.

ADEQUACY OF PRESENT DEVELOPMENT

Additional funds for water management are urgently needed. Flood-plain regulation deserves increased attention. Fish and game management funds should be increased. Land treatment on agricultural and forest lands must be expedited. Waste treatment plants can be made more efficient through modification and increased operator training and certification. Improved flood and low-flow forecasting, especially for smaller drainage areas, would reduce flood damages and help operators of water supply works, irrigators, and others in need of streamflow data. More widespread monitoring of water quality would assist in managing flows and operating treatment works. Desalination is not widely practiced, but the techniques are used to improve the quality of water for boiler makeup and hence reduce fire tube replacement costs. Attempts at weather modification are not widespread, and there is concern about the possible effect of such attempts in adjacent areas.

The modernization program for replacement of the antiquated locks and dams on the Ohio River tributary system must keep pace with economic activity.

The need for additional water-related recreation is great. An equitable solution to the conflict between water uses, especially recreation and flow-supplementation drawdown for water quality control in the Region, must be found. More recreation access points, improved water supplies and sanitary facilities, and boat launching sites should be provided.

Private, local, State, and Federal efforts in the Region have resulted in such major achievements as improved watershed land management; storage of water for many uses and control functions; construction of waste treatment facilities; and development of a waterway that carries more tonnage than the Panama Canal and the St. Lawrence Seaway combined (table 6–4–3).

TABLE 6–4–3.—*Status of water and related land development, 1965, Ohio Region*

Item	Percent
Sewerage systems with treatment plants[1]	79
Population which is served by sewers that have operational treatment plants[1]	94
Industrial plants with some form of waste treatment[1]	90
Flood reduction in terms of annual damage:	
Upstream	5
Downstream[2]	58
Navigation: Ohio main stem modernization	47
Recreation days satisfied	40
Hunting-days and angler-days satisfied	80
Acres of land treated[1]	25
Drainage of land with economic potential	66
Irrigation of land with economic potential	4

[1] Does not imply adequate treatment.
[2] 60% of the area associated with these reduced damages requires additional protection.

Current development primarily requires that the existing degree of performance be maintained and improved and that implementation of needed projects be accelerated. To keep up with the growing demands for water use, attention must first be focused on specific problem locations. Many upstream communities have shortages of water supply in the summer months when needs are greatest. Small drainage areas are in particular need of storage for flow supplementation and irrigation. Recreation areas around Pittsburgh, Cincinnati, Louisville, and other urban areas are overcrowded. And because there are 362,000 registered pleasure motorboats in the Region, congestion and safety are problems on waterways.

It is estimated that more than 190 stream reaches scattered throughout the Region have quality degradation at low-flow periods because of organic waste loads. Heat pollution is significant in some areas, particularly in the

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Beaver, Green, and Cumberland basins and at Charleston, Columbus, Dayton, and Indianapolis. Chloride pollution is significant in the Muskingum and Wabash basins and to a lesser extent in the Big Sandy and Green basins. Acid mine waste remains a serious problem, although some progress is being made; among other ill effects, the acid pollution increases corrosion of vessels and shoreside facilities. At several locations, dissolved oxygen drops to zero for extended periods, killing or driving away aquatic life. Land erosion is apparent in some areas.

Residual flood damages still average $111 million annually, or $6 per capita; 52% occurs in downstream reaches and 48% in upstream watersheds. There are 18 urban centers having over $100,000 average annual damages, and 11 of these have over $200,000. Much of the main stem Ohio River and most of the tributaries, including upstream areas, are in need of additional flood protection. Agricultural flood damages are considerable. Not all remaining damage areas have been studied, and in some areas local and State interests do not have the funds available for the non-Federal share of the cost of local protection projects.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Existing laws and regulations impose few outright prohibitions on water resource use and development in the Ohio Region. The common law riparian doctrine is generally accepted, usually with modifications which vary from State to State. Although a great deal of legislation has been enacted, courtmade rules provide a substantial part of the water rights law in the Region. In a few States, water and land use policy has been clearly set forth in a specific section of the statutes. In others, policy fragments stem from many separate sections of law, from custom, and from court decisions.

Even the river basin of small or intermediate size, containing several hundred to a few thousand square miles, often embraces several cities and a number of counties. Jurisdiction and responsibility are divided among many governmental units. The River Regulating District in New York and the Conservancy Districts of Ohio and other States are early examples of special-purpose political entities created in an attempt to harmonize institutional and fiscal aspects of water management with engineering considerations.

Some aspects of land and water management remain essentially, or even exclusively, non-Federal, despite the trend toward assumption of more responsibility at the Federal level. The functions, responsibilities, and authorities of local governmental units have their origin in State constitutions and statutes. Significant differences exist from State to State in policy, administrative structure, and procedures for financing or sharing in the cost of development. These are due, at least in part, to varying laws and to the more obvious differences in population density, economic development, and financial resources. Some States have been more active than others in planning and developing programs for the management of water and related land resources. Special studies are periodically published by States on water quality, streamflow, groundwater, and other resources. Recreation and fish and wildlife management, setting of water quality standards, and regulation of waste-treatment plant design and operation are primarily State responsibilities, but Federal guidance and financial assistance often play a role in these programs. Effective relationships require familiarity on the part of Federal planners with the laws, policies, programs, and administrative arrangements of the States concerned.

As the relative availability of land and water declines in relation to expanding needs, increasing legal and institutional problems are expected. The existing institutional framework is not regarded as permanent or inflexible. The need for new laws or institutions may be minimized, however, by taking advantage, within existing laws, of little-used alternatives, or by changes in the rules or practices of administrative agencies and local governments.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Region's population growth rate is expected to gradually increase, approaching the national rate by 2020. Expected future population, employment, personal income, and land use are shown in table 6–4–4.

Agriculture and mining will remain important in the Region's economy, although their relative positions in terms of total output and employment are expected to decline. Waterborne commerce is expected to increase nearly six times between 1960 and 2020 to a total of 150 billion ton-miles.

The major growth in population and manufacturing activities is expected to occur in subregions 3, 4, 7, and 8; the population is pro-

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TABLE 6–4–4.—*Economic and agricultural projections, Ohio Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total [2]	thou.	18,793	23,498	30,742	41,241
Per capita personal income	1954 dol.	1,840	3,050	4,900	7,750
Employment, total [3]	thou.	6,546	8,575	11,361	15,417
Agriculture	do.	439	213	152	136
Manufacturing	do.	2,067	2,676	3,271	3,979
Other commodity producing	do.	644	730	918	1,233
Distributive industries	do.	1,631	2,058	2,608	3,514
Service industries	do.	1,765	2,898	4,412	6,556
Land base [4]	thou. ac.	102,164	102,164	102,164	102,164
Agricultural	do.	91,994	88,944	85,384	81,574
Cropland, total [5]	do.	39,284	36,039	34,597	33,054
Used for crops	do.	34,777	30,323	29,167	30,754
Idle and fallow	do.	4,507	5,716	5,430	2,300
Pasture—permanent	do.	12,483	14,011	13,449	12,847
Forest and woodland	do.	40,227	38,894	37,338	35,673
Nonagricultural	do.	10,170	13,220	16,780	20,590
Irrigated land [6 7]	do.	[8] 35	215	774	1,420
Drained land [7]	do.	11,000	15,300	16,200	16,600
Urban land [7]	do.	5,300	6,300	8,300	9,700

[1] Some data for 1959.
[2] Type 1 study projections are 28.6 million for 2000 and 34.8 million for 2020 with consequent changes in employment. Per capita income estimates were 3-12% higher.
[3] May not check due to rounding.
[4] Type 1 study projections of land use differ from these WRC land use projections.
[5] Includes cropland used as pasture.
[6] Includes cropland and pasture.
[7] From type 1 study.
[8] In 1965, irrigated land was 55 thousand acres.

jected to double by 2020 and manufacturing output to increase about 6 to 8 times. Should the Appalachian Regional Development Program (PL 89–4) succeed, then substantial economic growth will also occur in subregions 1, 5, and 6.

Projected withdrawals and consumptive use of water for various purposes are shown in table 6–4–5, and demands on instream uses are summarized in table 6–4–6.

Control of high and low flows is of major importance for flood damage reduction and for low-flow augmentation for water quality control, withdrawal uses, and instream uses. Hydropower generation can also be developed or increased at many existing facilities. Projections of water control requirements to provide for most expected needs are given in table 6–4–7.

EMERGING WATER PROBLEMS

Expanding population and industrial activity in the Ohio Region will create an increasing demand for water in the years to come. Although not indicative of the relative magnitude or urgency of water resource development problems, the 1965 uses may be multiplied by the following factors to reflect the projected 2020 needs: irrigated acreage, 26; electric power, 11; hydroelectric power, 20; recreation days, 5; navigation ton-miles, 7; flood damages without effective flood-plain regulation or additional flood control works, 3; waste loads, 3; municipal and industrial withdrawals, 3; fishing-days, 2; and hunting-days, 1.2. Water quality control and aesthetic values will require consideration in all aspects of development plans.

By 2020, water withdrawal in the Ohio Region is estimated to be 73% of the average annual natural runoff. In 5 years out of 100, natural runoff is less than 54% of the average and in some years as little as 25%. Increased water demand will require more reuse, greater control of high and low flows, and intensive development of groundwater aquifers. In some areas, aquifer safe yields will be reached and artificial recharge must be practiced. Many streams will require conservation storage to satisfy downstream demands for water. In some areas there is a shortage of economical storage to provide for increasing low flows. Research

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TABLE 6–4–5.—*Projected water requirementts, Ohio Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	300	350	415	490
Municipal (public-supplied)	1,791	2,330	3,320	4,900
Industrial (self-supplied)	8,606	11,600	15,900	23,200
Steam-electric power (fresh)	17,400	27,300	45,200	61,200
Agriculture:				
Irrigation [1 2]	24	102	352	685
Livestock	134	129	194	258
Total	28,255	41,811	65,381	90,733
Consumptive use				
Rural domestic	200	250	290	340
Municipal	230	300	430	620
Industrial	410	550	770	1,100
Steam-electric power (fresh)	138	350	775	1,190
Agriculture:				
Irrigation [1 2]	24	102	352	685
Livestock	132	129	194	258
Total	1,134	1,681	2,811	4,193

[1] WRC projections differ.
[2] Requirement for normal years; dry year requirements may be up to 45% higher.

TABLE 6–4–6.—*Projected instream water uses, Ohio Region*

Type of use	Unit	1965	Projected requirementts 1980	2000	2020
Hydroelectric capacity:					
Conventional plants	mw	1,100	1,300	2,700	4,100
Pump-storage plants	mw	0	2,000	10,000	18,000
Navigation	bil. ton mi.	27.3	56	97	150
Outdoor recreation [1]	mil. user days	220	390	710	1,030
Hunting [1]	mil. user days	22.7	25.5	26.5	28
Fishing [1]	mil. user days	25.1	35.2	41.0	46.8
Average annual flood damages [2]	mil. dol.	111	144	209	296
Residual waste loads [3]	thou. population equivalents	4,130	6,000	8,770	13,300

[1] Total demand includes adjacent land areas.
[2] Assuming no additional protection beyond projects completed, under construction, and in advance planning stage in 1965.
[3] Assumes 85% removal of BOD.

and prototype experimental installations are needed for advance waste treatment and to increase stream reaeration by other means than flow supplementation. Research on reduction of cooling water needs for power generation is needed. The consequences of a catastrophic flood must be considered, even in cases where protection is already provided or may not be economically justified when computed on an average annual basis.

Economical large-storage reservoir sites are becoming scarce; remaining sites must be preserved for future development. The controllable drainage area and storage available per site is declining, thereby increasing the cost per acre-foot of storage—50% of the reservoirs consid-

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TABLE 6–4–7.—*Projected water control features, Ohio Region*

Type of feature	Year			
	1965	1980	2000	2020
Storage (1,000 af):				
Watershed detention	284	1,630	3,287	3,800
High flow	17,000	22,500	28,400	33,300
Low flow and other multiple use	2,300	—	—	[1] 17,000
Hydroelectric power	3,710	—	—	5,000
Local flood protection (miles of levees, walls, channels):				
Urban	600	760	910	1,030
Upstream watershed	961	3,370	6,400	7,300
Drainage (1,000 ac)	1,200	1,520	1,590	1,610

[1] 22 maf required of which about 5 maf will be provided by seasonal use of flood control storage.

ered potentially available to fulfill 2020 needs store less than 32.6 billion gallons (100,000 af). Progress has been made in the upstream watershed program, but the rate at which these projects are being installed falls short of water and related land resource development needs.

Increased storage at existing sites is generally physically possible, but in many cases uneconomical or unacceptable because of shoreline interests. Part of the problem may be the Federal policy of optimizing benefits rather than utilizing the full potential of available sites. Encroachment on flood control pools for conservation storage earlier in the spring can make more water available for lowflow releases, but there would be somewhat higher risks of flood damages.

Evaporation and transpiration are becoming significant as related to seasonal water needs. Increasing conflicts will develop among land and water resources needs for food and feed crops, timber and other fibers, mining, urban areas, electric energy, transportation corridors, and outdoor recreation. Optimum utilization of limited resources for all purposes is important. Land treatment and management should be improved on 88 million acres. The 25% presently treated is projected to increase to 46% by 1980, 70% by 2000, and 85% by 2020.

Acid pollution is one of the basin's most serious problems. Coal production is increasing, and all streams in the coal producing areas require consideration to make high quality water resources available for municipal, industrial, agricultural, fish and wildlife, and recreation uses. Economic relationships involved in flow management deserve particular attention. Conflicts among instream uses of water will increase as the demands grow. Even if waste treatment meets the requirements of law and policy, pollution may still be an occasional problem because of high concentration of municipal and industrial wastes during periodic low flows.

Water storage and management will be necessary to release water when it is needed for various purposes, to control and store excess flows, and to fully utilize the surfaces of impounded waters and adjacent lands for recreation purposes. The quality of water must be such that the streams can provide for the needs of the Region. In general, there is a backlog of authorized programs, and the pace of implementation even in critical areas is slower than growing needs. Financing water resources programs, especially for low-flow supplementation, will be a serious problem. Organized planning to maximize the return from the Region's resources is a continuing necessity.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

The period from now until 1980 is critical in the Ohio Region. Problems only now emerging will become serious. It is estimated that over 500 rural and urban areas will be in need of additional water supplies. Indianapolis, Dayton, Lexington, Columbus, and Charleston are among the heavy use areas not located on the main stem of the Ohio River. Unless flows are supplemented or advanced waste treatments are practiced, by 1980 more than 200 stream reaches are expected to experience periods of oxygen deficiency because of residual organic wastes. Indianapolis, Dayton, and Columbus are among

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the major population centers in need of water for dilution of already highly treated wastes. Many communities must increase treatment to comply with minimum standards. Flood damages are increasing and flood-plain regulation and additional control works are urgently needed.

It is estimated that by 1975, with optimum land utilization, approximately 60 million acres will require conservation treatment to meet the needs for food and fiber of the Region and the Nation. Approximately 230 watershed projects are needed by 1980, an increase of 60% over the present rate of development. These would provide an increase over the 1965 program of 425 billion gallons of storage for flood water detention, 110 billion gallons of storage for municipal water supply, 70 billion gallons of storage for water quality control, and 88,000 surface acres for recreation and fishing. Potential storage locations and lands for recreation and fish and wildlife management must be set aside to allow for an increase in requirements for outdoor recreation of 170 million visitor-days. The demand in the Region's national forests for recreation and fish and wildlife is expected to increase sixfold and threefold, respectively, by 1980. Irrigated acreage is expected to increase from 35,000 acres in 1960 to 215,000 by 1980, and farm drainage from 11 million acres to 15.3 million.

Existing laws, policy, and administrative procedures should be reviewed and improved for greater effectiveness. Past programs have fulfilled their major purposes, but their relationship to existing and future basinwide and local problems should be more fully explored.

The Ohio River Basin Comprehensive Study, a type 1 framework study, is scheduled for completion in 1968, as is the Appalachian Comprehensive Water Resource Survey. The Kanawha and Wabash type 2 basin studies are scheduled for completion in 1969. The latter three studies will recommend projects for authorization. All are being closely coordinated with Federal agencies and the States involved. Each State in the Region has prepared a comprehensive plan for general outdoor recreation development which includes fishing and hunting requirements. The FWPCA Ohio River basin comprehensive study will determine the type of waste treatment and management required, estimate costs, and consider the various alternatives to maximize returns under the various sets of water quality criteria. In addition, many detailed studies and plans for development by Federal agencies, States, and local governmental units have been recently completed or are under way.

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CHAPTER 5

Tennessee Region

SUMMARY

The average annual precipitation in the Tennessee Region is 52 inches, slightly more than 21 inches of which appear as natural runoff of 42 bgd. The runoff is controlled by a system of reservoirs under the jurisdiction of the Tennessee Valley Authority (TVA). The water is used to generate hydroelectric power through as many as 14 reservoirs in series and to maintain more than 750 miles of channel available for commercial navigation. Moreover, the storage averts millions of dollars in flood damages, creates lakes with high recreation and industrial value, and provides adequate flows during the dry season.

Since 1933, when the TVA was established, the Region's economy has been transformed from predominantly agricultural to largely industrial and commercial. The income per capita has risen from 45% of the national average to 70%, but more needs to be done to meet the needs of a population that is expected to increase by more than one-third in the next 20 years.

Water withdrawal and consumption are expected to increase substantially. Municipal, industrial, and agricultural (including rural domestic) uses constitute the greatest water consumption and together they consumed 325 mgd of the 1,438 mgd withdrawn for these uses in 1965. On the other hand, steam-electric powerplants withdrew about 4,330 mgd in 1965, but their consumption was only 6 mgd. Their major effect is an increase in the water temperature in the immediate vicinity of the plants.

The regionwide supply of water is adequate for all anticipated needs, but additional seasonal regulation will be necessary in local areas. Pollution by municipalities and by industries must be curtailed, and development of residential, recreational, and industrial lands along the waterfronts must be conducted with due regard for the control of erosion and sedimentation. Such objectives will be particularly essential on the smaller tributaries where dry-weather streamflows are small and floodflows are uncontrolled. Achievement of the objectives will require a flexible system of management to resolve conflicts in the several categories of resource use. One of the questions facing the Tennessee Region is whether present and potential water use requirements and conflicts necessitate changes in water-rights laws and in the organizations for administering such laws and dealing with water problems generally.

High on the priority list is implementation of a plan for meeting the complex water development needs of the French Broad River in North Carolina. Another priority item is enlargement of programs for recreation development to accommodate public use and protect public access to lakes and streams. More communities could benefit from expansion of programs for limiting development in areas subject to floods. Further efforts should also be made toward reclamation of strip-mined areas. These and other objectives can be met if local organizations will continue to work with State and Federal agencies in programs of tributary area development directed toward comprehensive and unified development of the resources of the Region.

DESCRIPTION OF THE REGION

The Region's area of 40,900 square miles includes portions of seven States (fig. 6–5–1). The whole area is replete with contrasts. For example, its topography includes both rugged mountains and broad valleys, it touches the Deep South on one side and the Midwest on the other, and its economy has shifted dramatically during the last 25 years from agriculture toward industry.

The Tennessee River, beginning at Knoxville, flows 650 miles southwestward, westward, and then northward to its outlet in the Ohio River at Paducah, Kentucky. There are seven major tributaries with drainage areas ranging between

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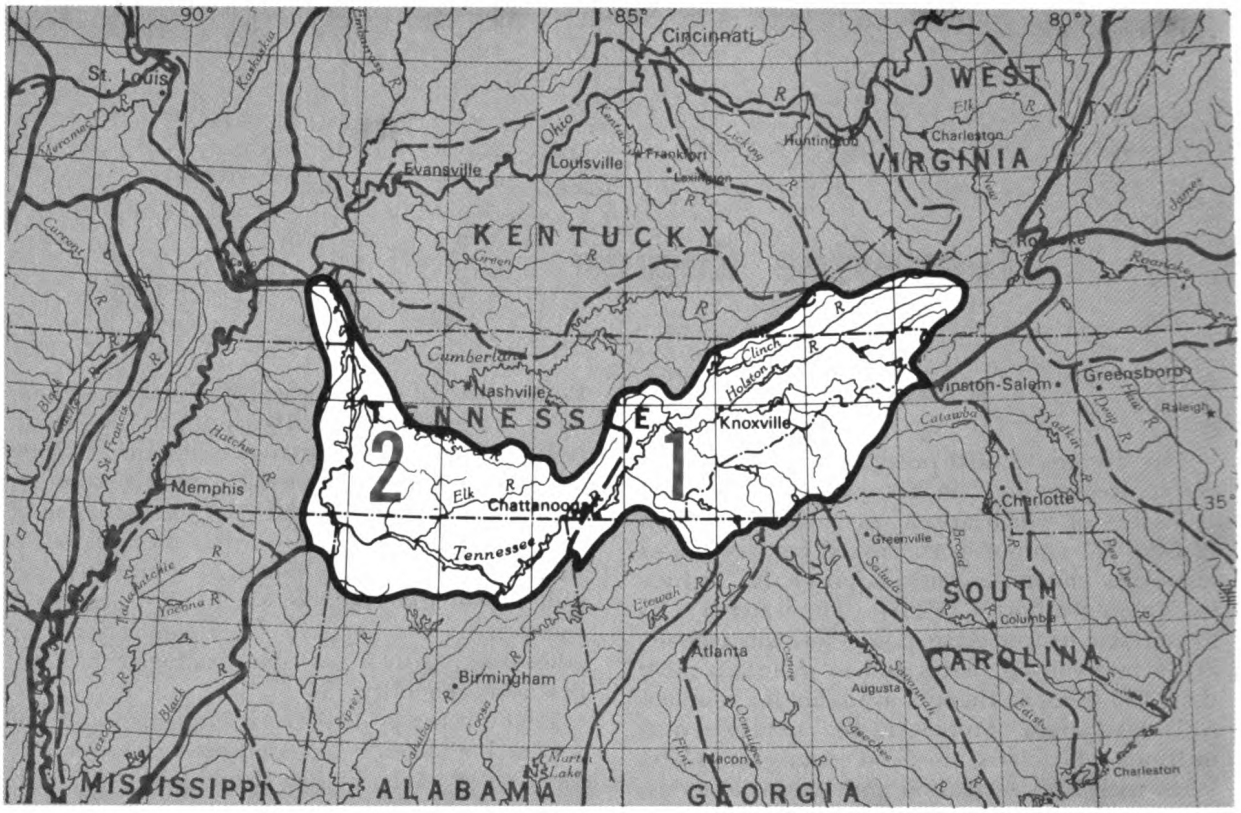

FIGURE 6–5–1.—*Map of the Tennessee Region.*

2,200 and 5,200 square miles; none of the other numerous tributaries drains more than 950 square miles.

The small regional areas (less than that of any other Region in the conterminous United States) includes marked diversities. In elevation, it ranges from 300 feet msl at its western extremity at Paducah, Kentucky, to 6,684 on Mount Mitchell, North Carolina, near its eastern boundary. Geologically, it ranges from a highly complex structure in the eastern portion to a comparatively simple structure in the western portion.

The climate is moderate, and extremes of temperate in either direction are rare. Mean January temperatures range from 33° to 43°, and mean July temperatures from 66° to 81°. Extreme temperatures have been -32° and 112°. The growing season lasts about 170 days to 195 days in eastern Tennessee and western North Carolina, and up to 220 days in the Alabama portion of the Region.

The soils vary greatly from place to place. Slope, drainage, stoniness, and depth, all of which affect the suitability of a soil for agricultural uses, may change gradually or abruptly within a few feet. Despite these extreme variations, the soils do have many important characteristics in common. They are low in inherent fertility as compared with the soils of the Midwest, but are generally responsive to good management.

The total forest area is over 15 million acres, 10% greater than in 1934. Tree planting constituted about half of the increase, and the remainder grew by natural seeding. The agricultural land has been used progressively more for pasture and less for cropland as dairy and beef industries displace cotton and corn production. At the same time, there is a continual trend toward more urban and industrial land use.

More than 3 million people live in the Region today. Some 4,400 manufacturing establishments provide jobs for about 400,000 and other nonfarm occupations offer employment to more than 600,000. Only about 100,000 people work on farms, and the number continues to decline. The nonfarm population has increased from 50% of the total population in 1940 to more than 80% at the present time. This shift in population has thrown a heavy load on municipal water supply systems and increased the overall domestic use of water.

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THE WATER RESOURCE

Hydrologically, the Tennessee Region is situated in one of the most humid areas in the United States. Annual precipitation averages 52 inches, and the average annual natural runoff is 41.5 bgd (21.3 inches). Sources of groundwater are uncertain, and in most areas yield only enough to satisfy rural domestic and small community uses. Natural mineral quality of surface waters varies considerably; the water lowest in dissolved minerals is located in the streams of the Appalachian Mountains.

The topography divides the Region into two rather distinct subregions as far as precipitation and runoff characteristics are concerned. In subregion 1, east of Chattanooga, where orographic influences are at a maximum, the average annual rainfall varies from about 40 inches to more than 90 inches, and differences of as much as 30 inches occur within distances of less than 10 miles. Average annual precipitation is about 51 inches.

Contrasted with the extreme variations of rainfall in the eastern part of the Region is the even distribution in the western part. Subregion 2, west of Chattanooga, where the land is gently rolling, is an area of uniform rainfall. The annual precipitation is about 53 inches, and the range in station annual averages is generally less than 10 inches.

Runoff in the two subregions varies with the rainfall. In the rugged eastern subregion, where 40 to 45 inches of rain falls in the valleys and 80 to 90 inches on the mountains, the annual runoff may be as low as 10 inches and as high as 53 inches. In the western subregion, where the annual rainfall ranges from 45 to 60 inches, the runoff ranges from 17 to 29 inches. Table 6–5–1 shows the average annual natural runoff of the Region.

High streamflow throughout the Region occurs generally in the months of December through April, while lowest flow occurs in September and October. Many small- to medium-sized streams in the western subregion go completely dry in the fall of drought years, and soil moisture also becomes very deficient.

The mean monthly unregulated flows of the Tennessee River below Kentucky Dam range from 134,000 cfs in March down to 22,000 cfs in October. Mean flows during the months of January through May have been decreased by regulation about 25%, while mean flows during the months of July through November have been increased by regulation almost 40%. The stabilization of average monthly flows is even more pronounced in the eastern subregion in the river reaches below the tributary storage reservoirs.

The natural mineral quality of most surface waters in the Region is satisfactory for almost all uses. About half of the Region—all of the southeastern area and much of the extreme western area—has soft water. Hard water (over 100 ppm) is present in the central basin portions of the Duck and Elk Rivers, along Paint Rock River in northern Alabama, along the North Fork Holston and Holston Rivers (due primarily to waste discharges), and on the Clinch River and several small streams in the eastern subregion.

The problems caused by the discharge of wastes in the Tennessee Region are not as critical as in some other Regions; in fact, the rivers are considerably cleaner now than they were in 1933. Nevertheless, the following streams have at least minor reaches where the volume and kinds of wastes already restrict water uses, although in some cases remedial action is under way: French Broad, Pigeon, Tuckasegee, Emory, Watauga, North Fork Holston, South Fork Holston, and Tennessee Rivers.

TABLE 6–5–1.—*Annual natural runoff, Tennessee Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	21,400	24.0	23.5	24.0	17.2	14.7
2	19,500	17.5	18.8	17.5	11.0	9.7
Regional value	40,900	41.5	21.3	41.5	28.2	24.4

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PRESENT WATER RESOURCES DEVELOPMENT—1965

As a result of the TVA development of the river system, the greatest water use in the Tennessee Region is instream use. The multipurpose reservoirs facilitate navigation, hydroelectric power, recreation, and fishing. The reservoirs also control major floods and significantly improve water quality. Withdrawal uses amount to about 14% of the natural runoff, but a high proportion of that is for condenser cooling at steam-electric powerplants (table 6–5–2).

Withdrawal uses total about 2.5 bgd in subregion 1, and 3.3 bgd in subregion 2. Almost 60% of the total water withdrawn in subregion 1 is used for condenser cooling at steam-electric powerplants, and over 30% is withdrawn by industry. Municipal use constitutes only 6% of the total withdrawals. In subregion 2, condenser cooling withdraws almost 87%, industry, 7%, and municipalities, 3%. Because of normally adequate rainfall, irrigation use in the Region as a whole is unimportant.

Consumptive use is relatively small. The estimated 331 mgd consumed is less than 6% of total withdrawals, and less than 1% of the regional runoff. About twice as much water is consumed in subregion 1 as in subregion 2.

Instream Use

Traffic on the more than 750 miles of commercially navigable waterways has grown from about 33 million ton-miles in 1933 to more than 2 billion ton-miles in 1965. Private industry has invested more than $1 billion in waterfront plants and terminals since 1950.

In 1965, water use for hydroelectric power generation was equivalent to six times the total flow of the Tennessee River at its mouth. This multiple use of the water is illustrated by turbine releases from Watauga Dam in northeastern Tennessee. Those releases are also used to generate power at four other tributary dams and nine main river dams before the water is discharged into the Ohio River below Kentucky Dam.

Recreation use of the 10,755 shoreline miles of major reservoirs in the Region has become more important every year. In 1965, the value of recreation development and equipment was almost $200 million. This included the value of more than 50,000 boats and 11,340 private residences, and improvements in 353 boat docks and resorts, 88 State and local parks, and more than 400 public access areas. Recreation visits in 1965 to the lakes and lakeshores totaled approximately 50 million.

TABLE 6–5–2.—*Present water use, 1965, Tennessee Region*

(Million gallons per day)

Subregion	Rural [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation	Livestock	
Water withdrawn							
1	33	155	835	1,470	2	19	2,514
2	31	98	241	2,859	6	18	3,253
Total	64	253	1,076	4,329	8	37	5,767
From:							
Groundwater	(51)	(71)	(50)	—	(1)	(29)	(202)
Water consumed							
1	32	28	135	2	2	19	218
2	29	18	39	4	6	17	113
Total	61	46	174	6	8	36	331

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 1,726,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishmentts.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).

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Fish and wildlife have developed into important economic assets through management programs, including the establishment of refuges and reservoirs. At the present time, an estimated 850,000 fishermen—a fourth of them nonresidents—are spending $42 million a year, which helps to stimulate a $53 million investment in lakeside service facilities. Commercial fishing also contributes to the Region's economy with a harvest of about 3,000 tons a year.

The 1,000-square-mile total area of impounded water in the Region has greatly improved conditions for migratory waterfowl. Thousands of ducks and geese now spend the winter on reservoir waters and adjacent lands.

Flood Control

The value of the multipurpose dams in controlling floods along the major streams in the Tennessee Region was again demonstrated in 1965. A flood in late March would have exceeded the flood stage at Chattanooga by 12.9 feet and would have caused damages estimated at $43 million. Regulation by the reservoirs lowered the crest 14.5 feet, and no damage resulted.

ADEQUACY OF PRESENT DEVELOPMENT

Since 1933, almost $1 billion has been invested in water control in the Region. As a result, the Tennessee River is one of the most highly developed river systems in the country. The return from this investment in water resources, which was planned as a part of a unified resource development program, will continue to increase with proper management.

Although the TVA reservoir system is one of the most complete river control systems in the Nation, there remain some communities and areas on unregulated streams with flood problems in the winter and spring and drought problems in the summer and fall. In certain areas of the western subregion, some minor streams cease to flow during drought periods and water supply for municipal, industrial, and agricultural purposes is inadequate. Planning for reservoirs on tributary streams has been expanded and will need to proceed systematically toward the implementation of multiple-purpose projects.

Sixteen small upstream tributary watershed projects, covering approximately 1.5 million acres, have reached the operational stage. Their emphasis has been upon watershed land management measures in connection with storage basins and channel improvements for flood prevention and sediment control. Where feasible, many of the more recent projects were formulated for municipal, fish and wildlife, and water-oriented recreation uses. Local sponsoring organizations have requested assistance on approximately 50 other small upstream watersheds, covering more than 2.5 million acres.

A number of towns and local communities are located on tributary streams where upstream reservoir control is impractical because of the lack of suitable reservoir sites or the high costs involved. In these areas and elsewhere, there is need for land-use control through zoning and subdivision regulations. In some instances, local protective works such as levees, channel improvements, or flood proofing are being planned.

There are still some reaches of streams in the Region where waste discharges restrict other downstream water uses. In recent years, the availability of Federal funds for municipal waste treatment plants and increased emphasis upon pollution control by the States have steadily reduced detrimental municipal waste discharges. However, controlling industrial pollution is a more complex problem.

Long-established industries provide some of the largest waste discharges. The discharges vary in kind and in degree, and different water-use conflicts are created on different rivers. Pulp and paper mills, chemical plants, and rayon plants are sources of the most serious pollution. The Region's many reservoirs form excellent natural purification units between upstream pollution sources and downstream points of water usage. Nevertheless, some wastes from large industries are responsible for oxygen depletion in the receiving streams and in the reservoirs below the plants.

The cooperative efforts of State and Federal agencies have succeeded in establishing water-quality standards for the streams and the degree of treatment required for municipal sewage and industrial discharges. Some streams, however, still need low-flow augmentation to maintain the required standards, even with a high degree of waste treatment.

The value of the lands along the shoreline of reservoirs can be substantially enhanced by appropriate development programs. These lands present unequaled opportunities for recreational and industrial development and expansion. Plans are being developed for reservoir shorelines so that key areas can be reserved and dedi-

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cated to industrial uses, parks, wildlife refuges, homesites, public access areas, and recreation development and use.

Recreation on reservoir impoundments has developed to such an extent that it is now an important aspect of most water resource development projects. On recent projects, substantial recreation benefits have been identified and taken into account. On some older projects, particularly tributary storage reservoirs, it has become apparent that more information is needed on the interrelationships between recreation, which is benefited by a relatively constant-level pool, and power and flood control, which require that the reservoir levels fluctuate.

Although most of the promising major damsites for hydroelectric power have been developed, there are a number of possible sites that should be examined in view of the basic power-load growth and the need for additional peaking capacity. Among the various alternative methods of obtaining this peaking capacity is development of pumped-storage sites.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

One of the questions facing the States of the Tennessee Region is whether present and potential water-use requirements and conflicts call for changes in their water rights laws and in their organizations for administering such laws and dealing with water problems generally. Studies have been made, and many legislative proposals are now under consideration.

Conservation and development of the water resources in small watershed projects within the Region is being carried out by special-purpose districts organized under State laws. The districts vary widely in their authority from State to State, but most of them are hampered by legal limitations that reduce their effectiveness. For instance, many districts lack the power of eminent domain or of taxation.

Primary responsibilities for water resource development in the Region were assigned to the TVA in 1933. In exercising its responsibility, the TVA has sought to cooperate with State, local, and other Federal interests concerned with resource development. In the area of water quality, the States have made much progress in setting and enforcing water quality standards; but some problems still persist, particularly where interstate pollution problems are involved.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The economy of the Tennessee Region has changed substantially in the past 30 years. Industrial activity has replaced agriculture as the major driving force of the economy. As industrial employment has grown, emigration has been reduced. Income levels per capita have risen, from 45% of the national average in 1933 to 70% of the national average in 1966. While unemployment has been reduced, wage levels are still low and underemployment high. Acute pockets of poverty still exist in remote areas where opportunity remains limited, and serious problems of environmental quality persist.

As indicated in table 6–5–3, substantial growth is expected to occur in the Region in the future. By 1980, population in the Region is expected to increase by more than one-third of the 1960 level, and manufacturing employment is expected to increase by more than 50%. Accompanying this industrial growth will be substantial gains in income and corresponding increases in requirements for water and recreation facilities. High standards for development of these elements of the environment will be expected—at the same time that the accelerated growth tends to reduce their quality. While agricultural employment will continue to decline, agricultural incomes will improve.

Although problems still remain, the outlook for the future is bright. Industrial development and income improvements are continuing, education is being given higher priority as recognition of its value increases, and the need for planning and development programs is widely recognized.

During the period 1959 through 1964, gross industrial water use increased at a higher rate in the Tennessee Region than it did in any other Region in the conterminous United States. Continued industrialization should bring substantial increases in water use in the future. Population growth accompanying continued industrial development will rapidly increase future domestic water requirements. Increased water use will also result from higher income levels and increased urbanization. Projected water requirements for withdrawals and consumptive uses are shown in table 6–5–4.

The projected water withdrawal for public supplies was based upon both the increasing per capita withdrawal and the increasing percentage of the population being served. Water for domestic use in the rural areas is predominantly supplied from wells. Both the percent-

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TABLE 6–5–3.—*Economic and agricultural projections, Tennessee Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	2,979	4,118	5,643	7,785
Per capita personal income	1954 dol.	1,508	2,625	4,225	6,900
Employment, total [2]	thou.	999	1,478	2,066	2,894
Agriculture	do.	117	50	32	27
Manufacturing	do.	311	493	623	767
Other commodity producing	do.	98	133	179	250
Distributive industries	do.	224	342	481	661
Service industries	do.	247	461	750	1,190
Land base	thou. ac.	27,321	27,321	27,321	27,321
Agricultural	do.	25,597	25,147	24,627	24,057
Cropland, total [3]	do.	6,504	5,952	5,829	5,694
Used for crops	do.	5,418	4,577	4,765	5,153
Idle and fallow	do.	1,086	1,375	1,064	541
Pasture-permanent	do.	2,723	3,113	3,049	2,979
Forest and woodland	do.	16,370	16,082	15,749	15,384
Nonagricultural	do.	1,724	2,174	2,694	3,264
Irrigated land [4]	do.	[5] 15	30	40	50

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965 irrigated land amounted to 20 thousand acres.

TABLE 6–5–4.—*Projected water requirements, Tennessee Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	64	128	167	212
Municipal (public-supplied)	253	358	560	872
Industrial (self-supplied)	1,076	1,600	2,360	3,100
Steam-electric power (fresh) [1]	4,329	10,100	10,700	13,800
Agriculture:				
Irrigation [2]	8	18	23	29
Livestock	37	48	67	93
Total	5,767	12,252	13,877	18,106
Total from groundwater	(202)	(314)	(438)	(569)
Total from reclaimed wastewater	—	—	(120)	(310)
Consumptive use				
Rural domestic	61	122	158	202
Municipal	46	64	95	140
Industrial	174	258	381	500
Steam-electric power (fresh) [1]	6	65	115	175
Agriculture:				
Irrigation	8	16	21	26
Livestock	36	47	64	89
Total	331	572	834	1,132

[1] 1965 figures from TVA; projections by Federal Power Commission.
[2] Based on an average season; use in a dry season could be as much as twice these amounts.

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age of the rural population living in houses with plumbing and their per capita withdrawal are expected to increase. The per capita withdrawal of those without plumbing is very small and is expected to remain essentially constant.

The use of sprinkler irrigation systems in the Region dates back at least to 1910. A period of rapid growth in supplemental irrigation was experienced during a series of dry crop seasons in the 1950's. Future needs for water for irrigation in the Region are difficult to estimate. There is no shortage of land available for irrigation, but future irrigation will prove successful only when farmers have built up the fertility of their soils and adopted other improved agricultural practices. The projections assume average effective precipitation; however, in wet years irrigation may be entirely unnecessary, and in dry years the amount of water required may be as much as twice the average. Water applied by means of sprinkler-type irrigation is almost entirely consumed. The use of water for livestock is expected to increase, but this will not constitute a major use.

Since the streams in the Tennessee Region have been so extensively developed, hydroelectric power installations now under construction, or those which may be constructed in the future, will add relatively little to the total instream water use. Projections of water use through 2020, therefore, assume no change from the 1965 use of about 230 bgd.

EMERGING WATER PROBLEMS

In general, the water supply in the Region is adequate to support all projected or anticipated growth, but specific problems will occur in certain areas as growth occurs.

The major developments in water-using industry will occur along the Tennessee River and along the lower reaches of the major tributaries, and will undoubtedly result in conflicts in water and related land use. Careful planning will be required to minimize the conflicts and to ensure orderly development. The river in this area is in reality a series of relatively stable reservoirs. Water quality in the reservoirs can be endangered by excessive loads of oxygen-demanding wastes or by excessively high plant nutrient concentrations. Thermal stratification is a natural phenomenon that can also result in problems of water management during certain periods.

The use of these reservoirs for recreation has more than doubled in the last 10 years to an annual use in excess of 40 million visits, utilizing recreation facilities valued at more than $150 million; continued increases are expected in the future. If water quality is not maintained, fish and wildlife habitat, recreation users, and owners of recreation facilities will suffer substantial losses. The orderly development of land adjoining the reservoirs, including provisions for public access, is necessary if the full benefit of the water control system is to be realized. Industrial sites, recreation areas, and fish and wildlife habitat must be protected and developed, and residential development must be controlled, if potential benefits are to be realized.

Careful management will also be required to minimize water problems along tributary streams. Local problems may occur where streams are uncontrolled and undeveloped or where water demand increases rapidly because of economic growth. Local water quality problems will occur where streamflow is low relative to population or where major water-using industries locate. Streamflow regulation, in addition to high levels of waste treatment, will be required to meet such conditions as they develop. Careful planning and wide understanding of local water resource capabilities will help to prevent some potential conflicts.

Reclaimed waste water is not at present utilized for process or cooling purposes by industries in the Region. However, process improvements and possible shortages of water during critical periods of the year may result in reclaimed waste water becoming a part of the industrial water supply in the future.

Continued efforts in flood-plain zoning will be required to control future flood damage potential. Where growth has already occurred in the flood plain, streamflow regulation or redevelopment will be required to reduce potential damage. In certain areas, future growth will be restricted unless flood damage potential can be reduced. Future urban development may also result in serious erosion and sedimentation unless development actions are consistent with established soil and water management practices. Continued efforts will be required to ensure continuation of sound agricultural land management practices.

Water-use conflicts will continue to emerge. Resolution of such conflicts and the full utilization of the area's water and related land resources will require flexibility in system management.

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DEVELOPMENT AND MANAGEMENT NEEDS—1980

Despite the fact that no widespread shortages of water are in prospect for 1980, serious problems may be anticipated in some portions of the Region. Complex problems in water development and management will need to be dealt with if the water resource is to make its full contribution to further development. Some institutional and planning needs are pertinent on a regionwide basis, others are appropriate to the existing mainstream system, and some are particularly evident in the tributary areas.

General Regionwide Needs

Increased water usage places greater emphasis upon management of the water system to protect water quality. In addition to industrial wastes and municipal sewage, sediment pollution requires attention. Soil and water resource conservation, including strip-mine reclamation and redevelopment, needs to be fully incorporated into overall planning and development programs. Approximately 240 additional small upstream watershed areas comprising nearly 12 million acres in the Region are potentially feasible projects for development. Problems needing solution in these watershed areas include 1.6 million acres subject to flood and sediment damages, 0.7 million acres with drainage needs, and 1.2 million acres of critically eroding lands that need stabilization measures to reduce the sediment load in surface waters.

The Main River System

The Tennessee River and some of its upstream tributaries are already rather fully developed for navigation, hydroelectric power, and flood control. Aside from the desirability of an additional increment of flood reduction at Chattanooga, larger navigation locks at several dams, and local navigational improvements, very little further development of the main system is anticipated. But as the needs of the Region change, the operating plan for the main river system and its related lands will need to be reappraised periodically to identify ways in which it can make its greatest contribution to these needs. Three purposes that were not incorporated into intial planning—water quality management, recreation development, and industrial water supply—will become increasingly important in the future.

Associated with meeting prospective future recreation demands is the need to (1) provide for assured public access to reservoir and associated recreation areas, (2) provide a variety of recreation opportunities and adequate facilities to accommodate public usage, (3) maintain adequate water quality for water-contact recreation, (4) maintain acceptable environmental quality in recreation areas, and (5) develop improved methods and data for appropriately valuing recreation in periodic reappraisals of the operating system. State and local groups have an important role in meeting these needs.

One type of water quality problem for which additional research is badly needed is nutrient pollution which leads to nuisance growth of aquatic plants. Such growth is harmful to recreation and many other water uses, and too little is known at present about feasible preventive and control measures and their prospective costs.

Tributary Areas

Water resource development needs are particularly evident in some of the tributary areas. In the upper Duck River area of Tennessee, water supply for industrial and domestic use will be an important need. For the towns in the narrow valleys of the mountainous Appalachian portion of the Region, floods pose a major problem and developable lands outside of the flood plain are scarce. At Athens, Tennessee, a growing town on a small stream, water for municipal use and dilution of treated wastes will be increasingly needed. For the French Broad River in North Carolina, there are needs for (1) flood control for both urban and agricultural areas, (2) water quality control of treated organic wastes and plant nutrients, (3) recreation lakes, and (4) additional storage for future municipal and industrial water supplies. These and similar combinations of water development needs are also found in other tributary areas.

Nonstructural means of reducing flood damage potentials have been promoted by providing flood-plain information and advice to local governments which have zoning and other planning authority. As population and urban development increase in the future, further work of this type is needed to identify the combination of flood damage prevention measures which can best meet the flood problems of the future.

Many storage or retention sites in the small upstream tributary watershed areas could be developed for multipurpose and nonconsumptive uses of surface waters. Water-oriented recreation facilities and fish and wildlife projects would allow reuse of water for domestic and agricultural purposes. Sites with recreation po-

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tential could be planned and spaced to provide for maximum 1-day or weekend usage throughout the Region.

The diversity of the needs and the variations in their priority from area to area require periodic reassessments for each tributary area. From these updated assessments, current multipurpose development and management plans for each area and for the Region can be prepared to direct water resources activities into avenues which best fit each area's respective needs and growth potential. State and local groups will continue to make an important contribution to this comprehensive planning.

The Role of Local Participation

If water projects are to make their full contribution toward meeting future needs, comprehensive water resource planning and project construction must be accompanied by implementation of developmental plans for other resources and by effective project management. Here, an important part of the responsibility rests upon local organizations, which thus become key elements in effective implementation of water resource plans. In the future, as water resource needs and water projects become more complex, the implementation responsibility of the local organizations becomes even more critical. TVA, through its tributary area development program, is working with local groups toward the unified development of all of the Region's resources. Experiments are being conducted with new organizational and procedural approaches to further improve the effectiveness of local participation. These approaches promise effective implementation of water resource plans as a part of comprehensive resource development, but the complexity of the job will require continued experimentation and adaptation, if future demands on the Tennessee Region's water and related land resources are to be met efficiently.

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CHAPTER 6

Upper Mississippi Region

SUMMARY

Water supplies for the Upper Mississippi Region are considered adequate until 1980. Beyond that date supplies for some areas will become scarce and intra-Region diversion may be necessary. Groundwater supplies, however, are plentiful and relatively untapped. Maintenance of adequate water quality at specific locations is one of the major problems of the Region; if adequate waste treatment is not applied, the quality of stream water will decrease with increased use of the water resources. Even now, the problem at various urban centers—among them Minneapolis-St. Paul, Chicago, and St. Louis—is of major significance. (This Assessment includes Chicago in the Great Lakes Region, but the water problems of its large metropolitan area strongly affect the water resources of the Upper Mississippi Region.)

Regional projections indicate that population, industry, and irrigated agriculture will increase many times by 2020. Such expansion, in turn, will impose greater demands on available water supplies, portending higher water costs, with accompanying pressures for reuse and efficient management. Land use management and the degree of waste treatment will continue as major factors in determining the quality of water which will exist in the Region's streams.

Flood control is of major concern for the Upper Mississippi Region; the 1965 and 1967 floods, for example, caused millions of dollars of damage. Flood damages can, however, be reduced by means of local protection works, reservoirs, better land management, proper recognition of the flood damage hazard, and proper zoning. Deterioration of stream quality and the loss of valuable land resources by sedimentation and erosion are also responsible for significant amounts of damages.

As pressures for more efficient land use grow, drainage of the land for more intensive use will increase. However, future requirements for fish and wildlife propagation must be considered as wetlands are converted to other uses.

The dearth of water-based recreation facilities in the mid-Region area is evident. Multipurpose use of surface water areas, both existing and new, appears to be the best solution to this problem.

The investment programs of the Federal, State, and local government agencies and private organizations that are concerned with water problems have not been sufficient to keep pace with the Region's water quality-control needs. The efforts and investments of the multilevels of government and of the property owner should be coordinated, so that a concerted attack can be made on the problems of the Upper Mississippi Region on both an immediate and a long-range basis.

DESCRIPTION OF THE REGION

The Upper Mississippi Region is defined as that tributary area upstream of the mouth of the Ohio River, exclusive of the Missouri River above the mouth of the Gasconade River (fig. 6–6–1). It encompasses a drainage area of 189,300 square miles, and includes parts of Minnesota, Wisconsin, Illinois, Indiana, Iowa, Missouri, and South Dakota.

The drainage area pattern is primarily the product of glaciation. In general the land is rolling, with altitudes ranging from 400 to 1,900 feet msl. Within the Region, the main stem of the Mississippi River flows southerly from Lake Itasca at the Region's northern tip for a distance of about 1,370 miles to the mouth of the Ohio River. From Lake Itasca, at elevation 1,470, the river falls about 1 foot per mile to elevation 1,150 at mile 1,000; between mile 1,000 and the head of navigation (mile 858) it drops about 460 feet. The river reach between Minneapolis (mile 858, elevation 690) and the mouth of the Ohio River (mile 0, elevation 280) has been improved by a series of low dams and channel works to provide a navigable depth of 9 feet.

Much of the Region is known as the "corn

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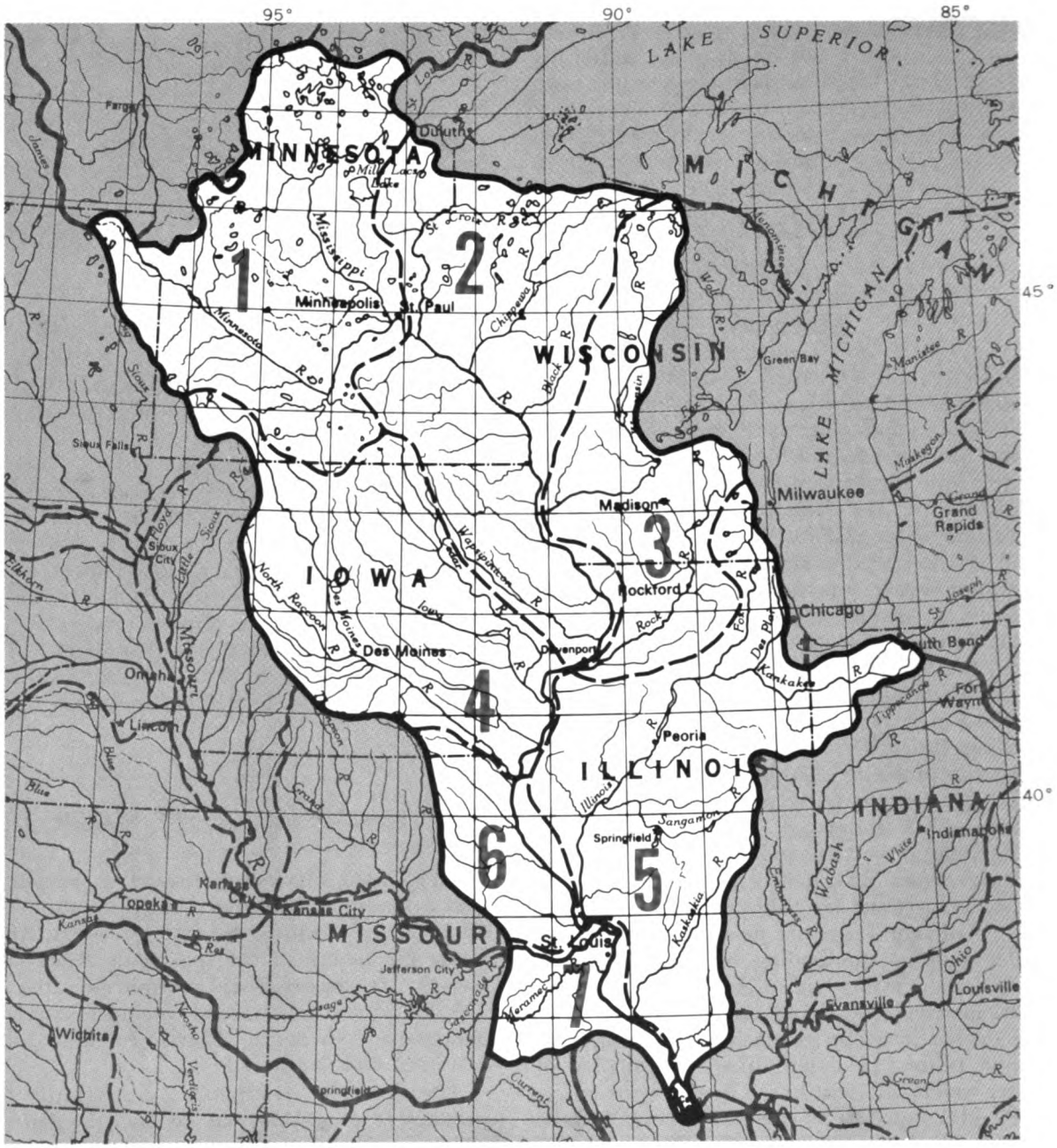

FIGURE 6–6–1.—*Map of the Upper Mississippi Region.*

belt" of the United States. The land is used intensively for agricultural purposes, and about 58% of the total land base is devoted to cropland. Other land uses are permanent pasture, 11%; forest and woodland, 22%; urban and built-up areas, 4%; and other land, 5%. Water surface areas make up about 2% of the total area.

Winters are cold and summers are hot and humid. Annual precipitation ranges from 22 to 46 inches, and most of the rainfall occurs during the summer months. The average annual precipitation is about 32 inches.

The 1960 population of the Region was 11.8 million, of which 7 million were classified as urban-area residents. The two largest metropolitan areas are St. Louis (about 2.2 million) and Minneapolis-St. Paul (about 1.5 million).

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Others over 100,000 include Davenport, Iowa,—Rock Island—Moline, Illinois; Peoria, Illinois; Des Moines, Iowa; Rockford, Illinois; Madison, Wisconsin; and Springfield, Illinois. (Chicago's metropolitan area population of 6.6 million is included in the data for the Great Lakes Region, but it has a significant effect on the water resources of the Upper Mississippi Region.)

THE WATER RESOURCE

The average annual natural runoff for the Region is estimated to be about 65 bgd (table 6–6–1). Runoffs from individual subregions vary from one-half of the regional average in subregion 1 to one-third more than the regional average in subregions 6 and 7. In addition to the natural runoff, the Region receives an export from the Great Lakes Region—about 2 bgd of wastewater used in the Chicago metropolitan area.

Low flows (occurrences of less than 5% of the time) range from one-quarter to one-half of the estimated average annual flow. Low flows in subregions 1 and 4 fall considerably below the regional average and reflect the lower annual precipitation falling on the west-northwest part of the Region.

Extreme low flows generally occur in midwinter and midsummer, and extreme high flows usually occur on the mainstream Mississippi and major tributaries in the spring. Small watersheds produce extreme high runoffs of short duration following summer rainstorms. Runoff is generally lowest in the western part of the Region.

Droughts vary in intensity, duration, and geographic location. The drought of 1931, one of the most severe, produced general lowflow conditions throughout the area, averaging from 12% of normal in subregion 4 to 68% in subregion 2. Periods of drought in the early 1940's and 1950's affected the southern portion of the Region. In the late 1950's the northern portion was subject to drought.

The availability and distribution of groundwater is considered good, although highly pumped urban areas are experiencing a gradual lowering of local water tables. Large amounts of groundwater are available for future development in many parts of the Region. The water varies in chemical quality but is generally satisfactory for domestic, industrial, and rural uses. Generally hard, it usually requires softening for domestic use.

The quality of surface water is generally suitable for water-based recreation, fish and wildlife habitat, and industrial and municipal uses, but river water immediately downstream of the larger urban developments is not satisfactory for body contact, water sports, or fish life. On the mainstream Mississippi the quality is generally satisfactory. However, to maintain this condition, a high degree of domestic and industrial waste treatment is constantly required.

Owing to the nature of land use in the Region, natural runoff is contaminated to varying degrees with herbicides, insecticides, fertilizers, and chemical spills, all of which can adversely affect the quality of water supplies available for domestic, recreation, and fish and wildlife use.

Surface water quality is also subject to decrease by sediment, particularly in the central and southern parts of the Region. Except for isolated areas of extreme erosion, the annual

TABLE 6–6–1.—*Annual natural runoff, Upper Mississippi Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	36,800	6.24	3.56	5.83	2.20	1.52
2	40,200	15.66	8.18	15.66	9.63	7.94
3	22,300	9.40	8.85	9.40	5.55	4.46
4	32,100	8.77	5.74	8.40	3.46	2.48
5	37,400	15.38	8.64	15.38	7.49	5.26
6 and 7	20,500	9.20	9.42	8.79	3.54	2.53
Regional value	189,300	64.6	7.17	64.6	36.4	28.5

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yield of sediment generally varies from about 10 tons per square mile in the northern part of the Region to about 2,500 tons per square mile in the southern part.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Total water withdrawn for use in the Upper Mississippi Region in 1965 averaged about 8.2 bgd (table 6–6–2). Of this total, 770 mgd is consumed or lost for reuse consideration. Although agricultural and rural domestic uses represented only 7.5% of the Region's withdrawals, they accounted for about 64% of the water consumed.

A low topographic relief of the Region limits large hydroelectric power installations. However, a number of small, privately owned plants have been developed, particularly on the tributary rivers in subregions 2 and 3. An estimated 193 bgd flow through them and reservoir storage has been developed to provide some of them with regulated flow.

Consumption of water by instream uses and the effects on water yield of land treatment practices, exposed wetlands, and water surface areas have not been estimated. Instream usage is a major factor in the Region. Navigation, fish and wildlife, recreation, waste disposal, and hydroelectric power are the main functions involved.

Flood damages are estimated to be $120 million per year. Some 9 million acres, or 8% of the regional land area, is now subject to flooding, and about 300 communities, each with populations in excess of 2,500, are located in these flood plains.

Land and streambank erosion cause direct sediment damages of $25 million per year. This

TABLE 6–6–2.—*Present water use, 1965, Upper Mississippi Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
1	31	187	355	550	6	44	1,173
2	35	87	64	110	14	63	373
3	40	147	221	570	31	36	1,045
4	26	148	163	620	29	104	1,090
5	56	252	790	2,620	15	45	3,778
6	5	10	4	10	—	15	44
7	10	272	67	320	—	7	676
Total	203	1,103	1,664	4,800	95	314	8,179
From:							
Groundwater	(188)	(541)	(640)	—	(80)	(258)	(1,707)
Saline	—	—	(18)	—	—	—	(18)
			Water consumed				
1	31	38	25	7	6	40	147
2	10	11	4	1	10	61	97
3	11	15	5	7	23	35	96
4	6	15	17	8	29	103	178
5	37	27	1	33	15	45	158
6	2	2	—	1	—	14	19
7	4	54	6	4	—	7	75
Total	101	162	58	61	83	305	770

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 9,159,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

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amount is exclusive of the value of the land resource that is lost.

ADEQUACY OF PRESENT DEVELOPMENT

Water supplies, both surface and ground, are considered adequate under present conditions in the Upper Mississippi Region. Municipal water supply systems have usually found adequate sources of water nearby. However, provision of adequate distribution systems has posed a problem. The problem is being alleviated somewhat by interconnected community water supplies which increase the reliability of the overall system. The State of Illinois plans to consider a statewide utility system for such supplies.

Illinois, by agreement with other Great Lakes States, has also secured the right to divert 3,200 cfs (2.06 bgd) from Lake Michigan at Chicago. This water is used in the Chicago metropolitan area for water supply and augmentation of Illinois River flow for waste dilution.

Self-supplied industry has obtained its water from both surface and ground sources. The availability of such water has played an important part in the location of major water-using industries. The steam-electric power industry of the Upper Mississippi Region has relied primarily on once-through type cooling. Large withdrawals are needed for this type of cooling, and the location of powerplants has been determined accordingly. Some of the newest nuclear powerplants, for example, are being located on the main stem of the Mississippi River.

Navigable depths on the Mississippi River from Minneapolis-St. Paul to St. Louis are provided by a series of low dams and associated navigation locks. The dams control water elevations to provide a navigable depth of 9 feet during the 8-month navigation season but provide no storage for control of flood flows. Water uses for navigation vary from 50 to 300 mgd, depending on the number of lockages performed. A series of low dams and diversions from Lake Michigan for waste dilution provide enough water for navigation on the Illinois River. The Mississippi River from St. Louis to the mouth of the Ohio River is open channel, and a minimum 9-foot navigable depth requires a flow of 35 bgd (54,000 cfs). Missouri River reservoir releases for navigation provide augmentation of low flows during the Missouri River navigation season, but not in the winter months. Thus, a deficiency of water on the Mississippi River below St. Louis sometimes occurs during those months. Channel degradation at the Port of St. Louis has been caused by permitting the river to deepen its own channel by scouring. Reliable navigable depths from St. Louis to the Ohio River can be obtained by channel constriction or by construction of low dams similar to those above St. Louis.

The availability of water-based recreation varies by subregion. In the northern subregions, the many natural lakes of Minnesota and Wisconsin provide a major portion of the whole Region's water-based recreation. At the other extreme, opportunities for such recreation are seriously lacking in the urban-farm area of the mid-Region belt from Chicago through Des Moines, Iowa. About 60% of the regional recreation requirement is not being satisfied, and demands are expected to increase nearly four times by 2020. Water quality for recreational use needs to be upgraded by better waste treatment and augmentation of low streamflows, particularly near urban areas.

Relatively unpopulated areas in both the northern and southern tips of the Region provide lands suitable for wildlife habitat. The many lakes and streams in Minnesota and Wisconsin provide fishing opportunity, but there is a great danger that man-made pollution may degrade these resources. In the central part of the Region, which is devoted primarily to agriculture, developments are needed to maintain and expand fish and wildlife populations.

One of the major instream water uses is disposal of sewage treatment plant effluents and other wastes. The future use of water for this purpose will depend on the demands and on approved standards for water quality and the ability of the Region to meet these standards. The degree of waste treatment required prior to disposal will depend on streamflow characteristics and the stream quality standards. The costs of adequate waste treatment facilities are high, but indications are that residents of the Region will agree to pay them.

The management and development of the land that is in agricultural use—about 90% of the total land area—has a significant impact on water development. About one-third of the presently needed conservation treatment has been completed. More has been accomplished for agricultural drainage needs, relative to total needs, than for other types of development. Nearly one-third of the land used for cropland needs erosion control practices. Improvements for only about 3% of the area having potential

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for watershed protection projects have been initiated.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Water law in the seven States of the Upper Mississippi Region has generally developed on the basis of "riparian doctrine." Under this doctrine, rights to use the waters of a watercourse or lake belong to those persons owning land adjacent to the body of water. However, this definition has been tempered somewhat by court decisions, and the philosophy of "reasonable use" governs the allocation of available water supplies. For instance, Minnesota stream and lake water is considered public water, subject to control by the State.

In most instances, property ownership extends to the center of the stream. Although the property owner does not in effect own the water, he does own the bed of the stream. These water and property ownership rights are subservient to the paramount interests of navigation as fixed by Federal and State law.

In the case of groundwater, common law doctrine seems to apply in most of the Region. This doctrine states that all percolating water under a plot of land belongs to the landowner. He may dispose of this water as he sees fit, except in Minnesota where the State can control the appropriation and use of groundwaters, as well as surface waters.

To date, owing to abundance of water resources, the States in the Region have had a minimum of water-oriented legal controversy. With the increased use of water in the development of tributary lands, however, the legal conflicts will undoubtedly increase and problems will probably be worked out on a case-by-case basis. It is apparent that much of the existing water law does not reflect the current technical level of water resources knowledge.

State water laws have applied different legal doctrines to water in different phases of the hydrologic cycle. Therefore, it would appear that the existing legal framework should be reconsidered to cope with some of the new and emerging water problems. Two such problems are of immediate importance: the transfer of water from one river basin to another, and the allocation of surplus flood waters captured in reservoirs.

States of the Region have assumed the responsibility for establishing quality standards for interstate waters. The purpose of these standards is to protect the public's health and welfare and to enhance the water quality.

It appears that the water and related land resource problems of the Region can only be solved through the cooperative efforts of Federal, State, and local government agencies and private individuals. Within this partnership concept, it should be recognized that State agencies concerned with water resources development should be staffed and funded to provide equitable participation. If partnership and coordination are not complete, the cooperative approach to the solution of water resource problems may be only piecemeal.

Interstate compacts are being considered for finding solutions to the water and land resource problems on streams that form State boundaries. For example, the Minnesota-Wisconsin Boundary Commission was established to consider common problems on boundary lands and waters, and the initiation of a five-State compact is being weighed for the main stem of the Mississippi River from Minneapolis to the mouth of the Ohio River.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The projected population and economic growth of the Upper Mississippi Region has a growth rate similar to that for the United States (table 6–6–3). A major exception is the increase of irrigated land, which is projected at a rate that is considerably faster than the national rate.

Projections of water requirements to meet this economic growth are shown in table 6–6–4.

EMERGING WATER PROBLEMS

It is recognized that the natural runoff of the Region (65 bgd) would be sufficient for projected water needs if this quantity were available in the right place at the right time. The problem of variable runoff can be partially solved by provision of reservoirs for capturing and storing flood flows to be released at times of low flow.

Projections indicate more use of regional water supplies for municipal and industrial purposes in the future. The population is expected to rise from 1960's 12 million to 27 million by 2020, and even if the amount of water used per capita remained the same, total water use in the

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TABLE 6–6–3.—*Economic and agricultural projections, Upper Mississippi Region* [1]

Item	Unit	1960 [2]	Projections		
			1980	2000	2020
Population, total	thou.	11,759	15,180	20,004	26,766
Per capita personal income	1954 dol.	1,986	3,175	4,950	7,700
Employment, total [3]	thou.	4,407	5,869	7,725	10,338
Agriculture	do.	590	376	304	289
Manufacturing	do.	1,146	1,574	2,005	2,603
Other commodity producing	do.	282	362	484	666
Distributive industries	do.	1,144	1,404	1,755	2,177
Service industries	do.	1,242	2,153	3,176	4,603
Land base	thou. ac.	112,003	112,003	112,003	112,003
Agricultural	do.	101,946	99,846	97,566	95,166
Cropland total [4]	do.	65,266	61,462	60,058	59,096
Used for crops	do.	61,549	54,376	54,579	58,706
Idle and fallow	do.	3,717	7,086	5,479	390
Pasture-permanent	do.	12,358	14,562	14,229	13,967
Forest and woodland	do.	24,322	23,822	23,279	22,103
Nonagricultural	do.	10,057	12,157	14,437	16,837
Irrigated land [5]	do.	[6] 80	210	390	550

[1] Excludes Chicago-Northwestern Indiana Standard Consolidated Area.
[2] Includes some data for 1959.
[3] May not check due to rounding.
[4] Includes cropland used as pasture.
[5] Includes cropland and pasture.
[6] In 1965 irrigated land amounted to 140 thousand acres.

TABLE 6–6–4.—*Projected water requirements, Upper Mississippi Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	203	143	132	130
Municipal (public-supplied)	1,103	1,770	2,760	4,000
Industrial (self-supplied)	1,664	2,800	5,300	10,000
Steam-electric power	4,800	9,500	21,500	25,900
Agriculture:				
Irrigation	95	110	200	280
Livestock	314	477	695	956
Total	8,179	14,800	30,587	41,266
Consumptive use				
Rural domestic	101	94	85	76
Municipal	162	258	403	580
Industrial	58	98	184	346
Steam-electric power	61	166	373	607
Agriculture:				
Irrigation	83	95	170	240
Livestock	305	392	563	775
Total	770	1,103	1,778	2,624

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domestic sector would increase with population. Expanded industrial activity will require more use of water, although more efficient use of water through recirculation and conservation will reduce industrial intake requirements in relation to gross requirements.

Currently, the Region is extensively developed for agricultural purposes. Projections of agricultural land use indicate a decrease from 102 million acres in 1960 to 95 million by 2020. Thus, more intensive use will be made of all land resources of the Region. As this occurs, it can be expected that improved watershed land management, as well as additional water, will be required on this land.

Rivers and streams of the Region are widely used for disposal of effluents from waste treatment systems. It is assumed that waste loads will continue to increase with population, industry, and agricultural growth. Experience shows that major urban areas, such as Minneapolis-St. Paul, Chicago, and St. Louis, are creating major stream pollution problems. Low stream flows will need to be augmented to carry wastes with reasonable stream water quality. The amount of water used for the cooling of steam-electric plants has risen sharply in past years, and projections are that about 26 bgd will be withdrawn for this industry by 2020. The ecological effect of increased stream temperatures must be studied to determine acceptable temperature changes.

With intensified land use, efficient land management will become a necessity for control of surface water qualities. Increased agricultural production will mean increased use of herbicides, pesticides, and fertilizers. The effect on fish and wildlife of such practices must be determined. The basic responsibility for this land management now lies with the private landowner. His goals of higher income must be balanced against the land management practices that will eliminate erosion of valuable lands and improve water quality.

Recreation and fish and wildlife, particularly, rely on uniform river flows and good water quality. The shortage of water-based recreation opportunities in the mid-Region is severe and will become more of a problem as the population increases. Efforts must be made throughout the region to improve water quality for recreation.

The groundwater of the Region is relatively untapped. In the Chicago area excessive pumping has lowered the water table as much as 10 feet per year; nevertheless, on a regional basis, groundwater quantity is adequate for the foreseeable future. Its quality has been degraded in some areas by overloaded septic tanks and unplanned land fills. Injection wells have sometimes been used for the disposal of liquid industrial wastes; the long-term effects of this practice on groundwater resources must be studied further.

The waterborne mosquito carrying encephalitis has been noted in some areas. This indicates the need for increased surveillance and control.

Flood damages are a major problem, and projections indicate that the problem will continue to grow. Present average annual flood damages are estimated at $120 million and are projected to increase to $375 million by 2020, if no further water resources developments in the flood plain are provided. Local protection works are needed to augment reservoir control. Recognition of the flood hazard in flood-plain areas is of major importance; once the hazard is known and understood, flood-plain management can follow. Information about potential hazards should be disseminated to landowners in the flood plains, and more emphasis should be placed on sound land use and management practices, including flood-plain zoning and policing. Realistic zoning ordinances would not only reduce incompatible developments in high-risk areas, but would also make provision for public land uses.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

A basic need for water resources development in the Upper Mississippi Region is a means to decrease high flows and increase low flows. This need was especially evident during the disastrous floods of 1965 and 1967. Flood damages could be reduced by the construction and efficient management of flood control structures and measures in the headwaters of the Region. It might also be feasible to utilize shallow aquifers as storage reservoirs for excess flows, which could later be used to advantage, during periods of low flow.

More uniform streamflow could also be achieved by efficient utilization and management of land resources. Flood-plain zoning, based on complete recognition of flood hazards and planned to restrict land use in order to prevent high-loss investments, would go far toward reducing flood damages. As competition for land continues to increase, the values of recreation and fish and wildlife will have to be balanced with such developments as drainage of wetlands. Preservation of certain reaches of "scenic rivers"

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should also be considered, and additional areas of water and land suitable to be developed for recreation should be reserved for public use. The increase in population will require an increase in multiple use of land and water resources, which in turn will call for a high degree of management to facilitate and integrate the uses, especially in areas near expanding urban centers.

Water supplies, both surface and ground, are considered adequate to 1980, with some scarcity expected in subsequent years. Major water problems will be related to providing water of adequate quality in the right place at the right time. With increased demands on the available water supply, more efficient use of water must be determined by economic analysis. Steam-electric plants, major users of water, will tend to shift from the once-through type cooling to other methods which require smaller withdrawals.

Municipal and industrial waste treatment facilities will need upgrading. Reliance must be placed on efficient waste treatment so that stream quality can be maintained and rehabilitated in those areas where it has fallen below acceptable standards.

Continuing public and private programs for water and related land resources developments do exist in the Region; however, an examination of their current activities indicates that the programs will not be sufficient for the needs of the future.

The management of the water and land resources is of interest to each citizen of the Region. Representatives of the Federal Government and the seven States that are party to the Upper Mississippi Region are now conducting a type 1 comprehensive framework study of the immediate and long-range water and land resource needs of the Region, which is scheduled for completion in 1969. After it is completed, some management organizational arrangement will be needed to carry out the recommended long-range coordination and implementation of the regional plan.

The long-range development of the Region's water and land resources will ultimately depend on the type of data and information that is available to planners. The Federal Government is now the prime collector of hydrologic data in the Region. States are assisting, as far as their financial and technical capabilities permit, and have concentrated primarily on collecting groundwater information. The data collection program for the Region should be optimized to provide more precise information on precipitation, streamflow, stream quality, flood frequency, flood warning, soil temperature and water content, and flood-plain information.

Applied research is needed for consideration of the many existing water and land resource problems. It could be directed toward all phases of the planning, design, construction, and operation of structural and nonstructural works for the Region. Coordination of the research should be carried out by a regional managing organization.

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CHAPTER 7

Lower Mississippi Region

SUMMARY

The Lower Mississippi Region is a strategic area in the development of the Nation's economy. Industry and commerce are expected to be increasingly attracted to the Region because of the Mississippi River's unparalleled opportunities for water supply, navigation, and waste disposal. The industrial complex developing in the New Orleans-Baton Rouge area is progressing upriver toward Memphis, and similar development is expected to progress downstream from St. Louis. Municipal growth and the development of a highly complex and intensive agricultural industry will contribute to the Region's future economic growth. As this growth takes place, the Region will experience water problems.

About 33% of the Region's 59,600 square miles is covered by one of its greatest natural assets—the rich, fertile soils of the valley alluvium of the Mississippi River. It is here that an intensive agricultural industry will continue to develop; by 2020, it is expected to be using for irrigation about 19% of the Region's projected fresh-water withdrawals. However, the amount of land devoted to agriculture will continue to decrease as more land is required for urban, industrial, and associated uses.

The Region is essentially "water rich," but the favorable supply will meet projected needs only if managed properly. Average annual runoff ranges from 14 inches in the north to 34 inches on the Gulf coast, and seasonal variation in rainfall also tends to make problems for water management. Groundwater in the Mississippi River's alluvium is abundant and at relatively shallow depths; supplies of deeper artesian water are available throughout most of the Region. Surface water quality is generally good, but chlorides induced by oilwell brine are prevalent in some areas, sediment is a problem during high flows, and biological quality is variable, with the coliform bacteria count generally high. Municipal and industrial effluents are becoming an increasing problem.

There is a paramount need for water-control measures throughout the Region to reduce floods, improve drainage, and provide for low-flow augmentation for water-quality improvement. Agricultural water withdrawals will increase about 350% by 2020, and withdrawals for urban, industrial, and other uses will increase about 700%. Projected 2020 withdrawals for all uses are 39.4 bgd, of which 6.3 bgd will be consumed.

Suitable physical sites for impoundments on the tributaries of the Mississippi River are plentiful, but costs for water storage will continue to increase because of preemptive developments in potential reservoir areas.

DESCRIPTION OF THE REGION

For this Assessment, the Lower Mississippi Region is divided into three subregions (fig. 6–7–1). Subregion 1 encompasses the Mississippi River and its tributaries from the mouth of the Ohio River to the mouth of the Yazoo, but excludes the White and the Arkansas. Subregion 2 encompasses the Mississippi and its tributaries between and including the Yazoo and the Big Black. Subregion 3 encompasses the Mississippi and its tributaries below the mouth of the Big Black but not the Ouachita and Red Rivers. It also includes direct drainage into the Gulf of Mexico from the outlet of Lake Pontchartrain to about 92° 15′ W longitude.

History

From its discovery by De Soto in 1541 to the present, the Mississippi River has been the artery for development of the Lower Mississippi Region. Marquette and Joliet explored the uper river in 1673, and in 1682 La Salle followed the river to its mouth. The first permanent European colony near the present Region was established on the Gulf coast in what is now the State of Mississippi. Trade and development radiated from that point.

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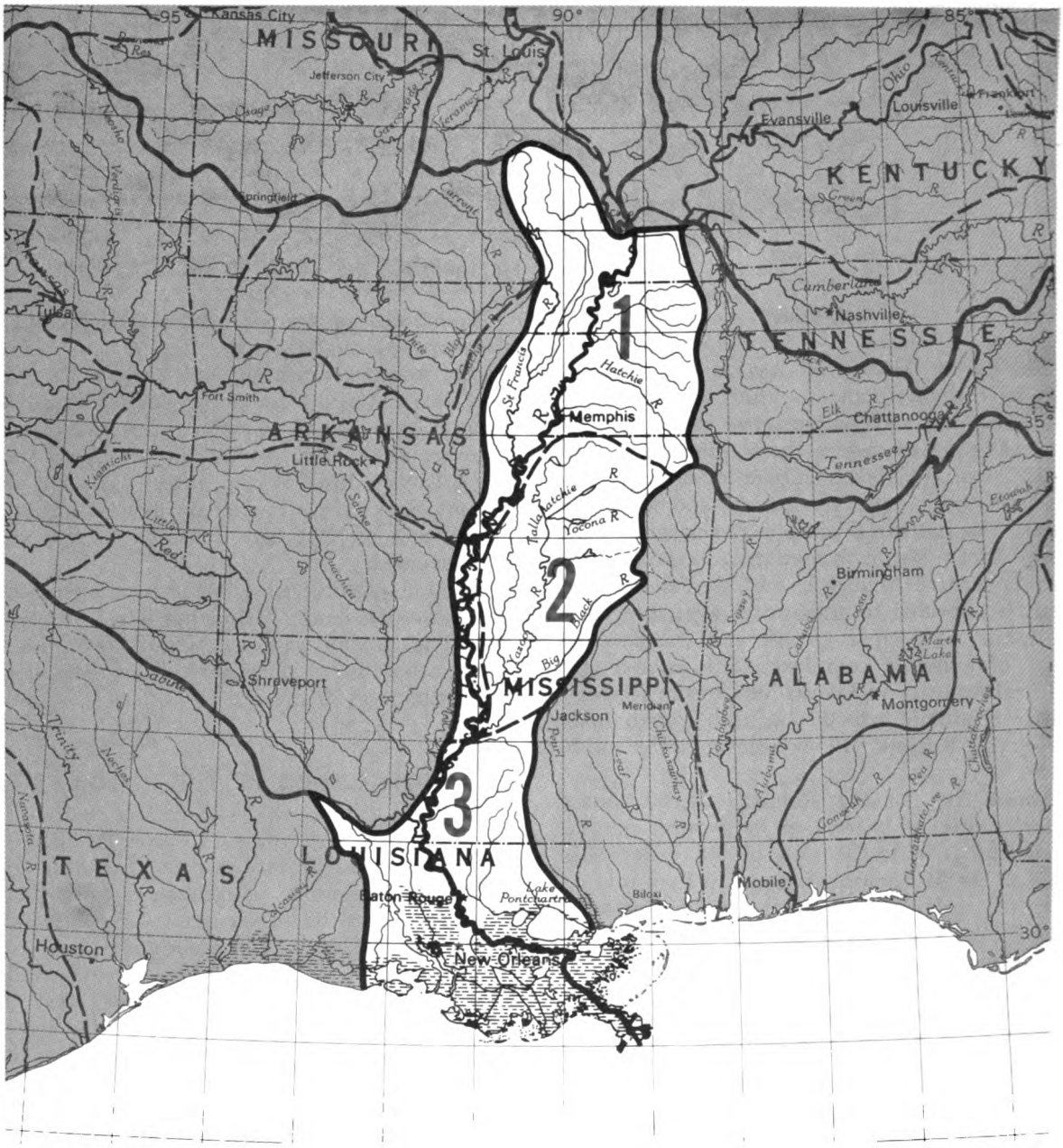

FIGURE 6–7–1.—*Map of the Lower Mississippi Region.*

In the early 1800's settlers were attracted to the area by the fertile farming land of the Mississippi's alluvial plain. The high price of cotton and low price of land drew from the older South (the Piedmont, principally) the "Great Migration" that was to accomplish the settlement of Mississippi and the "Valley" portions of Tennessee and Arkansas.

The development of water resources in the Region has been under way for over 150 years. Navigation, flood control, and major drainage have been the chief activities.

Demography

In 1960, the population was 4.6 million, about half of which accounted for the populations of the four largest metropolitan areas: New Orleans, over 900,000; Memphis, 675,000; Baton Rouge, 230,000; and Jackson, 222,000. The gen-

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eral movement of population has been from rural to metropolitan areas. During the period 1929-60, the Region grew more slowly than the Nation; the national population increased 48%, the regional population only 28%.

Economy

The Mississippi River is the chief transportation waterway of the Nation's interior. Ocean traffic moves to and from Baton Rouge, the Region's most inland seaport. Aluminum ore, fertilizer, sulfur, feed grain, and oil are transported by ships and barges on the river. During 1966, the main stem of the Mississippi River between Baton Rouge and the mouth of the Ohio River carried over 66 million tons of barge traffic. The 1966 seagoing traffic between New Orleans and the Head of the Passes amounted to over 74 million tons; of this amount, 34 million tons moved between New Orleans and Baton Rouge. The Gulf Intracoastal Waterway between the Mississippi and Sabine Rivers carried over 54 million tons of barge traffic in 1966.

Farming, petroleum, and timber are the largest sources of income for the Region, but petrochemicals and agricultural chemicals are presently the fastest growing industries.

Geography

The Region's area of 59,600 square miles (2.2% of the conterminous United States) extends from the mouth of the Ohio River to the Gulf of Mexico. Elevations in the alluvial valley range from mean sea level at the Gulf of Mexico to about 320 feet msl in Missouri. The lowland is bordered by abrupt escarpments. Occupying the eastern side of the valley are the distinctive Loess Hills, which lie within a zone 5 to 25 miles wide and extending southward almost to the Louisiana-Mississippi State line.

The land is drained by many small rivers—tributaries and distributaries of the Mississippi River, and there is some coastal drainage into the Gulf of Mexico. The largest of the rivers are the St. Francis, Yazoo, and Atchafalaya.

The exposed geologic formations of the Region are chiefly sedimentary and range in age from late Paleozoic to Recent. Most of the surface material is Quaternary alluvium. The soil in this valley alluvium is among the most fertile in the world.

Climate

The climate is typically humid, with long, hot summers and short, cool to moderately cold winters, but geographic and chronologic variations are considerable. Growing seasons vary from 6 to 10 months in the north and from 8 to 12 months in the south. Average annual precipitation ranges from 40 to 60 inches.

Damaging floods occur on an average of 2 to 4 times a year in the north, and 3 to 5 times a year in the south. Hurricanes are particularly damaging along the Gulf coast; since 1866, the Region's areas there have been affected by 23 storms of full hurricane intensity.

THE WATER RESOURCE

Both on the surface and underground, the Region is well endowed with water. The Mississippi River main stem and many tributary streams, the large flood control reservoirs in northwestern Mississippi and southeastern Missouri, and Lake Pontchartrain near New Orleans influence the economy, contribute to the area's aesthetic appeal, and offer recreation opportunities. The water resources are greatly enhanced by inflow from upstream Regions; the combined average inflow from the Ohio, the Mississippi above the mouth of the Ohio, and the White, Arkansas, and Red Rivers is approximately 360 bgd. The groundwater resource is one of the greatest in the Nation and is developed only slightly.

Quantity

Average annual natural runoff ranges from 14 inches in the north to 34 inches on the Gulf coast—representing about 30% to 60%, respectively, of the average annual precipitation in those areas. The runoff characteristics of the three subregions are shown in table 6–7–1.

Groundwater in the valley alluvium is abundant and at relatively shallow depths. Supplies of deeper artesian water are available throughout most of the Region and, in many locations, from more than one waterbearing formation.

Extremes

On the Mississippi River main stem, maximum flow generally occurs in the spring, and minimum flow during the late fall. The greatest flow of record on the Mississippi River at Vicksburg was 2,080,000 cfs in February 1937; however, a greater flood occurred in 1927 with an estimated confined discharge of 2,280,000 cfs. The lowest flow of record was 93,800 cfs in August 1936.

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TABLE 6–7–1.—*Annual natural runoff, Lower Mississippi Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	20,400	15.81	16.28	15.46	7.46	5.68
2	14,600	11.75	16.90	11.66	6.49	5.19
3	24,600	20.86	17.81	19.71	13.10	11.33
Regional value	59,600	48.4	17.06	48.4	29.7	24.6

Maximum runoff of the larger tributary streams follows general frontal storms, usually during the late winter or early spring. The occasional hurricanes that sweep up through the Region from the Gulf of Mexico, usually in late summer or early fall, are generally accompanied by heavy rainfall and cause severe flooding.

Maximum flows on the small streams result from intense local rainstorms generally associated with thunderstorm activity, and can occur during winter, spring, and summer. Minimum flows in the streams occur during the dry season that extends from late summer to late fall.

Groundwater levels in shallow aquifers reflect seasonal variations in both rainfall and withdrawals from wells. Thus, the levels are generally lower during the summer when withdrawals are heavy and rainfall is relatively less.

Water levels in wells in the deeper artesian aquifers often show some seasonal reflection of the variations in withdrawals. In all areas where withdrawals of water from these deep aquifers are appreciable and extended, groundwater levels have undergone a net decline over the past several decades.

Quality

Chemical quality of surface water in the Region is generally good. In the stretch of the Mississippi River near St. Francisville, Louisiana, which is considered representative of water in the lower part of the main stem, dissolved solid content is generally between 111 and 342 ppm. The water is moderately hard to very hard.

Most of the streams tributary to the Mississippi River contain soft to moderately hard water of good quality and generally of low mineral content. The major problems involve chloride from oilwell brine in some creeks, oxygen deficiency caused by municipal and industrial effluents, natural acidity, and both natural and oilfield brines brought into the Region in large quantities by the Arkansas and Red Rivers. The physical quality of the streams is impaired in places by color and turbidity. Heavy concentrations of sediment are prevalent in streams draining the Loess Hills during periods of storm runoff. Biological quality of the surface water is variable, but coliform bacteria counts are generally high and all municipal surface water supplies are chlorinated.

Groundwater has a higher but constant mineral content. Generally free of biological contaminants, it occasionally contains undesirable color and acidity. Fresh water occurs to depths greater than 3,000 feet in the southern part of the Region.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The Lower Mississippi Region withdrew about 5.3 bgd of fresh water and 240 mgd of saline water in 1965. Of the total water withdrawn, 1.5 bgd (26%) was consumed. Municipal use was at the rate of 131 gcd. Surface water sources furnished about 70% of total withdrawals, and about 65% of the total was used for self-supplied industries and steam-electric powerplants. However, about 70% of the water withdrawn for agriculture was obtained from groundwater sources. Availability of supplies and cost of development often preclude the use of groundwater where very large water supplies are required in a small area. Water use by source, purpose, and subregion is shown in table 6–7–2.

Projects for the control of floods in the Region have been under construction by both Federal and local agencies for many years. Substantial progress has been made, but much work remains.

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TABLE 6–7–2.—*Present water use, 1965, Lower Mississippi Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
Water withdrawn							
1	22	132	117	520	300	15	1,106
2	18	71	49	50	220	11	419
3	18	267	1,718	1,230	800	13	4,046
Total	58	470	1,884	1,800	1,320	39	5,571
From:							
Groundwater	(57)	(246)	(385)	(50)	(915)	(18)	(1,671)
Saline	—	—	(40)	(200)	—	—	(240)
Water consumed							
1	19	37	24	3	201	14	298
2	16	25	7	6	149	11	214
3	17	113	265	10	540	13	958
Total	52	175	296	19	890	38	1,470

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 3,583,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric power plants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

Many of the streams are used for disposal of municipal and industrial wastes. Complete data on the amount and degree of treatment of these wastes before introduction into the streams are not available at this time. Further, although the increasing use of herbicides in extensive agricultural areas is known to affect water quality, the degree of effect is still undetermined.

Instream use of water in the Region is of utmost importance. The value of the Mississippi River as a transportation artery for some 100 billion ton-miles of commerce per year would justify its rank at the top of the Nation's rivers even if there were no other uses for its water. Fish and wildlife habitat and water-based recreation have long been significant instream uses, and present needs for these uses are large.

ADEQUACY OF PRESENT DEVELOPMENT

Surface and underground sources in the Region are in general adequate for all present water uses except in some areas especially subject to pollution from waste disposal or contamination by saltwater intrusion. The cities of Houma and Franklin, Louisiana, are experiencing particularly large problems regarding municipal and industrial water supply. In recent years, the use of the Mississippi for municipal and industrial water supply has rapidly increased between Baton Rouge and the Gulf. The problem of pollution has grown with industrial development, and saline intrusion from the Gulf of Mexico is a frequent problem in the lower river during periods of low flow.

Shortage of water for irrigation is a problem in southern Louisiana. Saline intrusion into the coastal areas is reducing the potential supply, and low streamflows in the area are not sufficient for irrigation needs. Acute water shortages occur on the Calcasieu, Mermentau, and Vermilion Rivers and, to a lesser degree, on Bayou Teche, owing to large water withdrawals for irrigation of rice and sugar cane.

Municipal demands along the Mississippi have made it necessary to increase treatment and control of wastes discharged into the river. And several times each summer in recent years, swimming in Lake Pontchartrain has been banned because of augmented waste discharge from bordering areas.

Other areas of unsatisfactory water quality include Bayou Teche during the autumn cane-grinding season; much of the area between the Mississippi and the Atchafalaya Basin Floodway where rainfall is insufficient during autumn to

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prevent stagnation; and the entire coastal area of Louisiana where saline intrusion occurs.

Hurricane protection is inadequate in the southern portion of the Region. The coastal areas are subject to severe wind damages and to tidal overflow from the Gulf and connecting bays and lakes. Beach erosion is prevalent.

While significant progress has been made in controlling floods along the Mississippi River and in the St. Francis and Yazoo basins, comparatively little has been done on the other tributary streams. In the upland watersheds, less than 10% of the Region's land area is covered by effective flood-prevention programs. More than 15.9 million acres of land throughout the Region are still subject to flooding annually from overbank flows of major tributaries and from local streams. Another 10.3 million acres of land would be capable of increased agricultural production with drainage. Loss of income because of flooding and inadequate drainage is estimated to exceed $400 million annually. Most of this loss is suffered by the agricultural sector of the economy.

Land-management and watershed-treatment programs need to be accelerated in regard to further erosion control and reduction of sediment that enters the stream systems. More than 1.2 million acres of land are in critical need of land-stabilization measures.

Throughout the southern portion of the Region, a pressing need exists for further improvement and extension of low-cost water transportation.

In the past two decades of river basin planning in the Region, the primary concern has been with upstream and main stem structures to serve the purposes of flood control and navigation. Other purposes, such as recreation and fish and wildlife management or enhancement, were incidental. The emphasis is now shifting to the environmental quality of streams, estuaries, wetlands, and reservoirs for recreation, fish and wildlife, and domestic uses. Despite this change, present water resources development is not adequate to meet the increasing outdoor recreation needs of the Region. Areas of extreme deficiencies are generally within or immediately adjacent to urban complexes.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

With the exception of Mississippi, the States that are party to the Region have drafted very few laws or regulations specifically to control or prohibit the use or development of water. In Mississippi, the use or development of surface water is covered by legislation founded on the doctrine of prior appropriation.

In the other States of the Region, the riparian doctrine is generally accepted. Tradition and court action have modified the doctrine variously from State to State, and the water policy and management doctrines of individual States have generally stemmed from relevant sections of many laws, from tradition and custom, and from court decisions. This lack of uniformity of policy and doctrine within the Region is a major institutional problem.

The thesis that the waters within a State are the properties of that State and, therefore, subject to State control is widely held, despite the current fact that the Federal Government has been assuming more and more responsibility for all aspects of water and land management. The responsibility of the States and such other government units as counties, municipalities, and special-purpose districts, in the field of water management, is long-standing and generally had its origin in State constitutions and statutes. Thus, the overall development and management plans for the water resources of the Lower Mississippi Region must be in harmony with the goals of the traditional local management groups and compatible with their desires; otherwise severe and disruptive relations with these groups can result.

Adequate organizational structure and corresponding staffs have not been developed for water resources planning at either the State or the regional level. Increased State planning capabilities, assisted by Title III of the Water Resources Planning Act, would provide the means necessary to develop plans that will be understood and supported at local levels.

Legal and institutional problems can be expected to increase, especially under the loose legal framework now prevailing throughout the Region. However, several of the States are currently involved either in writing new laws or in modifying existing laws.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Lower Mississippi Region should experience a favorable growth rate because of the following environmental factors:

1. Strategic location on the principal waterway serving the industrial and agricultural heart-

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land of the Nation, and proximity to extensive supplies of fossil fuels;

2. A plentiful supply of water of good quality, which, if managed properly, will be adequate for all foreseen uses;

3. Generally favorable year-round climate, which makes the Region more inviting to industrial development;

4. Abundant and richly fertile agricultural lands, which, with further protection and development, can be used more efficiently and intensively.

Economic projections indicate that by 2020, 10.6 million people will live in the Region, supported by $76.2 billion in personal income earned by 3.9 million workers and entrepreneurs (table 6–7–3). This means that between 1960 and 2020 the population will increase about 130%; employment, 160%; and per capita income, 370%.

The expansion of employment opportunities is an economic concomitant of population growth. Jobs are increasingly concentrated in urban areas, and this trend has caused considerable movement from rural counties dependent upon agriculture as their employment base. The trend for agricultural land use is decreasing; however, the trend for irrigated land is increasing. By 2020, agricultural land is expected to decrease by 7% of the 1960 use, whereas nonagricultural land is expected to increase by 44%. Irrigated lands are projected to increase almost 500% over the same period.

With the increases in population, income, mobility, leisure time, and education, the Region will experience growth at a rate approaching that of the Nation. This economic growth will cause a corresponding increase in the need for recreation facilities. It is expected that participation in the major summertime outdoor recreation activities will triple between 1965 and 2000. The water-dependent activities will increase even more.

The increased demands on the available water supplies of the Region will stem basically from the increase in population and the expansion of industry. However, water requirements will be greater than indicated by projected levels of population and industrial employment because of several trends now evident. Extensive urbanization will raise water demand, since per capita consumption is higher in cities than in rural areas. More leisure time will amplify demands for recreation facilities. The need for clean, fresh water from streams will increase demands for treatment and dilution of wastes as the concentration of people and industry continues.

It is expected that water withdrawals for all uses will increase almost 600%—from 5.6 bgd in

TABLE 6–7–3.—*Economic and agricultural projections, Lower Mississippi Region*

Item	Unit	1960[1]	Projections		
			1980	2000	2020
Population, total	thou.	4,619	5,871	7,815	10,587
Per capita personal income	1954 dol.	1,526	2,700	4,450	7,200
Employment, total[2]	thou.	1,505	2,040	2,788	3,859
Agriculture	do.	249	102	64	53
Manufacturing	do.	248	363	504	705
Other commodity producing	do.	154	234	289	350
Distributive industries	do.	401	586	789	1,055
Service industries	do.	453	754	1,142	1,696
Land base	thou. ac.	41,664	41,664	41,664	41,664
Agricultural	do.	36,081	35,431	34,551	33,621
Cropland total[3]	do.	14,848	14,210	13,857	13,484
Used for crops	do.	13,147	14,099	13,747	13,375
Idle and fallow	do.	1,701	111	110	109
Pasture-permanent	do.	3,538	4,165	4,573	6,473
Forest and woodland	do.	17,695	17,056	16,121	13,664
Nonagricultural	do.	5,583	6,233	7,113	8,043
Irrigated land[4 5]	do.	[6] 700	2,100	3,050	4,150

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] Includes Allen and Jeff Davis Parishes, La.
[6] In 1965 irrigated land amounted to 900 thousand acres.

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1965 to 39.4 bgd in 2020. Consumptive use will increase from 1.5 to 6.3 bgd. The projections are shown in table 6–7–4.

The demands on instream water will also increase as navigation, fish and wildlife, and outdoor recreation uses increase. Management of water and related lands will demand more attention and become more critical as both water resources development and water-use competition increase. Even with satisfactory institutional arrangements to control, regulate, and allocate the water, pollution may still be a problem in the parts of the Region that contain high concentrations of municipalities and industries.

EMERGING WATER PROBLEMS

Inadequate management—physical, chemical, biological, or legal—is the greatest water resources problem facing the Lower Mississippi Region. A comparison of the available water supply with projected water requirements indicates, overall, no regional shortage of water (table 6–7–5). There are, however, indications of problems in local areas with water shortage, especially for irrigation. These could be solved through impoundments or diversions.

Comprehensive planning, with accelerated implementation of water and related land resource projects, will help to determine and satisfy regional needs. Joint State-Federal regulation of water management is needed to determine priority of use and to maintain quality standards for domestic, industrial, recreation, and other usage of water.

As the populace and transportation facilities of metropolitan areas increasingly spill over into rural areas, desirable sites for water-control structures are being preempted or made more costly to obtain. The lack of zoning for flood plains or of regulations restricting their use delays the solution of a continually growing problem. While the damages from floods mount annually, the means to control the floods and to reduce damage are becoming more complex, difficult, and costly.

The demand for more and better facilities to satisfy needs for recreation, particularly water-dependent activities, is increasing at an unprecedented rate. A great percentage of this demand will have to be satisfied through private enterprises.

TABLE 6–7–4.—*Projected water requirements, Lower Mississippi Region*

(Million gallons per day)

Type of use	Used	Projected requirements		
	1965	1980	2000	2020
Withdrawals				
Rural domestic	58	80	147	254
Municipal (public-supplied)	470	647	921	1,334
Industrial (self-supplied)	1,884	2,500	3,420	4,740
Steam-electric power (fresh)	1,600	5,900	16,700	19,500
(saline)	200	600	2,300	7,500
Agriculture:				
Irrigation	1,320	3,030	4,400	6,000
Livestock	39	59	79	114
Total	5,571	12,816	27,967	39,442
Consumptive use				
Rural domestic	52	72	133	229
Municipal	175	238	343	497
Industrial	296	400	550	760
Steam-electric power (fresh)	16	60	175	295
(saline)	3	4	7	40
Agriculture:				
Irrigation	890	2,180	3,170	4,320
Livestock	38	58	75	110
Total	1,470	3,012	4,453	6,251

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TABLE 6–7–5.—*Projected water available from the Mississippi River, Lower Mississippi Region*

(Billion gallons per day)

Item	1965	1980	2000	2020
Net runoff of upstream regions[1]:				
Upper Mississippi	65.9	65.6	64.9	64.1
Missouri	38.1	35.4	33.4	32.1
Tennessee	41.2	40.9	40.7	40.4
Ohio	124.1	123.6	122.7	121.6
Arkansas-White-Red	89.9	87.3	85.3	83.6
Total[2]	359.2	352.8	347.0	341.8
Natural runoff of Lower Mississippi Region	48.4	48.4	48.4	48.4
Total water available	407.6	401.2	395.4	390.2
Regional fresh-water withdrawals	5.3	12.0	25.0	30.0
Regional fresh-water consumption	1.5	3.0	4.4	6.2

[1] Average annual natural runoff plus net imports less consumptive use.
[2] Approximate value. Runoff data do not include channel losses and consumptive use data may include groundwater mining.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

It is estimated that the Region encompasses more than 525 small watersheds. About 85% of them are regarded as physically and economically feasible projects under existing planning criteria; to meet development needs, at least 140 of these should be planned and in operation by 1980 to supplement existing projects. In many of the upland watersheds, regulatory storage is needed. In total, over 20 million acres of land need various conservation practices to efficiently provide needed food and fiber for the Region and the Nation.

Under existing planning criteria, about 150 multiple-purpose projects with highly developed recreation facilities could be constructed. Added storage for fish and wildlife development and other purposes could also be included in other projects. These multiple-purpose projects could provide over 15 million recreation activity-occasions each year.

The acreage of irrigated land is expected to increase from 0.9 million in 1965 to 2.1 million in 1980. Water withdrawn for agricultural, including rural domestic, uses will increase from 1.4 bgd in 1965 to 3.2 bgd in 1980.

Considerable development of both surface and ground waters must take place to satisfy these needs.

There is a clear need for expansion of comprehensive water resources planning with broad interagency participation. Likewise, the relationship between Federal and State agencies needs to be defined more clearly, particularly in regard to cost sharing and support of projects. The evolution of water resources planning into a multidisciplinary operation is being furthered by current interest in pollution control, recreation, and studies of transbasin water diversions. It is increasingly apparent that, as more agencies become involved, institutional bodies must be developed to coordinate and manage local, State, and Federal water resources planning and development.

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CHAPTER 8

Souris-Red-Rainy Region

SUMMARY

The Souris-Red-Rainy Region is located along the northern boundary of the United States in North Dakota and Minnesota and extends short distances into South Dakota and Montana. Its drainage area is about 59,000 square miles. Annual precipitation averages about 14 inches near the northern North Dakota-Montana boundary and about 28 inches in the eastern headwaters area of the Rainy River, with the annual runoff varying accordingly from 0.2 inches to 10. Agriculture and agriculture-oriented industries are the main sources of income, although the Rainy subregion depends largely on income from the timber industry and recreation.

A majority of the Region's water problems are in the Souris and Red subregions. The considerable and sustained water resources development that has been carried out there includes several reservoirs for flood control, water supply, and water quality control; local protection projects; watershed-protection projects; fish and wildlife developments; land drainage; and some irrigation. Nevertheless, there are still many unmet needs, as well as emerging needs, for the future throughout the Region.

Economic projections indicate that 1960's population of 652,000 will double in a period of 60 years. The resulting increase by 2020 in consumptive use of water for all purposes except irrigation is projected at about 150%. The increase in consumption for irrigation will be almost 1,600%, but most of the water is expected to be supplied by diversion from the Missouri Region through the initial phase of the authorized Garrison diversion unit.

More intensive use of agricultural lands will require increased efforts by all Federal, State, and local agencies to provide the needed flood protection, drainage, irrigation, and soil conservation practices and at the same time preserve and develop the recreation and wildlife resources. A primary specific need in this regard is flood protection on 1.6 million acres (most of them in agricultural use) and complex drainage systems on 3.3 million acres (all agricultural).

The problem of stream and lake pollution, at present urgent only in localized areas, will become increasingly serious for the whole Region as population, industry, and urbanization expand and more intensive use is made of agricultural lands. The expected surge of demand for water-based recreation—which is projected as the greatest "growth industry"—will accelerate the need for water-quality controls.

Some of these needs can be met by the construction of about 240 upstream flood-water retarding structures and 8 major downstream reservoirs, some of which should be designed to serve multiple purposes. Local protection works for towns and cities, as well as channel improvements to complement the reservoirs and serve as outlets for drainage, are needed. An effort is currently being made by means of purchase and easements to preserve the most important wildlife producing lands.

The emerging needs of the Region will call for the coordination of all agencies and local interests in the development and implementation of a comprehensive plan for water and related land resources. The newly established Souris-Red-Rainy River Basins Commission is expected to provide such coordination and is responsible for the type 1 framework study just initiated.

DESCRIPTION OF THE REGION

The Souris-Red-Rainy Region (fig. 6–8–1) drains northward to Hudson Bay. It consists of three subregions: the Souris River (known in North Dakota as the Mouse River) on the west; the Red River of the North in the center; and the Rainy River on the east. The Region encompasses about 59,000 square miles, of which about 16% is in the Souris subregion, 65% in the Red, and 19% in the Rainy.

The Region was covered by a continental gla-

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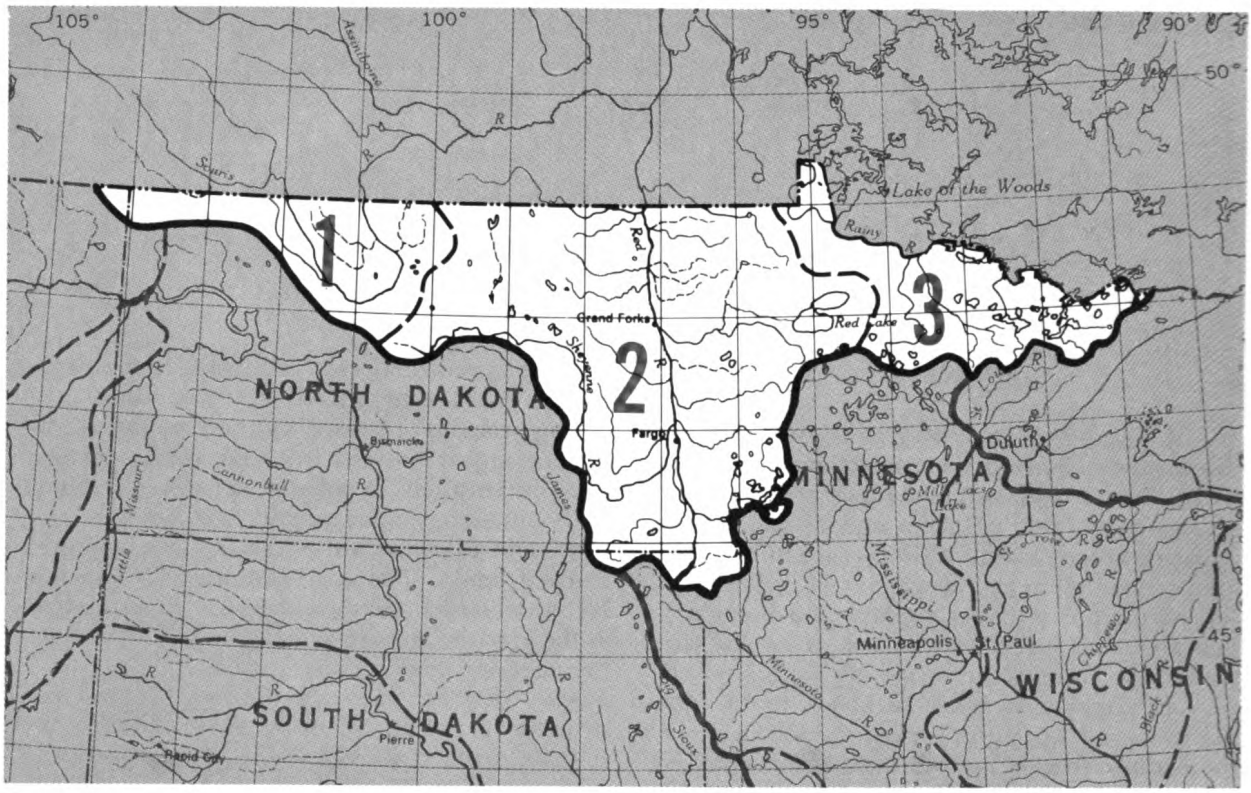

FIGURE 6–8–1.—*Map of the Souris-Red-Rainy Region.*

cier and as a result the surface is immature, flat, and poorly drained. It has broad divides, innumerable potholes, sloughs, and lakes. Many areas do not contribute to streamflow.

Extreme temperature variations are common, with seasonal readings ranging from -54° to 118°. The average annual precipitation ranges from about 14 inches in the west to about 28 in the east. About 75% of the annual precipitation occurs as rain. Precipitation for crop production is adequate during normal years; however, the western half of the Region suffers from occasional periods of severe drought.

The current population is estimated at 716,000. The Region is largely rural, with few towns of more than 2,500 people. The adjacent cities, Fargo, North Dakota, and Moorhead, Minnesota, whose combined population was about 72,000 in 1960, comprise the largest urban area. Indian inhabitants of the 6 reservations number about 16,000.

With the advent of the railroads in the early 1870's, settlement of the Region began to increase. During the years of heavy immigration to the United States, the settlers included people from many countries. Thus, the ethnic backgrounds of the present population vary widely.

Agriculture is the major industry of the Souris and Red subregions, with 20.2 million acres used for crop production and 4.0 million for pasture and range. Livestock operations account for about one-third of agricultural income, crops for two-thirds. Principal crops are wheat, barley, hay, oats, flax, corn, soybeans, potatoes, and sugar beets. Nonagricultural income sources include food-processing industries and natural resources—petroleum, lignite, and sand and gravel. About 197,000 permanent or semipermanent wetland areas contribute natural feeding and nesting areas for waterfowl.

About 85% of the Rainy subregion consists of forest land. Some 65% of it is publicly owned, including the Chippewa and Superior National Forests and several State forests. The area's wilderness characteristics and its network of lakes and streams make it one of the most important recreation sites in the upper Midwest. The subregion's primary source of income is the timber industry and its by-products. Other sources include resort business, fur trapping, guide services to hunters and fishermen, tourist trade, commercial fishing, and agricultural products from 235,000 acres of cropland and 25,000 acres of pasture.

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THE WATER RESOURCE

The available quantity and quality of water resources in the Region vary greatly from place to place, season to season, and year to year. In the Souris subregion, streamflow is normally inadequate to satisfy water needs, and the quality is generally acceptable but not good. During normal years, streamflow in the Red subregion is adequate and the quality is generally satisfactory. However, increasing municipal, industrial, and agricultural pollution is degrading water quality of the Red River main stem. In the Rainy subregion, water is abundant, and, with the exception of the Rainy River below International Falls, its quality is excellent.

The average annual natural runoff originating within the Region is shown in table 6–8–1. It ranges from 0.2 inches in the western part of the Souris subregion to about 10 in the eastern part of the Rainy subregion. Generally, minimum flows occur during the winter under ice cover that is 2 to 4 feet thick. Maximum flows usually occur during the spring breakup, with about 50% of the annual flow during April and May. Flooding is a major problem because of the flatness of the land and because the major streams flow north. The spring thaws occur first in the upper reaches, flooding still frozen areas downstream.

Except in the Red River valley area, lakes, reservoirs, and ponds abound in the Region. The largest natural lakes are located in Minnesota. The so-called "prairie potholes"—natural ponds only a few acres in size—are extremely abundant in the Souris subregion and along the western and eastern edges of the Red. Most of them contain water only during the spring and early summer and are chiefly valued as waterfowl habitat, livestock water, and groundwater recharge.

Major aquifers exist in the glacial drift and in the older sedimentary rocks which underlie the drift in the Souris subregion and most of the Red (fig. 6–8–2). However, much of the water in the sedimentary rocks is of poor chemical quality and thus undesirable for most uses. In the Rainy subregion, the glacial drift is directly underlain by Precambrian crystalline rocks which yield little or no groundwater.

Few, if any, aquifers are so continuous and uniform that production wells may be drilled without preliminary test drilling. In some places the aquifers are defined on the basis of scattered test-hole and well data; future work may modify interpretations. Yields of wells in the glacial drift range from a few gpm to more than 1,000.

PRESENT WATER RESOURCES DEVELOPMENT—1965

A considerable number of man-made reservoirs, large and small, have been constructed in the last 20 years, particularly in North Dakota. The largest of these is Lake Ashtabula on the Sheyenne River which holds about 22.5 billion gallons (69,000 af) of usable storage at maximum stage. One large reservoir and some two dozen low-level ponds and marshes have been constructed on the Souris River and its tributary, the Des Lacs River; these have a total reservoir capacity of about 98 billion gallons (300,000 af). More than 15,000 stockwatering ponds (mainly in the Souris and Red subregions), with total capacity of about 9.5 billion gallons (31,000 af), have been constructed with Federal assistance.

TABLE 6–8–1.—*Annual natural runoff, Souris-Red-Rainy Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	9,300	0.07	0.16	0.04	0.005	0.002
2	38,700	1.88	1.02	1.58	0.42	0.25
3	11,000	4.22	8.07	4.14	2.08	1.61
Regional value	59,000	6.17	2.20	5.95	2.60	1.91

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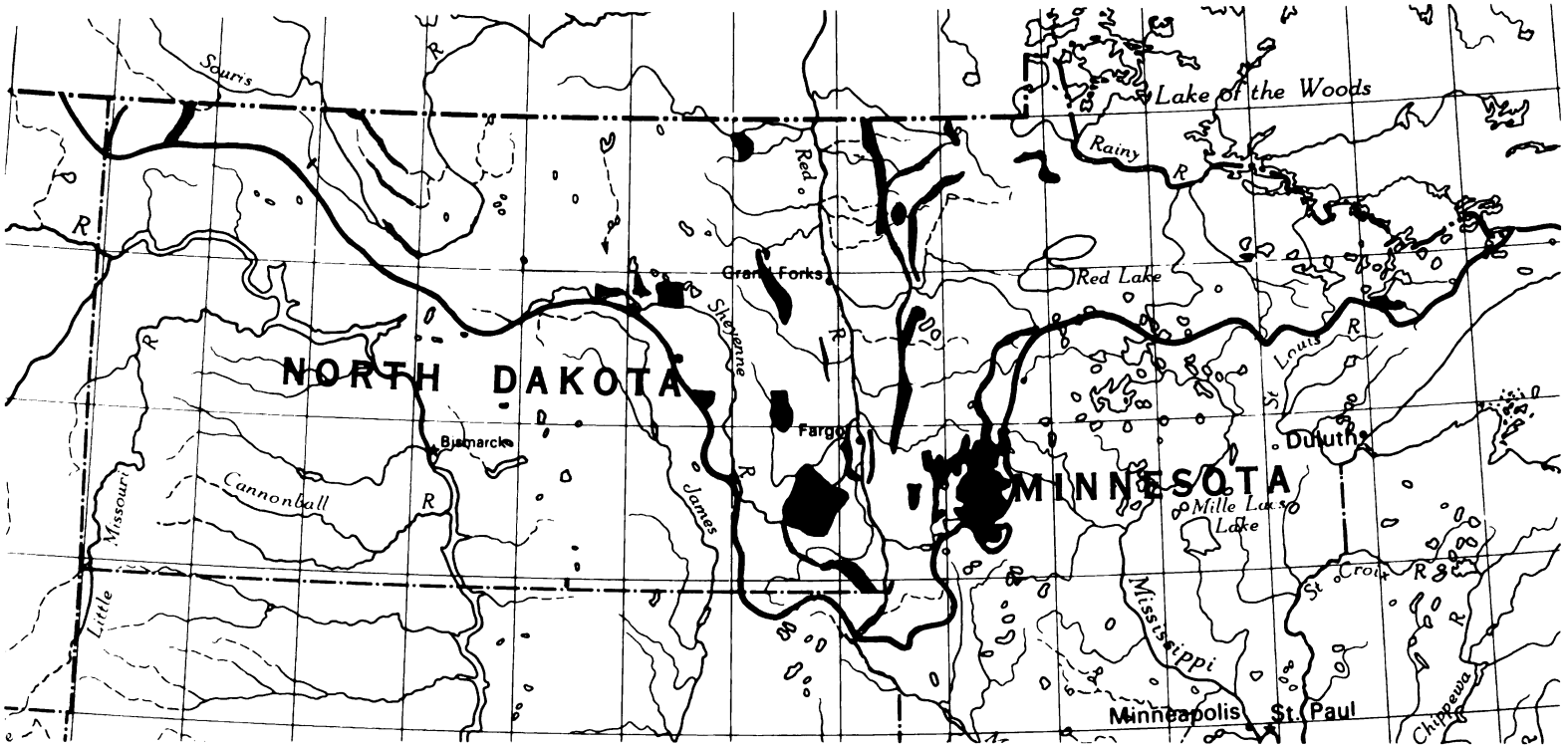

APPROXIMATE SCALE

25 0 25 50 75 100 125 MILES

EXPLANATION

(Estimated well yields, in gpm)

50–1000 — Aquifers consist of surficial sand and gravel deposits. Depths of wells generally between 50 and 150 feet. Water-table conditions. Recharge generally adequate. Calcium bicarbonate water, dissolved solids generally less than 500 ppm. Large potential for development.

50–500 — Aquifers consist of sand and gravel deposits buried by varying thickness of glacial till or other fine-grained deposits. Depths of wells generally between 100 and 300 feet, but in places are as much as 500 feet. Artesian conditions. Slow recharge. Generally calcium bicarbonate water, but deeper waters may have substantial sodium content. Dissolved solids generally between 500 and 1,500 ppm, but as much as 2,500 ppm locally. Moderate to large potential for development.

50–250 — Aquifers consist of relatively thin surficial sand and gravel deposits. Depths of wells generally less than 100 feet. Water-table conditions. Recharge generally adequate. Calcium bicarbonate water, dissolved solids generally less than 500 ppm. Small to moderate potential for development.

FIGURE 6–8–2.—*Groundwater resources, Souris-Red-Rainy Region.*

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TABLE 6–8–2.—*Present water use, 1965, Souris-Red-Rainy Region*

(Million gallons per day)

	Rural [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation	Livestock	
			Water withdrawn				
Total	14	36	98	200	24	19	391
From groundwater	(14)	(14)	(12)	(0)	(3)	(12)	(55)
			Water consumed				
Total	14	11	7	2	24	19	77

[1] Water used for domestic purposes not served by public water supply systems.
[2] Serves a population of 364,000 through public water supply systems.
[3] Water supplied by industry itself; also includes military establishments.
[4] Water supplied for cooling and operation of public utility steam-electric powerplants.

The Region's present consumptive use of water is estimated at 77 mgd. Municipal, industrial, and steam-electric power uses consume 20 mgd, and 14 mgd are consumed by rural domestic users (table 6–8–2). Much of the population, especially in rural areas, depends on groundwater as the source of supply.

Irrigation is practiced on a limited scale; in 1965, about 15,000 acres were irrigated. This acreage consumes about 24 mgd, almost 90% of which is surface water, whereas about 19 mgd are consumed by livestock, nearly 60% of which comes from groundwater.

The Region's 10 hydroelectric plants, 7 of them in the Red subregion and 3 in the Rainy, have a capacity of 14,325 kw. Together they use about 2,700 mgd but consume no water.

In the northwestern portion of the Region few lakes are suitable for water-oriented outdoor recreation, with the exception of hunting. In contrast, the northeastern portion's many lakes and streams surrounded by heavily wooded tracts make the area highly attractive to outdoor recreationists. In particular, its State and national forests and the Boundary Waters Canoe Area attract many visitors. The southeastern portion, especially in Minnesota's Otter Tail and Becker Counties, also has many lakes that are used for recreation.

Water for fish and wildlife in the Souris subregion is principally provided through reservoir storage on 9 national wildlife refuges. The Red subregion has 29 such refuges, the Rainy none. Evaporation losses from the refuges represent a sizable consumptive use, but, because reliable data are lacking, have not been included in the Assessment's estimates of regional consumption.

Local sponsors in 54 small watersheds in the Region have requested Federal assistance. Watershed work plans have been developed on 16 of these and planning assistance is being provided to 9 more. Two projects have been completed in the Red subregion and one in the Rainy.

Approximately 1.6 million acres, most of them in agricultural use, need flood protection under 1965 conditions. Existing facilities constructed under Federal (or federally assisted) programs have reduced flood damages on about 547,000 acres. Another half million suffer minor flood damages, but protective measures are not economically feasible under 1965 conditions. In addition, several towns and cities on the main streams suffer frequent flood damage.

ADEQUACY OF PRESENT DEVELOPMENT

The quantity of water in the Rainy subregion is adequate for all purposes at the present time; extensive water resources developments have therefore not been undertaken. Although occasional flooding occurs, flood damages are low because flood-plain lands are not intensively utilized and are generally of low value. Water throughout the subregion has a low mineral content and is generally of good quality. Municipal and industrial wastes have, however, degraded some areas for wildlife and recreation

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uses, especially in the Rainy River below International Falls.

In the Souris subregion, projects have provided a high degree of development for fish and wildlife uses on the main stem and tributaries of the Souris River. Drainage developments are mostly those of individual or small groups of landowners. Existing water resources developments on the main stem and major tributaries are inadequate for needed flood protection, municipal water, drainage, or quality control. There is not enough water to meet irrigation needs and no major irrigation projects exist. Although many conservation practices have been established, land treatment is not fully adequate to protect, conserve, and develop the subregion's land resources. Water-based recreation developments are few and are inadequate to meet local and tourist needs. The few good recreation developments are overcrowded. The mineral content of the water in the Souris River is higher than that of the other rivers of the Region.

In the Red River subregion numerous water resources developments provide water for municipal, industrial, fish and wildlife, livestock, recreation, and limited irrigation uses. In addition, several projects have been developed to provide drainage and flood protection. Nevertheless, present projects are not adequate to meet current needs—particularly those of flood control, irrigation, fish and wildlife, and industry. Project development for flood control shows the greatest deficiency. About 1.5 million acres of agricultural land and several cities and towns along the main stem and tributaries are in need of flood protection.

Additional treatment plants and other quality control facilities are needed to raise the quality of the Red River streamflows which are being fouled by food-processing wastes, silt, and other pollutants. Landowners have established needed soil and water conservation measures on about 50% of the subregion's land. Much of the land in the old Lake Agassiz area cannot be farmed economically without land drainage. About 957,000 acres have been improved in this area, with additional lands being improved annually. Water-based recreation developments in the western half of the subregion are inadequate to meet local needs, but the many lakes in the eastern portion, particularly in the Otter Tail subbasin, are suitable for outdoor recreation and attract many visitors.

The deficiency of flood control measures throughout the Region affects over 1.6 million acres, including 178,000 acres which are now receiving some degree of flood protection but for which additional protection is needed.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

The Region includes parts of four States, and many institutional and management problems are evident. Furthermore, some of the runoff originates in three Provinces of Canada and all three subregions discharge into Canada. Water management improvements in one nation producing significant effects on the water resources of the other nation are subject to review and approval by the International Joint Commission, in accordance with treaty agreements between the two nations. In addition, numerous Federal and State agencies are involved in various phases of water and related land resources functions.

Recognizing the many problems in the Region and the need for the development of a comprehensive plan, the Governors of North Dakota and Minnesota requested and President Johnson established a Souris-Red-Rainy River Basins Commission. The legislatures of North Dakota and Minnesota have each appropriated $95,000 for the 1968–69 biennium to help finance the Commission.

Major laws and regulations relating to water as they apply to North Dakota and Minnesota, the principal States of the Region, are outlined below.

North Dakota

The State Constitution provides that "All flowing streams and natural water courses shall forever remain the property of the State for mining, irrigating, and manufacturing purposes."

The Century Code provides: "In all cases where the use of water for different purposes conflict, such uses shall conform to the following order or priority: Domestic use; livestock use, irrigation and industry; fish, wildlife, and other outdoor recreational uses." . . . "The North Dakota State Water Commission shall have full and complete power, authority, and general jurisdiction to investigate plan, regulate, undertake, construct, establish, maintain, control, operate and supervise all works, dams, and projects, public and private which in its judgment may be necessary or advisable."

Several special-purpose districts may be formed to manage and utilize water resources, including water management districts, irrigation dis-

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tricts, flood irrigation districts, conservancy districts, drainage districts, and park districts.

The Souris River Reference (1940) to the International Joint Commission provides that Saskatchewan may retain one-half the water originating there and that North Dakota must allow a regulated flow of 20 cfs into Manitoba during June through October. In periods of severe drought when 20 cfs cannot be delivered, North Dakota is to provide flows to Manitoba as the International Souris River Board of Control determines for the primary objective of meeting human and livestock needs.

Minnesota

Subject to existing rights, all water in streams and lakes within the State which are capable of substantial beneficial public use are public waters subject to State control.

The State controls the appropriations and use of surface and underground waters. Written permits from the Commissioner of Conservation are required for performing any work affecting the beds of lakes and streams and for appropriating water (surface or ground) except for domestic use or use within the limits of municipalities. Permits are also required for the construction, reconstruction, repair, removal or abandonment of dams, reservoirs, and all control structures in any public waters.

Water cannot be diverted from one watershed to another except where required for the mining and processing of iron ore.

Under Minnesota law, local people, groups, or governmental units may carry out water management projects by establishing county ditches, judicial ditches, watershed districts, or county park commissions.

The Shipstead-Newton-Nolan Act (PL 71–539) provides that the public lands and waters forming the International Boundary in Minnesota shall generally be withdrawn from all forms of entry or appropriation under the public land laws of the United States.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Region's projected growth to 2020 is characterized by a continued increase in population (table 6–8–3). A slight decline in farmland area and a corresponding increase in land use for urban and industrial developments, recreation, and fish and wildlife areas will also occur. There will be substantial increases in em-

TABLE 6–8–3.—*Economic and agricultural projections, Souris-Red-Rainy Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	652	791	1,023	1,368
Per capita personal income	1954 dol.	1,708	3,175	4,925	7,700
Employment, total [2]	thou.	230	288	377	510
Agriculture	do.	71	43	34	32
Manufacturing	do.	15	19	26	36
Other commodity producing	do.	18	26	34	45
Distributive industries	do.	62	90	122	155
Service industries	do.	65	110	161	241
Land base [3]	thou. ac.	33,543	33,543	33,543	33,543
Agricultural	do.	30,661	30,561	30,401	30,251
Cropland, total [4]	do.	20,521	19,984	19,879	19,781
Used for crops	do.	14,982	14,219	14,507	15,462
Idle and fallow	do.	5,539	5,765	5,372	4,319
Pasture-permanent	do.	4,075	4,532	4,508	4,486
Forest and woodland	do.	6,065	6,045	6,014	5,984
Nonagricultural	do.	2,882	2,982	3,142	3,292
Irrigated land [5]	do.	[6] 10	90	240	250

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Based on county boundaries. Does not include Lake and St. Louis counties in Minnesota. For this report, these counties included in Great Lakes Region.
[4] Includes cropland used as pasture.
[5] Includes cropland and pasture. Projections reflect impact of authorized Garrison Diversion Unit.
[6] In 1965 irrigated land amounted to about 15 thousand acres.

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ployment in all industries except agriculture. Thus, the use of water will grow substantially, reflecting increased need for water conservation and development to adequately supply all areas of the economy by 2020.

Population is projected to grow from 652,000 people in 1960 to 1.4 million in 2020; the increase will occur in the urban and rural nonfarm areas of the economy, with a continued decrease in the number of persons living on farms. Recent years have shown a strong trend toward increased farm size. The trend is expected to continue at a slower rate beyond 1980, with the result that the number of farms in 2000 will be less than one-half the number in existence in 1965.

Farms in most of the Region are among the most mechanized in the Nation. This, plus the application of many new techniques, such as the use of fertilizers and insecticides, has brought about much more efficient use of the land and greater yields. The present high production will increase substantially in the future.

The regional economy will continue to be dependent on agriculture and on industries associated with agricultural production. The variety of crops grown and the increased development of irrigation will provide the basis for the expansion of existing food-processing plants and the introduction of new industries—for example, in the Souris and Red subregions, alfalfa dehydration plants and canneries.

The initial stage of the Garrison diversion unit, authorized in 1965, will bring an additional 190,700 acres of irrigation into the Souris and Red subregions by 2000. It will contribute to the economy over 39 million pounds of livestock meat (live-weight), enough annually for about 140,000 people. Production from these lands will increase local trade and services by $28 million annually.

The Rainy subregion supports a large forestry industry and the manufacture of pulp and paper. Expected expansion of the mineral industry and the associated increases in population and employment will add significantly to the economy of the subregion. Excellent copper-nickel prospects exist, and investigations are currently being made on the feasibility of a 30,000-ton per day underground mine and concentrator.

Regional water withdrawals in 2020 will be 2,758 mgd, with a consumption of 544 mgd (table 6–8–4). Municipal withdrawals will be 124 mgd; rural domestic, 21 mgd; self-supplied industrial, 297 mgd; and livestock, 40 mgd. Ex-

TABLE 6–8–4.—*Projected water requirements, Souris-Red-Rainy Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	14	16	17	21
Municipal (public-supplied)	36	49	82	124
Industrial (self-supplied)	98	150	212	297
Steam-electric power (fresh)	200	500	1,100	1,700
Agriculture:				
Irrigation	24	200	562	576
Livestock	19	21	29	40
Total	391	936	2,002	2,758
Consumptive use				
Rural domestic	14	16	17	21
Municipal	11	16	26	35
Industrial	7	8	10	12
Steam-electric power (fresh)	2	4	10	20
Agriculture:				
Irrigation	24	150	402	416
Livestock	19	21	29	40
Total	77	215	494	544

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cluded from the livestock requirements are evaporation losses from farm ponds. Withdrawal requirements of 609 mgd (680,000 af/yr) for irrigation, municipal, industrial, fish and wildlife, and recreation uses will be met by importing water from Garrison Reservoir in the Missouri Region. The increased need for municipal and rural domestic water will require considerable surface and groundwater development.

Power requirements will increase to 5.3 billion kwh by 1980, 15.6 billion by 2000, and 30.5 billion by 2020. The water requirement for power in 2020 is estimated at 1,700 mgd, with a consumption of 20 mgd mainly through evaporation in the cooling process of steam-electric generation. Additional development of hydroelectric power is not planned because of limited hydroelectric resources.

Recreation will play an increasingly important role in the regional economy. The projected demand shows that the number of resident activity-occasions will increase from 55 million in 1960 to 261 million in 2020. There will be significant uses of the recreation resources, particularly those of the Rainy subregion, by nonregion and out-of-state visitors.

The Garrison diversion unit will enhance recreation and fish and wildlife developments in numerous areas of the Souris and Red subregions, including the restoration of Devils Lake. Although certain areas of these subregions have for years been regarded as the Nation's "duck factories," unmet needs for fish and wildlife environments will remain high.

EMERGING WATER PROBLEMS

The Region's future water demands, water resources development needs, and problems in quality control are reflected in the projected doubling of the 1960 population of 652,000 by 2020. With the trend to urbanization continuing, municipalities will provide residence for the increased population, whereas the farm population will decrease.

Total domestic use of water is expected to triple by 2020. Little difficulty is anticipated in meeting this need in the eastern part of the Region. In the western part, particularly in the Souris subregion, good quality water is in short supply, but the initial stage of the Garrison diversion unit will help to provide a more adequate supply of water for domestic needs.

Anticipated industrial water needs of the Region can probably be met from the Garrison diversion unit if, at the same time, better use is made of existing supplies. However, special water supply measures may be necessary in the Rainy subregion to meet the needs of potential mining and mineral processing developments.

Because the regional economy will continue to depend heavily on agriculture, efforts to improve and protect soil resources must be intensified. Among the most urgent needs will be adequate flood prevention for about 1.6 million acres and land treatment measures on about 10.2 million acres of cropland and 1.2 million acres of pastureland. About 3.3 million acres of agricultural land will require complex drainage systems that can provide both maximum crop production and preservation of valuable natural wetlands. This will require continuance and expansion of existing Federal, State, and local conservation programs.

Consumptive use of water for irrigation and livestock will increase from 43 mgd in 1965 to 456 mgd by 2020, mainly because the water can be made available from the authorized Garrison diversion unit. However, the unit's anticipated full development, which will serve about 1.0 million acres in North Dakota, will not be completed until after 2020. The North Dakota State Water Commission has granted a water right of 2.81 bgd (3.15 maf/yr) of Missouri River water for full development of the unit; approximately 2.18 bgd (2.45 maf/yr) will be used in the Souris-Red-Rainy Region.

Recreation is expected to be the Region's greatest "growth industry." There are now 55 million activity-occasions per year and the figure is expected to increase about 500% by 2020. Providing water-based recreation, either as part of multiple-use developments or as independent recreation facilities, may be a problem of great magnitude.

Anticipated water quality problems which must be prevented or minimized by advance planning include (1) bacteriological degradation and oxygen depletion from sewage and industrial wastes, such as those from food-processing plants; (2) increasing agricultural chemicals and total dissolved solids in irrigation return flows; (3) plant nutrient pollution of lakes and reservoirs, stimulating algae bloom and secondary oxygen-demanding pollution (eutrophication); (4) water temperature increases from steam-electric plants; and (5) the degradation of water quality from other physical and chemical constituents. These pollutants will, if not treated or controlled, damage all water uses.

The greatest challenge in the future develop-

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ment of the Region will be to achieve comprehensive, coordinated planning by all local, State, Federal, international, and private interests.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

The most urgent development and management needs in the Souris-Red-Rainy Region are flood prevention and control, water for municipal and industrial uses, water quality control, and water management on agricultural lands, including preservation of high value wetlands. These and other needs can best be met by a water management program that consists of a system of multiple-purpose reservoirs and channel improvements, plus local protection works for main stem communities. Such improvements will need to be supplemented with watershed land management, including soil conservation practices and flood plain regulation.

Multiple-purpose reservoirs can provide widespread benefits. Recent studies indicate there are 240 potential upstream floodwater-retarding structure sites, many of which would have multiple use. About half of these need to be constructed by 1980. A report recommending multiple-purpose reservoir development of the Pembina River awaits action by the International Joint Commission, and studies are currently under way regarding major multiple-purpose reservoirs on the Souris, Sheyenne, Goose, and Park Rivers in North Dakota and on the Buffalo, Wild Rice, and Red Lake Rivers in Minnesota. Those found to be feasible need to be constructed during this period. There are no reservoir sites available on the main stem of the Red River, and many of the tributaries lack a sufficient number of sites with adequate capacity; thus, the flood problem will not be solved even with optimum development of reservoir storage. Channel improvements also will be needed to further reduce flooding and to provide outlets for farm drainage.

Irrigation on 90,000 acres in the Souris and Red subregions is expected by 1980. Water for this purpose will come from reservoirs, groundwater, and water diverted from the Missouri Region. The diverted water will also help meet municipal, industrial, recreation, fish and wildlife, and other needs.

The anticipated demand for water supplies for taconite and copper-nickel mining and processing in the Rainy subregion may require several large reservoirs to meet estimated mineral industry needs of 21 mgd by 1980.

Recreation and fish and wildlife developments of all kinds are needed to cope with the expectation that recreation will become the Region's greatest "growth industry." A new national park area (which would be called Voyageurs National Park) along the International Boundary in the upper regions of the Rainy subregion is under consideration. The Chippewa and Superior National Forests need further development for public recreation use; all such projects should include facilities to prevent lake and stream pollution. The proposed national park and, if developed, the two national forests would provide additional recreational opportunities for people coming as visitors to the Region. To meet the expected increase in local recreation requirements, many additional small to large reservoirs are urgently needed.

Existing Federal programs and plans along with those of the State agencies need to be further coordinated to assure that they are in accordance with the overall objectives of the Region.

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CHAPTER 9

Missouri Region

SUMMARY

The Missouri Region covers an area of about 515,000 square miles in the northern part of the Great Plains and includes all or parts of 10 States. It is traversed by the Missouri River's course of 2,315 miles from Three Forks, Montana, to near St. Louis, Missouri, where it joins the Mississippi River. From part to part of the Region, the climate varies from arid to subhumid, and precipitation ranges from 6 to 44 inches, with the extremes of precipitation causing droughts or floods.

Average annual precipitation is 20 inches, which supports an average annual natural runoff of 2.2 inches or 54.1 bgd (60.7 maf/yr). In 1965, rural domestic, municipal, industrial, irrigation, and livestock uses consumed about 10.6 bgd (11.9 maf/yr). Net evaporation from all water surfaces was estimated at about 5.8 bgd (6.5 maf/yr).

Federal and State agencies and local interests have undertaken significant water and related land resources development programs, but there are a number of unsatisfied current needs, as well as undeveloped potentials. In addition, the initiation of some planned work awaits funding.

Most States in the Region operate under the appropriative doctrine of water rights and use. Consequently, they have been active in granting water rights and regulating water use. Through the auspices of the Missouri Basin Interagency Committee and Missouri River States Committee, they have become more involved in basinwide water resources planning and development. Most of them are currently engaged in preparing State water plans through State appropriations and Federal assistance obtained under Title III of the Water Resources Planning Act. Historically, legislative and institutional arrangements were developed to meet problems as they arose, but now and in the future such arrangements will be formulated with greater consideration given to emerging and potential water problems.

It is estimated that population in the Region will expand by about 256% of the 1960 population over a 60-year period, with total and per capita personal income showing even greater gains. By 2020, also, agricultural production is expected to be approximately three times that of 1960; almost all other economic sectors are expected to expand similarly.

This projected growth presages increasing demands on available water and land resources. In turn, the demands will undoubtedly lead to increased competition among uses for available supplies, and create problems in resource development, management, and control. To meet foreseeable requirements and to improve present conditions, the rate of development will need to be accelerated. Water shortages are being experienced in some areas of the Region now; should further shortages be allowed to develop, local development and growth may be limited. Future needs and problems vary greatly in different parts of the Region, and not all problems are of major regionwide significance. Rather, some problems will be major in some areas and not in others, and solutions will differ accordingly.

DESCRIPTION OF THE REGION

The Missouri Region encompasses one-sixth of the conterminous United States. Frequently described as the northern part of the Great Plains, it is bordered on the west by the Rocky Mountains and on the southeast by the Ozark Mountains (fig. 6–9–1). Its area of about 515,000 square miles includes all of Nebraska and parts of Missouri, Kansas, Colorado, Wyoming, Montana, North Dakota, South Dakota, Iowa, and Minnesota, and is drained by the Missouri River's long flow of 2,315 miles from Three Forks, Montana, to a few miles above St. Louis, Missouri. The river's drainage area outside the Region includes some 9,700 square miles in southern Canada and a few hundred square

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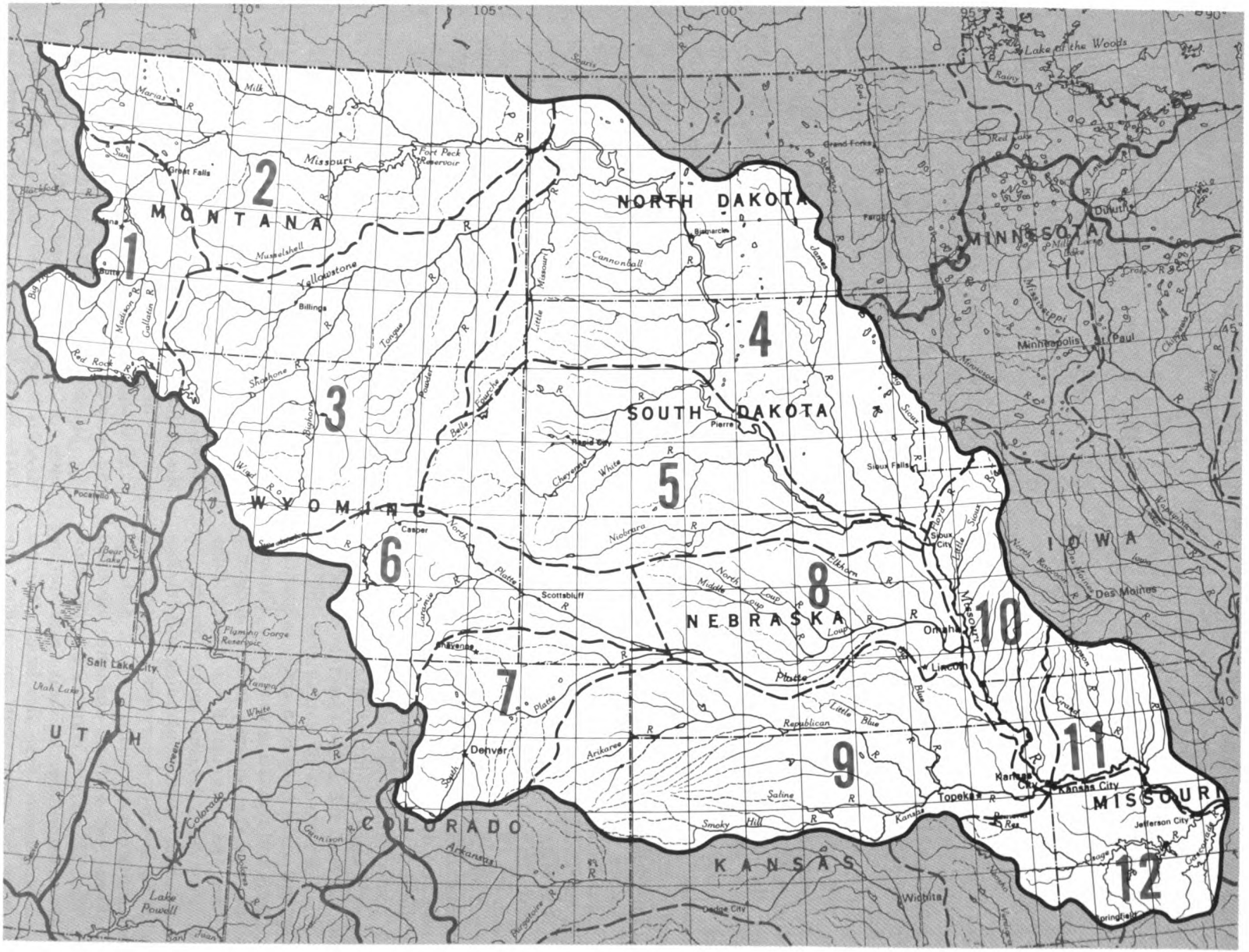

FIGURE 6–9–1.—*Map of the Missouri Region.*

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miles in the Upper Mississippi Region between the mouth of the Gasconade River and the point where the Missouri joins the Mississippi River.

Climate varies widely throughout the Region. Average precipitation ranges from 6 inches in the northwestern plains and 20 inches in the mountains to almost 44 inches in the southeastern portion. Seasonal temperatures range from —60° to over 120°, with below zero to over 100° temperatures experienced over much of the area.

For this Assessment, the Region was divided into 12 subregions as follows:

1. Headwaters—the Missouri River and its tributaries to above Great Falls, Montana.
2. Upper Missouri—the Missouri River from Great Falls to the mouth of the Yellowstone River and the intervening tributary areas.
3. Yellowstone River—the Yellowstone River and its tributaries.
4. Dakota Tributaries—the Missouri River and tributaries on the right bank of the Missouri River from the mouth of the Yellowstone River to the mouth of the Cheyenne River and on the left bank of the Missouri River from the mouth of the Yellowstone River to and including the Big Sioux River.
5. Cheyenne—the Missouri River and right bank tributaries of the Missouri River from and including the Cheyenne River to Sioux City.
6. North Platte River—the North Platte River and its tributaries.
7. South Platte River—the South Platte River and its tributaries.
8. Main Platte River—the Platte River below the confluence of the North and South Platte Rivers and its tributaries.
9. Kansas River—Kansas River and right bank Missouri River tributaries from the mouth of the Platte River to the mouth of the Kansas River.
10. Iowa Tributaries—the Missouri River from the mouth of the Big Sioux River to the mouth of the Kansas River and the intervening tributaries.
11. North Missouri Tributaries—the Missouri River and left bank tributaries from the mouth of the Kansas River to the mouth of the Gasconade River.
12. South Missouri Tributaries—the right bank Missouri River tributaries from the mouth of the Kansas River to and including the Gasconade River. (The area of the Missouri River basin below the mouth of the Gasconade has not been included here, since it is considered to be a part of the Upper Mississippi Region.)

The Missouri River area was first explored at the request of President Thomas Jefferson, following its acquisition as part of the Louisiana Purchase. The Lewis and Clark Expedition left St. Louis in May 1804, proceeding by boat up the Missouri. Early in November, the party arrived near what is now Bismarck, North Dakota, and settled down for the winter with the Mandan Indians. In the spring, it proceeded west. Reaching the three-forked source of the Missouri in July, Meriwether Lewis and William Clark gave names to the three rivers—Gallatin, Jefferson, and Madison. In August, the Great Divide was crossed and the party descended finally to the Columbia River valley.

Shortly after the expedition's return to St. Louis in September 1806, settlers began moving into the new lands. The first steamboat entered the Missouri River in 1819. In 1838, the Corps of Engineers began the first improvement work on the river to reduce steamboat sinkings. In 1912, Congress authorized a Missouri River project for continued bank stabilization and navigation improvement. The Fort Peck Reservoir in Montana, begun in 1933, was designed primarily to regulate flows for navigation.

Agriculture in the Region was successively encouraged by the Homestead Act of 1862, railroad construction in the late 1800's, and the establishment of land grant colleges and agricultural experiment stations. Irrigation began in the 1860's in western parts of the Region where supplemental moisture was required for successful crops. Between 1902 and 1907, as a consequence of the Reclamation Act of 1902, the Huntley, North Platte, Shoshone, and Milk River irrigation projects were undertaken by the Federal Government.

In the early 1940's, the States of the Region began to consider comprehensive planning for the development of water and related land resources. The Missouri River States Committee was formed in 1942 to promote and coordinate development activities. After Congress approved a comprehensive plan for water resource development for the Missouri River basin in the Flood Control Act of 1944, the Missouri Basin Inter-Agency Committee was formed to bring about more effective exchange of information and to coordinate the activities of Federal and State agencies.

Agriculture and agricultural-oriented industries and services are still the principal economic activities in the Region. The mineral industry, however, has taken on considerable economic significance, and is currently valued at $1.3 billion. These and other industrial developments have been hampered by the costs of

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transporting goods to the principal centers of population in the eastern part of the Nation and along the West Coast. In recent years, hunting, fishing, and recreation uses of natural scenic resources, particularly in the mountains, and the attendant growth in service functions, have become economically important in several of the States. There are extensive areas of public lands within the Region for these activities, and recent programs have led to their better management.

For the most part, the Region is sparsely populated The greatest population densities are in the more humid southeastern portions. Most of the large cities are located adjacent to rivers, which initially supplied transportation and subsequently have been sources of water supply and a ready means for disposal of wastes. In 1960, the regional population was 7.8 million, of which over 4.5 million lived in urban communities, about 1.5 million on farms, and the remainder in rural nonfarm areas. It is significant that while the total population has been increasing, the farm population has been declining.

THE WATER RESOURCE

Average annual precipitation over the Missouri Region is about 20 inches, and about 2.2 inches or 54.1 bgd (60.7 maf/yr) of this occurs as runoff. The breakdown of average annual natural runoff for the 12 subregions is shown in table 6–9–1.

Droughts occur frequently. The drought of the 1930's was the most extensive in recorded history, adversely affecting nearly all parts of the Region. More recently, serious droughts have occurred in the southern portion. Drought conditions are more understandable when the variability of natural runoff is considered: 29.9 bgd (33.5 maf/yr) in 10% of the years of historical record, and 23.9 bgd (26.8 maf/yr) in 5% of the years.

Floods have been a problem in the Region from the days of its earliest settlement. The major flood of 1844, one of the first to be recorded, occurred before there was any development or much settlement, and thus could not compare in damage to recent floods. The 1951 flood, which was primarily a lower basin occurrence originating on the Kansas and lower river tributaries, caused damages of about $1 billion. Reservoirs and protective works now in place would substantially reduce losses were a similar flood to occur. The 1952 flood was primarily an upper basin occurrence, caused by the spring breakup of ice and snowmelt from the plains. The water discharges were of record proportions throughout the Dakotas and on the Missouri River as far down as Omaha, Nebraska.

Precipitation and runoff follow a general sea-

TABLE 6–9–1.—*Annual natural runoff, Missouri Region*

Subregion	Drainage area [1]	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	23,000	4.98	4.55	4.98	3.51	3.10
2	60,000	3.37	1.18	3.25	1.42	1.04
3	72,000	8.92	2.60	8.67	6.54	5.98
4	96,000	2.87	.63	2.45	.67	.41
5	55,000	2.09	.80	1.95	1.24	1.05
6	32,000	2.44	1.60	2.34	1.65	1.46
7	24,000	1.67	1.46	1.51	.88	.74
8	33,000	3.55	2.26	3.40	2.36	2.09
9	65,000	5.14	1.66	4.52	1.37	.88
10	17,000	3.41	4.21	2.87	.75	.45
11	14,000	4.93	7.40	4.33	1.32	.85
12	24,000	10.73	9.39	9.66	3.19	2.10
Regional value	515,000	54.1	2.21	53.7	29.9	23.9

[1] Does not include 9,700 square miles in Canada.

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sonal pattern, although floods can occur in any part of the Region at almost any time of the year. During the winter, snow may accumulate to considerable depth; melting snow together with early spring rains may break up the winter's accumulation of ice in the streams, causing ice jams and flooding. The normal pattern of precipitation usually includes rains from April through June, with fairly dry late summer months, then increased precipitation in September and October. During the summer months, thunderstorms may occur over the plains and the lower mountains, creating local centers of great precipitation which cause floods.

Another important aspect of the Region's water resources is the amount of groundwater storage, which has been estimated as about 1,000,000 billion gallons (3,000 maf). Groundwater provides about half of the supply for domestic, stockwater, municipal, and industrial water uses. It is also used throughout the Region for irrigation, and particularly in Nebraska where there are over 29,000 irrigation wells. In some areas of intensive use, the levels have declined appreciably, and users are becoming concerned with the effects of groundwater mining on the resource. With lower yields and higher pumping costs, interest in groundwater regulation and control is increasing.

While not of large magnitude in terms of total water supply, water importations from the Upper Colorado Region are significant to the South Platte River basin in Colorado (subregion 7). The existing systems are capable of importing an average of 0.59 bgd (0.66 maf/yr).

In general, the Region's water is of fair quality. On some streams and in some sources of groundwater, however, the concentrations of dissolved solids are relatively high. Municipal, agricultural, and industrial wastes have decreased the quality of many streams, but an active pollution abatement program is ameliorating this situation. Sediment is fairly high in many of the streams. Although land treatment programs have been effective in reducing silt loads in some localities, more extensive watershed treatment and management will be required to effectively reduce silt loads throughout a large part of the entire area.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Water and related land resources development in the Missouri Region has a long history. The earliest efforts were usually single-purpose, concerned with navigation, mining, public water supplies, or irrigation. This approach has gradually been replaced by the multipurpose project. Table 6–9–2 indicates the amount of past and present Federal development in the Region. In addition, individuals, companies, States, and local governments have contributed a great deal. For example, over 50 non-Federal hydroelectric powerplants are in operation, with

TABLE 6–9–2.—*Federal projects in operation and under construction, 1965, Missouri Region*

Federal projects	Unit	In operation	Under construction
Reservoirs	no.	78	9
	af	95,521,000	10,880,000
Hydroelectric powerplants	no.	22	3
	kw	2,293,200	547,100
Transmission lines	cm [1]	10,020	128
Watershed projects	no.	24	81
Project areas	ac	740,000	3,626,400
Reservoirs	af	60,000	290,100
Channel improvement for navigation	mi	735	—
Local flood protection projects	no.	43	14
	ac	241,000	135,000
Total area receiving flood protection	ac	3,000,000	—
Irrigation projects	no.	40	1
	ac	2,166,000	[2] 5,900
Waterfowl management areas	no.	390	—

[1] Circuit miles.

[2] In 1967 construction was initiated on the Garrison Diversion Unit to serve 250,000 acres of land of which 59,300 acres would be in the Missouri Region.

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installed aggregate capacity of over 600,000 kw, and approximately 70% of all existing irrigation development—approximately 5 million acres—is attributable to local efforts.

Present water use in the Region is indicated in table 6–9–3. A comparison of the 1965 water consumption, as given in the table, and the average annual natural runoff from table 6–9–1 shows that total consumption is approaching natural runoff in the North Platte and South Platte subregions, and that the largest amounts of unconsumed runoff are in the Yellowstone and Lower Missouri subregions. It should be understood, however, that the figures do not, in all cases, reflect consumptive use of streamflow. Some of the water consumed is mined from groundwater, thus depleting groundwater storage, rather than streamflow. It is estimated that one-third of the municipal water supplies, 90% of the rural domestic supplies, and 55% of the livestock supplies are obtained from groundwater sources. About 20% of the water for irrigation and about 60% for self-supplied industrial use are derived from groundwater. An undetermined amount of this pumpage represents groundwater storage depletion.

In addition to the water consumed for use, about 5.8 bgd (6.5 maf/yr) is lost through evaporation from the area's 6 million acres of water surface. When both consumption and

TABLE 6–9–3.—*Present water use, 1965, Missouri Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total [6]
					Irrigation [5]	Livestock	
			Water withdrawn				
1	1	22	13	0	1,694	7	1,737
2	3	15	4	0	1,588	12	1,622
3	4	36	71	30	4,170	18	4,329
4	18	59	17	40	199	90	423
5	5	17	22	0	337	31	412
6	1	25	31	100	2,370	11	2,538
7	4	266	71	10	2,498	15	2,864
8	4	137	23	340	1,257	40	1,801
9	36	192	44	240	1,879	46	2,437
10	9	38	18	140	44	27	276
11	10	24	20	20	1	30	105
12	11	138	128	480	2	41	800
Total	106	969	462	1,400	16,039	368	19,344
From groundwater	(94)	(341)	(278)	(40)	(3,044)	(208)	(4,005)
			Water consumed				
1	1	1	5	0	1,185	6	1,198
2	3	1	1	0	1,111	12	1,128
3	4	9	7	1	2,182	17	2,220
4	17	19	5	3	123	89	256
5	5	5	10	0	192	30	242
6	1	8	4	0	1,129	11	1,153
7	2	68	16	10	1,398	14	1,508
8	4	8	1	1	893	40	947
9	35	69	5	3	1,540	45	1,697
10	3	5	2	2	44	26	82
11	4	3	2	1	—	27	37
12	6	25	13	3	1	38	86
Total	85	221	71	24	9,798	355	10,554

[1] Water used for domestic purposes not served by public water supply systems.
[2] Serves a population of 6,074,000 through public water supply systems.
[3] Water supplied by industry itself; also includes military establishments.
[4] Water supplied for cooling and operation of public utility steam-electric powerplants.
[5] Conveyance losses not included in consumption.
[6] Does not include 5.8 bgd of evaporation from 6 million acres of water surface.

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evaporation are considered, it can be seen that at the present time 30% of the Region's average annual natural water supply is consumed.

ADEQUACY OF PRESENT DEVELOPMENT

While water resource development in the Region has been substantial to date, it does not meet current needs. Inadequate average annual rainfall coupled with droughts during nearly all growing seasons have led to the development of substantial irrigation projects. The 7.4 million acres of land now irrigated comprise only 7% of the total cropland but production is a much larger share of the basin's average agricultural output. Further, this production is an important factor in stabilizing the livestock and general economy during recurring drought periods. Local people favor additional irrigation development to further enhance and stabilize their overall economy.

Additional flood control developments are also needed. Although reservoirs and local protection works have been constructed for many of the more highly developed areas, a substantial portion of the Region is still plagued by recurring floods that cause death and destruction and create health hazards.

The Missouri River was the principal means of transportation before the development of railroads and highways, and it is still a relatively less expensive means of transport for bulk commodities such as grain. Since 1912, development work along the Missouri River has been under way for navigation in association with bank stabilization. Continuation of these improvement works is important since they serve both to maintain navigable channels and to protect valuable bottom lands from bank erosion.

Hydroelectric power has been developed by private companies, non-Federal public bodies, and Federal agencies in connection with other water resource developments in the Region. At present, it appears except for pumped-storage projects that most, though not all, of the feasible hydroelectric power has been or is being developed. Thus, future requirements for additional power will have to be met largely from steam-electric plants.

Watershed development is a relatively new resource activity in the Region, which has so far been successful, particularly in the southeastern subregions. In general, it provides a coordinated approach to conservation and erosion protection of the lands of the small watersheds and to resource development works that stabilize streambanks, control floods, or provide conservation storage for other water uses. This type of development is expected to expand in the future.

The Congress has established a policy that public lands either be disposed of or retained and managed to provide the maximum benefit for the general public. Studies are under way which will provide background data necessary for carrying out this policy as well as for recommending modification of existing laws, regulations, and management policies and practices.

Developments in the Region for fish, wildlife, and recreation purposes have been relatively scarce in the past; moreover, some deterioration of wildlife habitat has occurred. Heightened public interest in the out-of-doors, however, together with new legislation and strengthened programs have increased the consideration given to such developments, and in some instances they have been included in multipurpose projects.

The Region's existing commercial fisheries are based chiefly on habitat furnished by the Missouri River, its main stem reservoirs, and reservoirs on major tributaries. Historically, the character of the instream water supplies and the associated habitats has been adequate for commercial species, and it is expected that this character will continue at a level suitable for present and anticipated future use.

Although the Indians living in the Region are a relatively small part of the population, they control significant land areas. In the past, beneficial use of water on their lands has generally not been comparable to that on non-Indian owned lands. Among some of the Indian groups this has been partially due to nonrecognition of the social and economic importance of resource development. This factor now appears to be changing for the better.

Provision of water quality is just coming into prominence as a function of the Region's water resource development. The problem of whether assured water supplies, of adequate quality, can be made available for competing uses has not yet been solved. Experience with specific water quality problems will guide this phase of development in the future.

In some instances, limited water supplies in the Region have precluded development commensurate with demands or have made desirable objectives infeasible. There are also some instances where water rights for one use have been transferred to other uses, indicating a shortage of water to meet all needs. Such transfers may become more prevalent in the future as the

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population expands and additional needs for water develop.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Current and future water management problems in the Missouri Region are in part linked to the problem of legal water rights and priorities and their administration. At present, 7 of the States in the Region operate under the appropriative doctrine of water rights; 1 State has a permit system. Existing State water laws were usually designed to solve particular problems at the time of enactment and have been amended to solve other problems as they have arisen. Interstate compacts and court decrees regulate the use of water from many of the interstate streams, and compacts for other streams are pending. It can be anticipated that existing laws will continue to be modified to deal with water resources problems as they emerge. Generally, the States' water laws tend to recognize domestic, municipal, irrigation, and industrial uses as beneficial. Thus, there are problems in assuring water supplies for recreation, fish and wildlife habitat, and water quality maintenance.

Another item requiring consideration is the future use of water on Indian lands. Though several court decisions confirm the Indians' rights to the use of water on their lands superior and prior to other claimed rights, a precise judicial determination has not been made as to the definition of beneficial use or whether the right to use water is without limit.

One of the major management problems in water resources planning and development involves the relationships between different levels and units of government. The formation of the Missouri River States Committee (1942) and the Missouri Basin Inter-Agency Committee (1944) signaled the beginning of State participation in planning activities, precluded at one time by limited funding. Cooperation among the Federal agencies and between them and the States and coordination of their respective programs have been materially enhanced through the operation of these Committees. Further coordination of the activities of the multiple State agencies associated with water resource activities would be desirable, because of the increasing number and complexity of programs and the increasing workloads. Comprehensive State planning financed by State and Federal funds under the Water Resources Planning Act should help this situation.

Certain problems have been generated by the fact that most States provide mechanisms which permit local subdivisions of government to sponsor projects. Because of the proliferation of such organizations, their limited areal coverage, and the difficulties with financial arrangements, it may be necessary for the States to consider creating overriding supervisory organizations or using fewer organizations with broader authorities.

It is foreseen that problems will also arise concerning the following: (1) the management of interbasin transfers and interstate and intrastate diversions of water supplies; (2) the relationship of resource developments to water quality standards for interstate and intrastate streams; and (3) alteration of stream ecology due to water and related land resources development.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Missouri Region is a major part of the agricultural heartland of America; its economy, therefore, has been largely based on the production of crops and livestock and related industries. Among the projections of its future economic activity, increases in agricultural production are important. However, increases are also anticipated in industrialization, as well as in service functions associated with the rapidly growing recreation activities of the Region. Economic and agricultural projections, shown in table 6–9–4, indicate that the population will be 32% larger in 1980 than in 1960, 82% larger in 2000, and 156% larger in 2020. Per capita personal income is expected to be 170% of the 1960 level in 1980, 270% by 2000, and 420% by 2020. During this 60-year period, it is expected that land used for agricultural purposes will decrease slightly, and that the number of farms will decrease about one-half by 1980, and two-thirds by 2020. Thus, the increased population of the Region will be primarily urban, with substantially fewer people involved directly in farming. Because of the increasing population, both in the Region and the Nation as a whole, there will be a need for food and fiber approximately three times what is currently produced.

Some of the projected increase in the production of food and fiber can be met with improved technology and increased efficiency on the farm. Nevertheless, a substantial increase in irrigation will be necessary to stabilize agricultural pur-

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TABLE 6–9–4.—*Economic and agricultural projections, Missouri Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	7,845	10,337	14,260	20,079
Per capita personal income	1954 dol.	1,800	3,075	4,850	7,550
Employment, total [2]	thou.	3,003	4,063	5,575	7,824
Agriculture	do.	521	338	273	248
Manufacturing	do.	408	653	879	1,202
Other commodity producing	do.	329	412	522	686
Distributive industries	do.	835	1,128	1,501	1,993
Service industries	do.	909	1,532	2,400	3,695
Land base	thou. ac.	329,430	329,430	329,430	329,430
Agricultural	do.	313,331	312,331	311,051	309,671
Cropland, total [3]	do.	115,125	105,845	105,411	104,943
Used for crops	do.	88,007	74,571	76,979	88,751
Idle and fallow	do.	27,118	31,274	28,432	16,192
Pasture-permanent	do.	166,843	175,223	174,505	173,731
Forest and woodland	do.	31,363	31,263	31,135	30,997
Nonagricultural	do.	16,099	17,099	18,379	19,759
Irrigated land [4]	do.	[5] 6,600	8,050	9,000	9,600

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965 irrigated land amounted to 7,400 thousand acres.

suits, as well as to help to meet the increased demand for agricultural production. The framework plan is not complete, but the increase in the Region's irrigated area is estimated to be 25% in the next 20 years and perhaps more, if water and land resources are properly managed. Watershed developments combined with increased on-farm efficiency will somewhat reduce runoff, and the projected irrigation is expected to consume about 14.4 bgd (16.2 maf/yr) by 2020. Municipal, industrial, and thermal power uses will consume 845 mgd (950,000 af/yr) by 2020. Projected water requirements are shown in table 6–9–5.

Predicted continuing growth of urban areas in the Region and increased flood plain values indicate that potential flood damages will increase substantially. Some of the damage may be avoided by nonstructural measures, though the difficulties involved in restricting utilization of flood plains may limit this approach. However, the increasing potential of urban and agricultural flood damages will still require reservoir regulation and other flood protection measures.

Recreation and fish and wildlife development are receiving considerably more attention in resource planning than heretofore, and potential increases in population, leisure time, income, and mobility indicate that demands for this kind of water use will grow. Normally, these uses only involve consumption of water in the form of evaporation from water surfaces. Increased water requirements for these purposes cannot be estimated until planning has proceeded further.

Water quality improvement is another use which may require substantial additional supplies in the future if quality criteria are to be met, but, currently, in most of the regional States it is not considered a beneficial use for which water rights can be granted. Progress has been made in the treatment of municipal and industrial wastes, although more attention must be given to such treatment. Undoubtedly, streamflow in some localities will have to be supplemented to care for residual pollution loads. Further, the anticipated development and operation of steam-electric powerplants may cause thermal pollution problems that can be solved or alleviated, but will require additional capital expenditures for ponds or cooling towers.

Surface water and groundwater supplies have been developed to meet most existing water needs, and some areas in the Region appear to have adequate water to meet foreseeable future needs. For certain other areas careful husbanding of the supplies will be required, if the most critical future needs are to be met.

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TABLE 6–9–5.—*Projected water requirements, Missouri Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
	Withdrawals			
Rural domestic	106	134	162	190
Municipal (public-supplied)	969	1,225	1,481	1,738
Industrial (self-supplied)	462	584	707	829
Steam-electric power (fresh)	1,400	1,500	3,200	4,800
Agriculture:				
Irrigation	16,039	19,300	21,600	23,000
Livestock	368	521	726	1,015
Total	19,344	23,264	27,876	31,572
	Consumptive use			
Rural domestic	85	108	130	153
Municipal	221	280	339	397
Industrial	71	90	109	128
Steam-electric power (fresh)	24	80	200	320
Agriculture:				
Irrigation	9,798	12,100	13,500	14,400
Livestock	355	502	701	980
Total	10,554	13,160	14,979	16,378

EMERGING WATER PROBLEMS

With an expanding population in the Region and a national need for greater agricultural production, many water resource problems will arise. Present trends indicate that urban areas in the Region will continue to expand in population, with the larger metropolitan areas probably growing most rapidly. Urban expansion will result in loss of agricultural areas and sometimes involve land of high quality. Such growth will increase the problems of industrial and municipal water supply, waste treatment, and pollution abatement. Since many of the urban areas are located on water courses, their growth along the flood plains will increase the flood damage problem. In rural areas, more intensive use of agricultural lands has in some cases adversely affected fish and wildlife habitat, and may continue to do so.

Inadequate attention in the past to treatment of municipal, industrial, and other pollutants has lowered the quality of streamflows, creating problems for municipal water suppliers and other users. The establishment of interstate quality standards, currently under way, will provide a better means of quality control.

For many areas, increasing demands for water are causing (and will continue to cause) groundwater supplies to be used in excess of the annual recharge of the local underground storage. Thus, several localities are already beginning to experience lowering groundwater levels. Additional work in delineating groundwater supplies, determining the limits of natural recharge, and finding means of artificially recharging underground supplies will be required, if the groundwater resource is to be properly managed to meet future needs.

A current water problem, which will undoubtedly also be a future problem, is lack of foresight. Many small municipalities tend to judge water supplies in the context of the average or near normal supplies which satisfy their day-to-day needs for water, rather than in the context of relatively adverse periods of drought with accompanying low streamflows or falling groundwater levels. A similar lack of foresight allows a flood plain development to be managed solely for normal or below normal flow periods without consideration of potential flooding. There have also been instances where irrigation projects and individual well-service areas are expanded beyond the capabilities of their works to supply adequate water during adverse periods, causing later consideration of developing sup-

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plemental water supplies for such areas. In many of the agricultural areas, economic pressures have led to implementation of measures and management techniques that extracted the maximum return from the land at the time, rather than those which would have sustained long-term capabilities. All these existing conditions and situations illustrate the desirability and necessity of farsighted, comprehensive, coordinated planning so that future water requirements can be met.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

During the next few decades, land conservation and watershed development programs must be continued and efforts must be accelerated to control pollution and improve water quality. A program of flood plain zoning and management must be instituted and carried forward, and flood control projects should be initiated at many locations, particularly in the middle and lower areas of the Region. Irrigation systems should be developed in the more arid parts of the Region. Fish and wildlife facilities need to be improved throughout the entire area, and attention should be given to adjusting imbalances in recreation demands and supplies. Improved management of water and land resources and other nonstructural measures will enhance use of the resources.

The Missouri Region comprehensive framework study being undertaken jointly by the 10 basin States and interested Federal agencies will provide guidance for the coordination and the optimum development of water and related land resource developments required in the future.

Management and institutional arrangements for water and related land resources development will be considered in the comprehensive framework planning activities. In addition, most of the States will formulate State water plans that will include review and reappraisal of State and related Federal laws and policies affecting these resources. Where warranted by current and projected needs and conditions, policy changes will undoubtedly be proposed. Because water will be in short supply in some areas in the future, more attention needs to be given to increased efficiency in its use. And since more use will also be made of groundwater, information must be gathered relative to its occurrence and control and appropriate measures taken for its development.

Management, institutional, and legal problems will arise for solution during the planning and development outlined above. The manner in which they are handled will enhance or inhibit the general course of development. Among the issues that will lead to these problems are the following: the use of compacts in the division of interstate waters; intrabasin and interbasin transfers of surplus water; provision of low flow augmentation for quality control, recreation, fish and wildlife, mining, and additional industrial development; new water quality standards; and groundwater management for sustained utilization. Research and development programs will have to be expanded and accelerated in many fields of water and related land developments.

Coordination between Federal and State agencies should continue through the efforts of the Missouri Basin Interagency Committee and Missouri River States Committee, or through efforts of other institutions. The comprehensive framework study scheduled for completion in 1969 should be updated periodically and expanded as appropriate to guide development. Detailed plans for the study's implementation should be developed for optimum use of the Region's water and related land resources.

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CHAPTER 10

Arkansas-White-Red Region

SUMMARY

The relative urgency of finding solutions to water problems varies widely throughout the Arkansas-White-Red Region. In the western part and portions of the central part, inadequate supply can be expected to restrict future economic development; in much of the central part, poor quality is also a limiting factor. Excess water is a major problem in the east, and flood problems exist throughout the Region.

In general, the Region has two overriding water problems: (1) water is not available in sufficient quantities in the particular areas in which it is needed, and (2) considerable water is unfit for agricultural, municipal, industrial, and other uses because of natural and man-made pollution. These problems cannot be wholly solved by local action; they call for planning and action in concert by States, groups of States, and the Federal Government. The expected growth of the regional economy makes it imperative to find adequate solutions in the very near future.

DESCRIPTION OF THE REGION

The Arkansas-White-Red (AWR) Region embraces about 282,000 square miles in the south-central portion of the United States (fig. 6–10–1). The three major rivers—the Arkansas, White, and Red—drain approximately one-eleventh of the Nation's conterminous land area, including all of Oklahoma and parts of Colorado, New Mexico, Kansas, Texas, Missouri, Arkansas, and Louisiana.

History

Exactly when man first initiated water development activities in the area is not known, but there is evidence that some group of prehistoric inhabitants practiced irrigation. Signs of ancient irrigation canals are found along the Cimarron, Beaver, and Canadian Rivers in western Oklahoma. Early explorers navigated the Arkansas, White, and Red Rivers when the flows permitted.

The settlement and growth of the Region have generally been paralleled by development of water supplies, first for agriculture, then for municipalities and industries. Most of the smaller towns and cities utilized groundwater, while most of the larger cities developed the more dependable of the surface flows. Many communities, principally in the central and western sections, are outgrowing their present sources of water and are being forced to consider larger and more expensive sources.

Economy

In 1965, the population of each of the following cities was in excess of 50,000: Oklahoma City and Tulsa, Oklahoma; Colorado Springs and Pueblo, Colorado; Wichita, Kansas; Wichita Falls and Amarillo, Texas; Springfield, Missouri; Little Rock and Fort Smith, Arkansas; and Shreveport, Louisiana. The total population of the Region was estimated as 7.4 million.

Agriculture is a major economic activity, with cattle, wheat, cotton, grain sorghums, and rice as the chief farm products. In recent years, over one-tenth of the Nation's cattle and calves, about one-third of the wheat, one-fourth of the sorghums, and about one-sixth of the rice have been produced in the Region. Nearly one-fourth of the Region is covered by forest lands, which account for about one-twelfth of the Nation's commercial forests.

Manufacturing represents a growing and increasingly important segment of the regional economy. In the past it was concentrated in a few major industries, among them food and lumber products and printing and publishing. Other presently significant industries in the Region include aircraft assembly, iron and steel milling, oil and other petrochemical refining, and glass manufacturing. Current trends in

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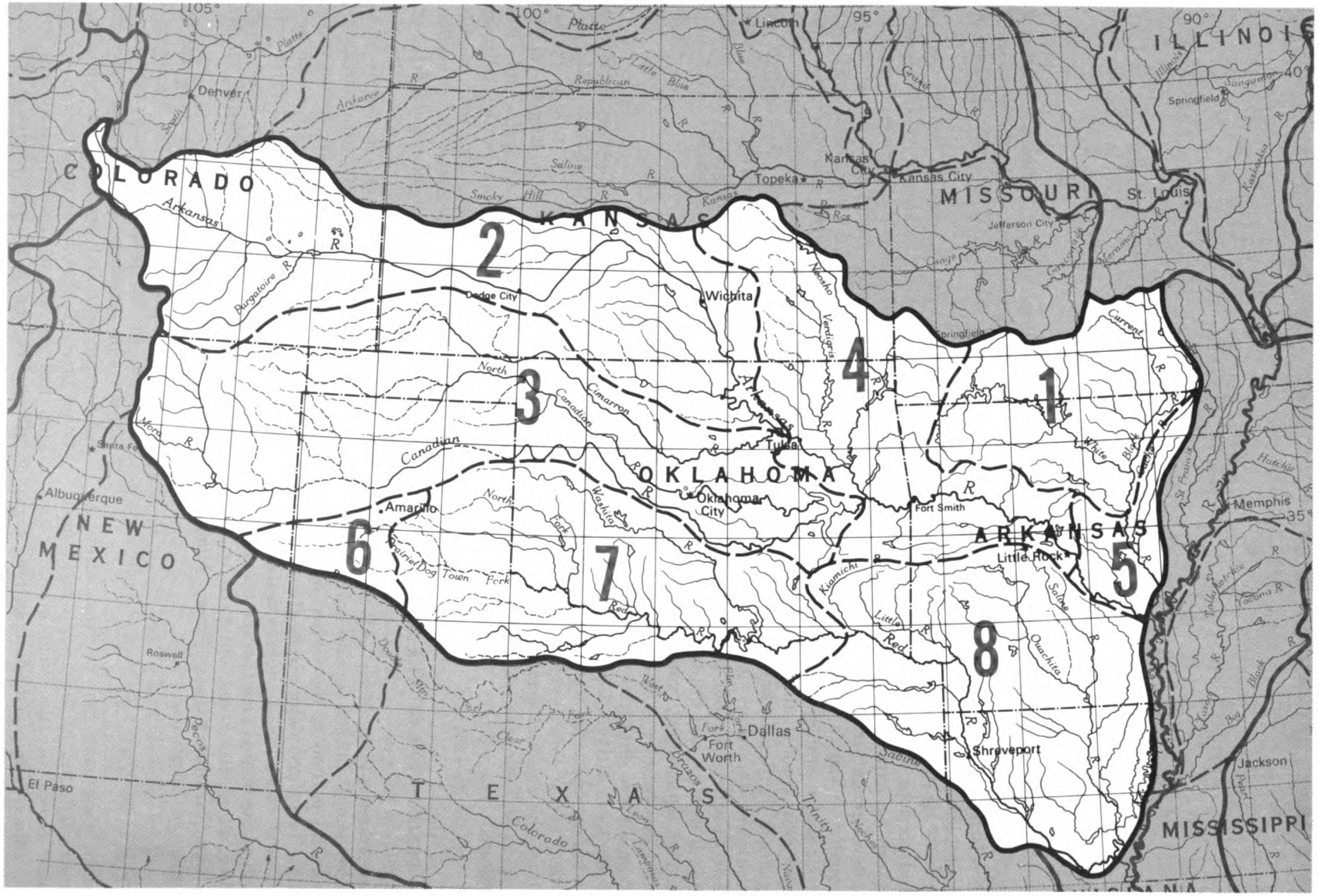

FIGURE 6–10–1.—*Map of the Arkansas-White-Red Region.*

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manufacturing indicate that the industrial base will continue to broaden and that the area will become less dependent on resource-based industries.

The interrelated outdoor recreation and tourism industries have grown in the last 20 years and are expected to continue expanding. Millions of visitors come into the Region every year seeking outdoor recreation of various kinds, and particularly fishing and hunting. Their expenditures are the major source of revenue for the many enterprises that directly serve the travel and recreation industry and also have indirect effects on other lines of business. Future expansion of these industries will depend on further development of water and related land resources for recreational purposes.

Of the Region's many mineral resources, petroleum and natural gas are the most important. The natural gas field near Hugoton, Kansas, is reported to be the largest in the world. The Region produces about one-fifth of the Nation's oil, and about one-third of the natural gas. Other significant minerals produced are zinc, lead, germanium, gold, silver, molybdenum, bauxite, copper, cadmium, mercury, tungsten, tin, iron, and manganese. There are vast coal reserves, but coal mining is competitive only in localized areas. The Region also has extensive deposits of cement raw materials, building stone, ceramic clays, sand, gravel, and salt, all of which are produced in substantial amounts.

Geography

The principal surface features of the Region consist of some high mountains in the west, a large area of low mountains which rise abruptly from the coastal and Mississippi alluvial plains in the east and, between the two mountain areas, a broad expanse of interior lowland that is part of the southern portion of the Great Plains, sloping gradually from west to east, broken occasionally by escarpments, hills, and a few old, eroded mountains.

The Arkansas River and its longest tributary, the Canadian River, and their headwater streams, have their sources in the Sangre de Cristo, Sawatch, and Front Ranges of the southern Rocky Mountains in Colorado and New Mexico. From eastern New Mexico and Colorado, the nearly unbroken surface of the High Plains—the more elevated portion of the Southern Great Plains—extends eastward for many miles. The Arkansas, Cimarron, Canadian, and North Canadian Rivers flow generally eastward across the High Plains. The Red River rises in this area, fed by tributary streams which have intermittent flows. Progressing eastward, the High Plains become more dissected by stream valleys and give way to the Central Lowlands. Within this formation, drainage courses become more numerous and streamflows increase notably. In particular, the Verdigris and Grand (Neosho) Rivers contribute large flows to the main stem of the Arkansas River.

The Ozark Plateaus north of the Arkansas Valley and the Ouachita Mountains to the south are rugged, with steep slopes and narrow valleys. The White River and its major tributaries which drain the Ozark area are clean streams with rapid flows.

As the Red River emerges from the Central Lowlands, it passes through the low and gently rolling coastal plain. Numerous tributaries, which rise in the southern Ouachita Mountains and the hilly areas to the west, contribute to the substantially increased flows of the Red River in eastern Oklahoma and western Arkansas. The Ouachita River, the major downstream tributary, rises in the Ouachita Mountains and flows through the hilly uplands of southeastern Arkansas and the alluvial valley of the Mississippi River before entering the Red River just above its mouth.

The rivers with sources in areas of precipitous slope change from swiftly flowing to slow and sluggish streams meandering through wide alluvial valleys. During the extended droughts that are characteristic of the western half of the Region, only major rivers maintain continuous flows. In the humid eastern lowlands, recurring floods frequently engulf adjacent lowlands. The western half of the Region is subject to damaging floods at less frequent intervals.

Climate

The climate ranges from humid in the east to semiarid in the west and is characterized by long, hot summers and short, cold winters. The western half experiences temperature extremes and moisture deficiencies associated with its interior continental location. In winter, there are frequent intrusions of cold, dry continental air from the north; in summer, hot, dry winds blow from interior Mexico. The climate of the eastern part of the Region is influenced primarily by the warm, moist air from the Gulf of Mexico.

Annual precipitation averages about 60 inches in eastern Louisiana, decreases rather uniformly westward to about 12 inches in the western Great Plains, then increases to 32 inches in the moun-

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tains of Colorado and New Mexico. In the Great Plains, annual rainfall is low and highly variable and serious deficiencies occur during the growing season. The eastern section is subject to both severe rainstorms of several days' duration and precipitation deficiencies, though the latter are less frequent than in the Great Plains. Localized floods in the central and western sections result from infrequent but intense rainstorms of short duration. High wind velocities and high evaporation rates are associated with the dry climate of most of the western half of the Region.

THE WATER RESOURCE

Surface Water

Wide ranges in climate, topography, geology, soils, and vegetative cover in the AWR Region are responsible for equally wide ranges in the rate and character of surface runoff. Storms range from large-scale, of several days' duration, to intense, of small areal extent but with point rainfalls exceeding 20 inches in 12 hours. Average annual natural runoff for the eight subregions is summarized in table 6–10–1. These figures approximate the runoff unaffected by man-made withdrawals, consumption, or river regulation. However, since this runoff represents water that has reached stream courses, any watershed changes—man-made or otherwise—that affect it before it reaches the stream are reflected in these data.

Surface water in the upper reaches of the Arkansas River in Colorado and New Mexico is derived largely from snowmelt and rainfall occuring in the Rocky Mountains. This supply is augmented with imports from the Upper Colorado Region. Quality is satisfactory for upstream uses; farther downstream, however, the mineral content makes the water unsatisfactory for municipal purposes and limits its use to some degree for irrigation.

Surface runoff in the High Plains is scanty. This is attributable to low precipitation, high evaporation, numerous noncontributing areas, and upstream developments on the main stems of the Arkansas and Canadian Rivers.

The surface water supplies are substantially greater in the Central Lowlands, but much of the supply is seriously polluted. For example, the Arkansas River water below Great Bend, Kansas, is impaired by salt marsh drainage, discharges from salt works, and oilfield brines. Farther south, the Cimarron River crosses salt beds in the vicinity of Waynoka, Oklahoma, which pollute the stream to such an extent that the water is unsuitable for either municipal or irrigation use. The Cimarron also carries a heavy load of sediment. The North Canadian River below Oklahoma City and the Canadian River below the mouth of Little River are polluted by oilfield brines and by drainage from salt beds in their upper reaches. In addition, the Canadian has one of the heaviest sediment loads in the Nation.

Near Muskogee, Oklahoma, the polluted water of the Arkansas is diluted by good quality inflows from the Verdigris and Grand (Neosho) Rivers. The Verdigris has a small base flow but

TABLE 6–10–1.—*Annual natural runoff, Arkansas-White-Red Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	22,000	18.16	17.33	17.87	9.15	7.14
2	52,500	4.18	1.67	3.61	1.03	.64
3	79,100	6.64	1.76	5.80	1.73	1.10
4	33,800	18.11	11.25	16.75	6.10	4.16
5	6,400	5.85	19.20	5.60	2.30	1.66
6	3,600	.04	.23	.04	.01	.01
7	38,600	6.17	3.36	5.71	2.08	1.42
8	46,000	36.68	16.75	35.21	14.78	10.71
Regional value	282,000	95.8	7.13	93.4	44.3	33.4

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contributes a large volume of flood flow to the Arkansas. The Grand (Neosho), because of upstream regulatory structures, has a relatively large base flow; it also contributes flood flow to the Arkansas, as do other rivers and streams which enter the Arkansas between Muskogee and Fort Smith, Arkansas. The quality improvement of the Arkansas River's water resulting from this dilution makes it usable for most purposes down to the mouth of the Canadian, where the improvement is partially offset by the Canadian's poor quality flows. In the reach below the confluence of the two Rivers, the discharge of untreated or inadequately treated municipal and industrial effluents tends to further degrade quality, to the extent that water from the main stem in this reach is not used for domestic purposes except in emergencies, and has limited industrial use.

In Arkansas, tributaries draining the Boston and Ouachita Mountain highlands contribute considerable quantities of excellent quality water to the Arkansas River. Near Little Rock the river enters the alluvial valley of the Mississippi River. Although streamflows of tributaries in this area are generally of good chemical quality, with only a few localized sections of pollution, the main stem of the Arkansas is polluted by sewage from towns along its course and by coal mine drainage; sediment is also a major pollutant in the main stem. Thus, the water in the reach below Little Rock is used only for emergency municipal and limited industrial supply.

Development of additional surface water supplies in the Red River basin above Denison Dam is limited by flow characteristics of the streams. Provision for sediment accumulation in impoundments along these streams notably increases the cost of development. Significantly, the Red River obtained its name from the color of its heavy load of suspended sediment. The flows are polluted also by natural mineralization and by municipal and industrial wastes. The waters of some of the major tributaries in this part of the basin are again unsuitable for municipal and industrial uses.

Below Denison Dam, the tributary streams of the Red River basin contain large volumes of excellent quality water, particularly in southeastern Oklahoma. Nevertheless, sediment and municipal and industrial wastes are sources of stream pollution in some areas of this part of the basin.

Rugged terrain in the headwater areas of the Ouachita River, a tributary of the Red River, is conducive to rapid runoff and high peak flows. In this drainage area, most of the runoff occurs in the winter months. The quality of water in the upper reaches, primarily in the tributaries above Camden, Arkansas, is excellent. However, here again industrial and oilfield wastes cause some pollution problems.

In the White River basin, most streams have well-sustained dry-weather flows of cold, clear, high-quality water. Intense rainfall in the highland area causes floodflows of considerable magnitude, which frequently inundate large areas of the downstream alluvial valley. In general, the chemical quality of the surface waters of the basin is excellent, and sediment is less significant than in the Arkansas and Red basins.

Groundwater

The primary water resources of the High Plains are the groundwaters that are common to most of the area and essentially independent of the valley alluvium. The principal aquifer is a vast deposit of sand, gravel, and clay, in places attaining a thickness of 500 feet or more. The amount of water stored in the aquifer is very large but is being rapidly depleted in some areas.

Groundwater resources of the Red River basin are limited and lie generally in disassociated bodies along the stream alluviums. However, quality is generally good and a majority of the towns and cities in the basin obtain their municipal supply from the source.

Large supplies of groundwater of good quality are available in the alluvium of the eastern portion of the Region, but in some localized areas high mineralization and overdevelopment are problems. Groundwater resources available in many other areas of the Region are not utilized extensively because of high mineral content.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Groundwater provided almost 60% of the total of 9.4 bgd (10.5 maf/yr) of water withdrawn for use in the AWR Region in 1965. Almost 75% of the total withdrawals was for irrigation. Consumptive use was 5.9 bgd (6.6 maf/yr) (over 60% of total withdrawals) and irrigation alone accounted for over 85% of the consumption. (See table 6–10–2.)

Instream water is chiefly used for navigation, hydroelectric power, recreation, fish and wildlife habitat, and quality control. Although storage may be required to support these uses, their actual consumption of water is very small and the water used is generally available for reuse.

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TABLE 6–10–2.—*Present water use, 1965, Arkansas-White-Red Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
1	10	18	57	30	75	16	206
2	16	170	144	20	2,706	30	3,086
3	12	118	87	130	2,680	28	3,055
4	23	173	160	90	279	36	761
5	4	8	71	0	480	1	564
7	10	85	18	20	565	20	718
8	28	115	373	310	175	19	1,020
Total	103	687	910	600	6,960	150	9,410
From:							
Groundwater	(97)	(269)	(457)	(10)	(4,710)	(55)	(5,598)
Saline	—	—	(75)	—	—	—	(75)
			Water consumed				
1	7	3	9	1	53	15	88
2	14	53	15	10	1,788	28	1,908
3	11	38	31	11	2,100	28	2,219
4	21	57	72	7	198	35	390
5	4	1	60	0	336	1	402
7	9	41	6	4	429	20	509
8	28	48	129	8	126	19	358
Total	94	241	322	41	5,030	146	5,874

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 5,465,000 through public systems, and includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

ADEQUACY OF PRESENT DEVELOPMENT

Many cities and towns in the Region have insufficient water supplies during drought periods. Most of the shortages, however, are due either to a lack of long-range planning or to inadequate financial capability. Similar conditions also exist in many rural areas. Three major problems complicate the water situation: in some areas, good water is available but not needed; in other areas, water is needed and available, but its quality is poor; and in still other areas, sufficient water is not available.

At present, the western and central portions of the Region obtain most of their water supply from groundwater sources. In the eastern portion, most of the supply is from surface storage.

Available surface water in the upper reaches of the Arkansas River basin in Colorado and New Mexico has, with minor exceptions, been fully appropriated. Thus, an increase in water use in this area will depend largely upon more efficient use or imports from other basins. The existing Tucumcari Project in New Mexico and the recently completed Canadian River Project in the Texas Panhandle will utilize a considerable portion of the Canadian River flows which originate upstream from the Oklahoma-Texas State line.

The High Plains portion of the Region is an area of low and erratic rainfall, limited water resources, and fertile soils that are particularly suited for irrigation. Groundwater storage is large; however, in keeping with the relatively low precipitation, high temperatures, and dry winds during part of the year, recharge is low. Current estimates indicate that the average annual recharge is less than 1 inch per year—clearly inadequate to supply the existing irrigated lands of the area indefinitely.

Irrigation in the Central Lowlands, though not as necessary for agricultural success as in the High Plains, is desirable to stabilize agricultural production. There are surface water

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resources which can be developed in this portion of the Arkansas River basin.

Considerable surface water development has been accomplished on Red River tributaries in the southern portion of the Central Lowlands and there are indications that some additional development may prove feasible. Characteristically, surface waters in this area have long periods of negligible flow interrupted by short periods of intense flood flow. This variability accentuates soil erosion, sedimentation, and flood control problems, and also necessitates construction of reservoirs to provide carry-over storage.

Groundwater resources in the Red River basin are limited, but their quality is generally good. In a number of instances, however, the water has been unsatisfactory because of early depletion, or because of the intrusion of salt water or oilfield wastes into the water-bearing strata. Irrigation from groundwater sources is minor in the area, since the pumping lifts required are usually excessive and supplies are undependable. Municipal supply problems are acute in a number of instances and difficult to solve, because of the unpredictable quality and quantity of the groundwater resource and the lack of economical storage facilities for surface water. When communities therefore accept short-range solutions, the problems merely repeat themselves.

In the eastern portion of the Region, where ample amounts are available, little difficulty has or will be experienced in meeting water demands. Flood control and drainage are the principal problems, though they have been somewhat reduced with the completion of numerous projects. Many dams in this area contain hydroelectric powerplants. The water resources in the lower reaches of the various rivers of the Region are tremendous and if developed could more than meet any foreseeable future demands in their respective areas.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

All but the three eastern States of the AWR Region—Missouri, Arkansas, and Louisiana—conform to the appropriation doctrine in the management and use of water resources. In some areas, water rights have been granted which exceed the available supply. Water laws vary among the States as to priorities of use; all generally assign first priority to domestic and livestock use, but priorities thereafter may range from several to none.

State laws normally authorize the organization of special districts to develop and manage various water resources programs. Problems that develop at the local level generally stem from an unclear definition of a district's authorities and responsibilities. Complications may also arise when the authorization limits responsibilities too specifically. For example, a district may be authorized to control only one developmental purpose in a program; another may lack the rights of eminent domain or taxation. Other problems occur where several districts are included in one basin or watershed. In some cases, these special districts, or local interests acting as sponsors of Federally assisted projects, either are reluctant to cooperate fully or lack financial capacity to do so.

Many of the interstate problems that have been experienced by regulatory and/or management bodies in different States—with differing laws, standards, and so on—can be solved or avoided by interstate compacts. Such problems usually involve the equitable division of water between the States or the establishment and enforcement of water quality standards. Several interstate compacts are in force or presently under consideration among contiguous States in the Region. Those in force include the compact between Colorado and Kansas concerning the Arkansas River; between Kansas and Oklahoma, also concerning the Arkansas; and between New Mexico, Texas, and Oklahoma, concerning the Canadian River. Oklahoma and Arkansas are presently considering a compact concerning the Arkansas, as are Oklahoma, Texas, Arkansas, and Louisiana, concerning the Red River.

The recently ratified Kansas-Oklahoma Compact included water quality provisions. And all of the States in the Region are in the process of establishing standards for all interstate streams in accordance with the provisions of the Federal Water Pollution Control Act, as amended.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

In 1965, the population of the Region was estimated as about 7.4 million. It is expected to increase to about 9 million by 1980; to 12 million by 2000; and to 16.1 million by 2020 (table 6–10–3). Production in the petrochemical industry is projected to increase more than 5 times by 2020, and the output of forest products about 3.5 times. About a threefold growth in agricultural production is expected during the same period; this will call for more equipment, irri-

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TABLE 6–10–3.—*Economic and agricultural projections, Arkansas-White-Red Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	7,122	8,972	11,952	16,055
Per capita personal income	1954 dol.	1,590	2,774	4,400	6,975
Employment, total [2]	thou.	2,519	3,311	4,458	6,044
Agriculture	do.	283	104	60	47
Manufacturing	do.	414	666	907	1,214
Other commodity producing	do.	352	452	579	757
Distributive industries	do.	687	909	1,212	1,586
Service industries	do.	782	1,179	1,700	2,441
Land base	thou. ac.	170,432	170,432	170,432	170,432
Agricultural	do.	155,323	154,223	153,143	151,973
Cropland, total [3]	do.	50,953	46,352	46,028	45,677
Used for crops	do.	38,816	35,734	37,808	37,608
Idle and fallow	do.	12,137	10,618	8,220	8,069
Pasture-permanent	do.	59,374	63,194	62,751	68,350
Forest and woodland	do.	44,996	44,677	44,364	37,946
Nonagricultural	do.	15,109	16,209	17,289	18,459
Irrigated land [4]	do.	[5] 3,100	5,600	6,400	[6] 6,850

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture
[4] Includes cropland and pasture.
[5] In 1965 irrigated land amounted to about 3,800 thousand acres.
[6] Significantly more land could be irrigated in the High Plains if supplemental water supplies were imported.

gation water, and fertilizer. Cattle feedlot operation is currently one of the most rapidly growing industries.

The increase in population, in conjunction with the expanding economy, will require substantial increases in water resources development to meet the 2020 demands. For the near future, accelerated planning of flood control appears to be the greatest need; however, further developments for quality control, conservation storage, and navigation will also be urgently required. (Projected water withdrawals and consumption are shown in table 6–10–4, and projected instream water uses and water control requirements in table 6–10–5.)

EMERGING WATER PROBLEMS

Among the Region's emerging water problems, two are especially serious: (1) water is not available in sufficient quantities in the particular areas in which it is needed; (2) considerable amounts of water are largely unfit for agricultural, municipal, industrial, fish and wildlife, and recreation uses because of mineral, municipal, and industrial pollution.

In the arid western and central portions of the Region, where groundwater is being mined widely, estimates on the life of the recoverable storage range from 10 to 50 years. Since surface water impoundments in these areas are subject to high evaporation rates and phreatophytic growth, the unit cost of surface water yields is higher than that of groundwater yields at the present time. Eradication of phreatophytes and reduction of evaporation by chemical or other means may be a means of raising the yield-storage ratio and lowering the unit cost of surface water yields. Other possible means of supplementing the water supply in these areas include water impoundments for artificial recharge of groundwater aquifers, and transfers from the surface water surplus of the eastern portion of the Region.

In the more humid portion of the Region, there is still the need to transfer water to local heavy-use areas. Examples are the Atoka Reservoir and conveyance facility, constructed by Oklahoma City, Oklahoma, and the water supply of Tulsa, Oklahoma, which is transported about 75 miles. The main problem in the central portion of the Region is one of water quality. Tulsa, Oklahoma, Wichita, Kansas, and Fort Smith and Little Rock, Arkansas, all located on the Arkansas River, do not use its water because of the high mineral pollution. Most of the man-made pollution could be eliminated in the near future if State pollution laws were strictly enforced. Natural pollution will also

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TABLE 6–10–4.—*Projected water requirements, Arkansas-White-Red Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
	Withdrawals			
Rural domestic	103	213	356	515
Municipal (public-supplied)	687	1,418	2,375	3,438
Industrial (self-supplied)	910	1,880	3,147	4,553
Steam-electric power (fresh)	600	[1] 4,140	[1] 8,440	[1] 11,140
Agriculture:				
Irrigation	6,960	9,400	10,700	11,500
Livestock	150	228	318	443
Total	9,410	17,279	25,336	31,589
	Consumptive use			
Rural domestic	94	134	325	470
Municipal	241	496	832	1,205
Industrial	322	674	1,114	1,611
Steam-electric power (fresh)	41	95	205	310
Agriculture:				
Irrigation	5,030	6,800	7,800	8,300
Livestock	146	223	311	433
Total	5,874	8,482	10,587	12,329

[1] Includes 40 mgd of saline water.

TABLE 6–10–5.—*Projections of instream uses and control requirements, Arkansas-White-Red Region*

Item	Unit	1980	2000	2020
Instream uses:				
Power, hydroelectric[1]	thou. kw	6,500	16,500	31,900
Navigation, waterways	mil. ton-mi	20,570	22,970	23,570
Recreation	thou. user-days/yr	161,700	215,400	289,800
Fish and wildlife	thou. user-days/yr	50,210	66,880	89,960
Control requirements:				
Watershed projects[2]	thou. ac.	62,660	80,990	92,610
Flood damage reduction[3]	thou. ac.	6,920	8,540	10,160
Bank and channel stabilization	mi.	810	1,160	1,510
Drainage[4]	thou. ac	1,340	3,590	5,820
Water quality	thou. af/yr	9,280	9,520	9,810

[1] At 20% August load factor.
[2] Acres in projects
[3] Includes flood protection for upstream watersheds.
[4] Excludes woodland drainage.

have to be removed by structural or other means if this vast resource is to be used to satisfy the agricultural, municipal, and industrial needs of the future. Although considerable groundwater is available in the eastern portion of the Region, much of it is also highly mineralized and treatment costs are high.

It is important that these problems be solved soon if the Region's economic growth is not to lag. Especially urgent is the problem of the

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presently irrigated lands that depend on groundwater mining; in many cases, depletion of the underground source is imminent. Unless suitable alternate supplies can be developed quickly, economic decline of this portion of the agriculture sector is certain.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

With the expanding economy, it is desirable that the Region consider all multiple-use aspects and develop all reservoir sites, except those on reserved free-flowing streams or scenic rivers, to their physical limits or to the limit of the yield of the streams. This magnitude of development may not seem economically sound when a project is built, but, as the need for water increases, the soundness of the effort will be confirmed. All existing projects should be reevaluated periodically to ascertain if expanded development is in order, or if reallocation of storage would better meet the needs of the Region's growing economy. Storage potentials are becoming more valuable for water supply or water quality control. As water needs increase, it will be necessary either to shift the point of use of the supply or to convey the supply to the point of use, and there must be a continued search for means to better utilize available water.

Flood plain management is a must for optimal regional flood damage reduction. Flood proofing and zoning and other local restrictions, along with better information about flood hazards, will do much to alleviate damages. The Flood Plain Information Program is an important step in this direction, and should be expanded in the future.

Water quality must be improved by reducing stream pollution, including sediment. Manmade pollution will be reduced, if not eliminated, with the establishment of water quality standards and their implementation, surveillance, and enforcement under plans now being formulated by the States and the Federal Government. Effective erosion control and alleviation of natural chloride pollution in the Arkansas and Red River basins would make vast amounts of water available for present and future uses.

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CHAPTER 11

Texas-Gulf Region

SUMMARY

The Texas-Gulf Region's total withdrawals in 1965 averaged 16.4 bgd (18.4 maf/yr), of which about one-half was groundwater. In major use areas, where pumpage for irrigation and other purposes has been increasing at a rapid rate, the groundwater is dwindling. Parts of the High Plains, north-central Texas, the Winter Garden, and some coastal areas of Texas and Louisiana are already critically affected. Accompanying salt-water intrusion and subsidence are also significant in some of the coastal areas.

In most of the Region, agriculture is destined to remain the basic economy, on which urban and industrial growth will continue to depend. This is not to minimize the seriousness and magnitude of the problem of providing for the fivefold increase in municipal and industrial water use that is expected to be required for industrial and population growth along the coast and in many other areas by 2020. These requirements must and will be met.

The 91 existing major reservoirs are a good start in developing the surface waters of the Region. Numerous smaller impoundments serving agricultural, community, and individual industrial uses add important supply elements; however, their continued development may have serious impact upon optimal water supplies in some of the river basins. At least 44 additional major reservoirs, plus some modification of existing facilities, will be required to approach optimal stream yields.

This storage will necessarily be concentrated in eastern areas, although most anticipated needs are in water-short areas to the west. Maldistribution will need to be corrected by development of water transmission facilities linking sources to use areas. Large deficits in supplies for future water needs in western portions of the Region will exist, even with optimal regional development. Therefore, sources of supply outside the Region and the feasibility of facilities to handle large imports—as much as 13.5 bgd (15 maf/yr)—to these western areas should be investigated.

Flood control and limited measures for protection against hurricane damage along the Gulf Coast have been achieved to some extent by major structures, local protection facilities, and upstream watershed programs, but substantial needs remain. Drainage improvement is a major need in the eastern river basins and along the coast.

All navigation at present is in coastal waters without freshwater requirements. However, navigation has been authorized in the Trinity River and is being considered for other streams.

There are numerous concentration points of water pollution or potential pollution throughout the Region. These are being given adequate, effective attention in planning, development, and water-quality management.

The commercial and sports fishery, recreational, and other values of important coastal waters are being given full consideration in regional water development.

The State of Texas has launched a $3.7-billion program to carry Texas and thus most of the Texas-Gulf Region well into a 50-year program for urgently needed water development. To accomplish the intended objectives, leadership, legislation, institutional adjustment, organization, local-State-Federal cooperation, ingenuity, understanding, and an abundance of patience and money will be required.

DESCRIPTION OF THE REGION

The Texas-Gulf Region covers an area of some 182,400 square miles, of which 168,600 are in Texas, 10,100 in Louisiana, and 3,700 in New Mexico. Its river basins drain into the western Gulf of Mexico (fig. 6–11–1). Subregion 1, in the eastern portion of the Region, encompasses the Sabine, Neches, Trinity, and San Jacinto basins and the intervening coastal basins and extends into southwestern Louisiana to include the

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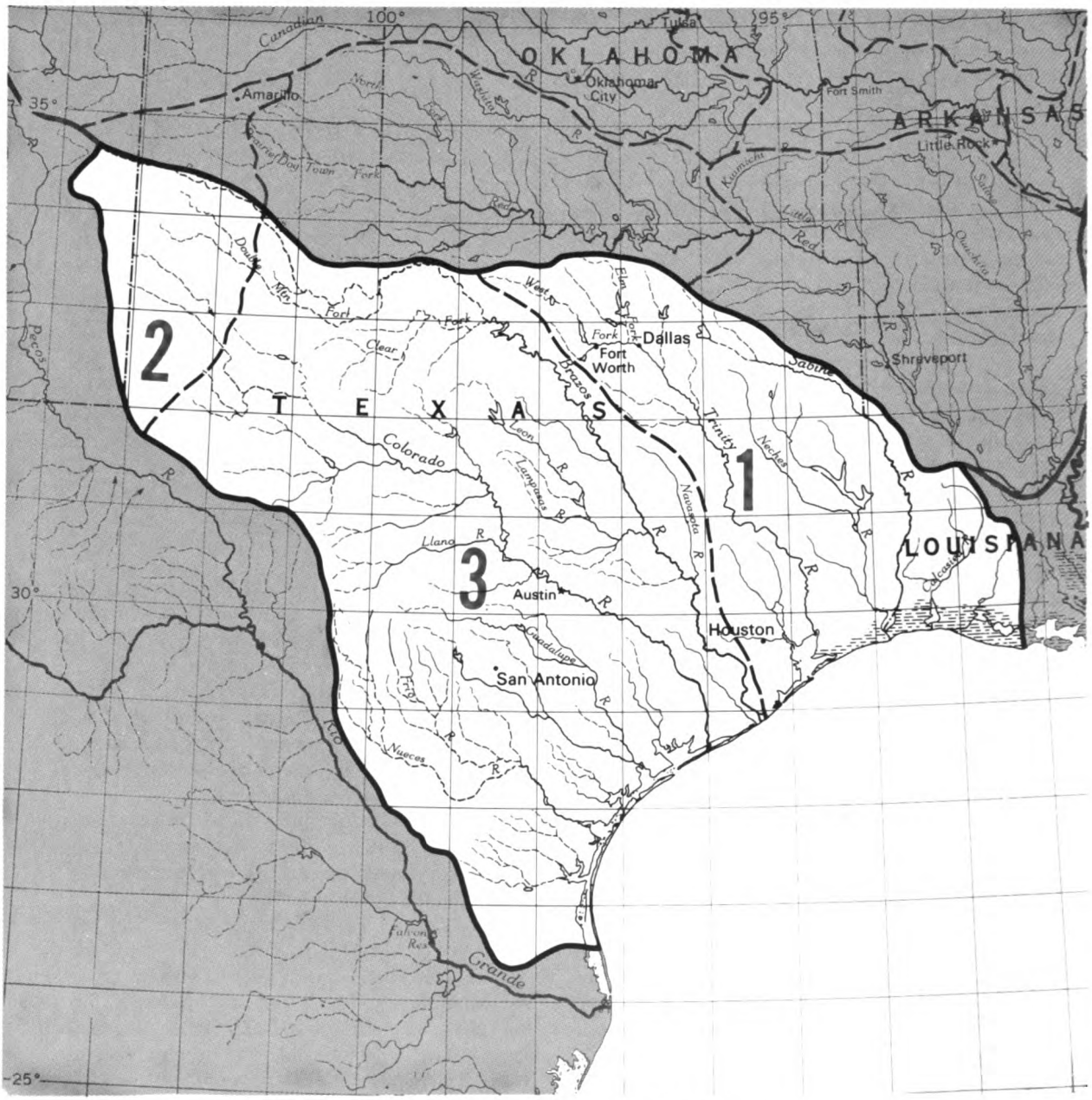

FIGURE 6–11–1.—*Map of the Texas-Gulf Region*

Calcasieu and Mermentau basins. Subregion 2 is confined to the southern High Plains in Texas and New Mexico. Subregion 3 includes the remainder—the Colorado and Brazos basins (which cross Texas from the High Plains southeastward to the Gulf Coast), the Guadalupe, San Antonio, and Nueces basins, and the intervening coastal basins. The drainage areas of the subregions are shown in table 6–11–1.

The regional geology, climate, topography, soil, and level of economic activity vary widely

TABLE 6–11–1.—*Drainage area, Texas-Gulf Region*

(Square miles)

Subregion	New Mexico	Texas	Louisiana	Total
1	0	41,900	10,100	52,000
2	3,700	15,400	0	19,100
3	0	111,300	0	111,300
Total	3,700	168,600	10,100	182,400

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from area to area. Subregion 2 is an intensively developed farming area. Ranching and irrigated crops, including cotton, grain, sorghum, wheat, and certain vegetables, provide the base of an agricultural economy that is supporting a rapidly expanding population. The principal urban center of the subregion is Lubbock.

Coastal portions of the other two subregions are undergoing increasing urbanization and industrial development in the Corpus Christi, Houston-Galveston, and Beaumont-Port Arthur-Orange areas. Nevertheless, rice and livestock production remain basic to the coastal economy. In the inland parts of subregion 1, water and related land resources are used chiefly for forest and other agricultural production and for recreation. Industry is also expanding, especially in the Dallas-Fort Worth and Tyler metropolitan areas. Much of the inland part of subregion 3 is sustained by ranching and farming, although considerable industrial development has occurred in San Antonio, San Angelo, Midland-Odessa, Abilene, Austin, and Waco.

THE WATER RESOURCE

Annual precipitation ranging from 40 inches to nearly 60 inches produces large quantities of runoff in subregion 1 (table 6–11–2). The eastern areas of higher rainfall have greater amounts of water available than local use requires. Water quality is inherently good, but because streams and coastal waters are widely used for treated effluent disposal, man-made pollution is a problem of gradually increasing severity. Good quality groundwater is available in many localities.

Subregion 2 is a relatively level, smooth plain containing many small depressions (playas) without natural outlets. Precipitation ranges from 14 to 20 inches, but there is little runoff and practically no flow to the Brazos and Colorado River systems. High quality groundwater is being pumped from the underlying Ogallala Formation, but withdrawals far exceed recharge.

Precipitation in subregion 3 ranges from 20 to 40 inches per year. Although coastal areas receive more rainfall than the headwater drainages to the west, they have a "feast or famine" moisture pattern—torrential tropical storms interspersed with extended rainless periods. Periods of inadequate water supply are frequent in some parts of the subregion. Groundwater accretions to the upper Brazos River system accumulate high salt and gypsum concentrations as they pass over and through gypsiferous formations and saline lenses. Waters of the middle and lower Colorado, Guadalupe, Lavaca, San Antonio, and Nueces River systems and the intervening coastal streams are generally of satisfactory quality. Man-caused pollution in some areas, however, has limited use of water for some purposes.

Groundwater is the source of supply in many localities of subregion 3. High quality artesian water, from the Edwards (Balcones Fault Zone) aquifer, supports flows of large springs. These springs supply many users below the Balcones Escarpment (which rims the Edwards Plateau in west-central Texas), including the San Antonio urban-industrial complex. Coastal aquifers are important sources of water, but quality deteriorates progressively southwestward along the coast. The Carrizo-Wilcox aquifer provides high quality water for all purposes, particularly in the Winter Garden area. However, serious depletion is beginning to be experienced in many areas.

TABLE 6–11–2.—*Annual natural runoff, Texas-Gulf Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	52,000	26.88	10.86	25.86	11.07	8.09
2	19,100	.08	.09	.06	.02	.01
3	111,300	12.11	2.28	10.71	3.32	2.16
Regional value	182,400	39.1	4.50	37.5	15.8	11.4

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TABLE 6–11–3.—*Present water use, 1965, Texas-Gulf Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
1	10	560	2,530	1,580	1,120	30	5,830
2	5	95	155	15	4,780	10	5,060
3	25	400	2,780	705	1,550	60	5,520
Total	40	1,055	5,465	2,300	7,450	100	16,410
From:							
Groundwater	(40)	(590)	(1,250)	(300)	(6,150)	(60)	(8,390)
Saline			(3,100)	(200)			(3,300)
			Water consumed				
1	10	180	500	33	750	30	1,503
2	5	50	120	11	3,820	10	4,016
3	25	170	260	15	1,240	60	1,770
Total	40	400	880	59	5,810	100	7,289

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 8,234,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves, including secondary recovery operations in petroleum production. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The figures in table 6–11–3 are based on data used to develop a preliminary Texas Water Plan and have been supplemented with data from the States of Louisiana and New Mexico and from Federal sources.

In subregion 1, water is predominantly used for municipal and industrial purposes in the Dallas-Fort Worth area and along the Gulf Coast. Groundwater supplies most of the smaller communities, the pulp and paper industry, urban-industrial needs near the coast, and oilfield repressuring operations. Water for irrigation of rice near the coast is withdrawn from surface water. Elsewhere in the subregion, however, irrigation is not a large user.

Municipal and industrial usage of groundwater in subregion 2 has been increasing in recent years due to the expanding economy, which is based largely on irrigated farming that has been burgeoning since the 1940's. By far the greatest use of water is for High Plains irrigation—the largest area of groundwater-supplied irrigation in existence anywhere. Depletion of the supply, however, is currently causing a decrease in irrigated acreage.

About 50% of the total fresh water withdrawal in subregion 3 is for irrigation. The chief irrigated areas are along the coast (rice production), the Winter Garden (vegetable production), and lands below the Balcones Escarpment. There are, however, numerous smaller irrigated areas in the north-central and central Texas farming areas, and along the Brazos River and other streams. Groundwater is furnishing approximately two-thirds of the irrigation supply; surface water supplies needs along the coast south and west of Victoria, where groundwater quality is poor. Numerous canal systems and water supply companies and districts serve coastal irrigation areas with water from the Brazos, Colorado, Guadalupe, and other streams. This coastal area is an important segment of the Nation's principal rice-producing area.

Groundwater is used throughout the Region for secondary recovery operations in petroleum production. This is classified with self-supplied industrial uses of water in table 6–11–3.

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Pollution is present in portions of streams throughout the Region. Pollutants include municipal and industrial waste discharges, agricultural chemicals, and brine associated with oil and gas production. Some water is used for dilution of streamflows, but this is only a temporary abatement measure pending correction of pollution at its sources. Phreatophytes are common in the Texas portion of the Region. Their drain on water supply is most critical in the central and northwest areas of the State.

Coastal waters are important for commerce, commercial and sport fishing, recreation, and seaside residential sites. Maintaining optimal quality and quantity of fresh water inflow to these bays and estuaries will continue to be an important water management consideration.

Hydroelectric power is being generated on the Neches, Brazos, Colorado, and Guadalupe Rivers, and units are being installed on the Sabine River. Flood prevention and flood control involve considerable amounts of reservoir storage capacity which may, in some instances, tax storage potentials and lead to problems concerning the priorities of competitive uses of reservoir storage.

ADEQUACY OF PRESENT DEVELOPMENT

Groundwater is being pumped from a number of aquifers to furnish about 50% of the regional withdrawals. The 91 existing major reservoirs, each with 1.6 billion gallons (5,000 af) or more of conservation storage capacity, have helped to develop surface water yields. Nevertheless, present developments are not adequate to meet demands. At least 44 additional major reservoirs, many smaller structures, water transmission and distribution facilities, and expanded water wellfields are or will soon be urgently needed.

Subregion 1 has sufficient water available to meet its own increasing needs and to supplement supplies elsewhere. At present, there is some transfer of water westward to concentrated-use areas, including Dallas-Fort Worth; but additional diversions will be required. The subregion's groundwater supply is now adequate, although some new or expanded well fields will be required in the future to meet increasing community needs and such industrial requirements as oilfield repressuring and pulp and paper production. Along the Louisiana and Texas coasts, where saline waters are already intruding into heavily pumped sand aquifers and subsidence is occurring, caution must be exercised in groundwater use and development.

The water source in subregion 2 is primarily groundwater from the Ogallala Formation. A number of communities and industries own and operate their own water wellfields, all of which will have to be expanded or augmented periodically to keep pace with demands. A few smaller communities and industries have small surface water impoundments, and the recently completed Canadian River Project provides part of the supply for several municipal systems through a 322-mile aqueduct.

Irrigated acreage in subregion 2 is now diminishing, as groundwater storage dwindles. Irrigators, adjusting to inadequate supplies, have modified some of their practices. Pumps are being lowered, and pumping lifts and costs are increasing. New wells will need to be developed and irrigators must continue to adjust their operations to the situation until supplemental supplies become practical and feasible.

Most urban areas in central Texas (subregion 3) have plans for meeting their water needs. Several new reservoirs are under construction or in the planning phase. Sufficient water is available in the highland lakes on the lower Colorado River to supply the Austin area, as well as to serve power generation, fish and wildlife, recreation, residential, and tourist-attraction purposes. Irrigation use of water is not heavy in this area.

Large quantities of groundwater are available near the coast, but its poor quality in the Coastal Bend and lower coast areas has led most communities to seek a better source. Rapidly expanding municipal and industrial water requirements in coastal areas, including Corpus Christi, call for increased water-supply storage. Upstream reservoirs and diversions from sources outside the subregion will need to furnish some of the supplies.

Coastal irrigation, including that of the Nation's largest rice-producing area, uses some groundwater and much surface water. Under existing crop allotments, water supply from sources within the subregion is not only presently adequate but also would allow for some expansion without development of additional sources.

Water stored in the Carrizo-Wilcox aquifer in the Winter Garden (subregion 3) is showing signs of depletion. Irrigation has been curtailed, particularly in the southern part of the area; water is available, however, for urban and industrial purposes. Increased drafts on groundwater from the western extension of the Edwards (Balcones Fault Zone) aquifer for irriga-

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tion and other uses may, in the future, exceed known natural recharge. Underground flows move northeastward around the Balcones Escarpment, and toward important urban-industrial groundwater use areas, including San Antonio; the increased usage to the west thus threatens interception of vital supplies for these areas. This problem requires immediate attention.

Wastes from many communities, industries, and individual septic tanks or other types of disposal systems are creating widespread water quality problems in the lakes, streams, and coastal waters of subregion 3. The need for preventive or control measures is greatest below areas of major urban and industrial concentration.

In the Region a total of 2,800 billion gallons (8.6 maf) of flood storage is provided in 17 of the existing major reservoirs and, when completed, 3 others now under construction. In addition, a number of small watershed protection and flood prevention projects have been completed. In the State of Texas, about 1,200 structures have been installed, most of which are located in the Texas-Gulf Region. Many areas, however, are still threatened by floods and would benefit from flood control measures. Channel improvement and other local protection projects are also needed. Where large reservoirs are planned, flood-control storage capacity is generally being included, and upstream watershed protection and flood-prevention projects, where compatible with other water resource development purposes, are being developed to attain much of the control needed. Plans are also being developed for protection from hurricane damage along the entire Gulf Coast.

At present, about 0.6 million acres in the Region are adequately drained. Drainage improvements could enhance 5 million more acres; the principal areas needing drainage are in the east Texas timberlands and the coastal plains.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Over the years, surface-water rights throughout the State of Texas have become confused. Permits in some areas exceed dependable supplies. In the eastern basins, in particular, adherence to the riparian doctrine has persisted. The Texas Water Rights Commission has begun a vigorous program to clarify the situation. Under new procedures, for example, riparian users may establish their rights and will then be issued permits; thus, all of Texas will be under an appropriation system.

In 1966, the State Constitution was amended to provide that anticipated in-basin needs for water over an ensuing 50 years will be included in any water planning or development carried out with State funds. This requirement will be an important guideline for Texas in its development of State water plans now and in the future.

The 1931 Wagstaff Act stipulated priorities among surface water uses in Texas from highest to lowest as follows: domestic and municipal, industrial, irrigation, mining, hydroelectric power, navigation, and recreation. Though these criteria have generally been followed, some recent court decisions have involved special interpretations of the law.

Certain problems arise in the Region from the multiplicity and overlapping authorities and responsibilities of agencies concerned with water and related land resources development. Water users throughout the State of Texas are served by numerous water-supply districts (such as water control and improvement districts), river authorities, other public entities, and permitted water supply companies. Together, these groups form a complex organizational structure within which resource development must be planned and managed.

River authorities have been established for a number of Texas river basins or parts of basins. There is, however, great variation in responsibility and authority from one to another.

In New Mexico, public control of groundwater use and management has been established. Under Texas and Louisiana law, however, groundwater use is a property right.

The Water Quality Board of Texas establishes standards and obtains compliance with them. Some river authorities in Texas have also been given certain responsibilities for water quality control. Coordination of views and programs of all the levels and agencies of local, State, and Federal governments having responsibilities in this field will be needed.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The Texas-Gulf Region embraces one of the most rapidly developing areas of the United States. Between 1950 and 1960, its manufacturing output increased at a fast rate, mining and agriculture grew steadily, and employment in the service sector expanded. As a result, popula-

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tion of the Region, which had been 6.5 million in 1950, exceeded 8 million in 1960. Continued development of job opportunities is expected to increase population to nearly 13 million by 1980, over 18 million by 2000, and about 26 million by 2020. However, the ability (or inability) to meet municipal, industrial, mining, and agricultural water requirements will be a major factor determining future growth rates. Economic and agricultural projections are shown in table 6–11–4.

Data compiled for the Texas portion, applicable to the Region as a whole, covering the decade 1954-63, show that value added by manufacturing almost doubled from $3.1 billion to $6 billion. Mineral industry receipts continued a steady upward trend from $2.9 billion to $3.3 billion. The value of farm production grew from $1.2 billion to $1.6 billion. Growth of these basic industries led to an even faster expansion in trade and services over the same period—wholesale trade sales jumped from $9 billion to $16.2 billion, and retail sales increased from $7.5 billion to $10.6 billion. This pace of economic development accompanied the growth of a large urban market with an effective buying income of $15.8 billion in 1963.

While present population will more than triple by 2020, projected annual municipal and industrial water requirements by 2020 will be about four times present usage (table 6–11–5).

Irrigation farming, a large user of water, developed slowly until the 1930's. In the High Plains, groundwater development for irrigation has been extremely rapid since the 1940's. In 1965, the Region's productive irrigated land totaled about 5.5 million acres, of which about 5 million actually received water; over half the annual value of crops produced was attributable to irrigated crop production. The Region is expected to continue as a major agricultural production area, and projections made by the States of Texas and New Mexico indicate the need for nearly 11 million irrigated acres by 2020. The projections of irrigated land and irrigation water requirements used in this chapter are not based on imports and indicate water requirements to maintain the present agricultural economy.

Navigation places no demands on fresh water at present, because it is confined to coastal waters. Future navigation requirements, however,

TABLE 6–11–4.—*Economic and agricultural projections, Texas-Gulf Region*

(Million gallons per day)

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	8,109	12,491	18,230	25,901
Per capita personal income	1954 dol.	1,713	2,925	4,675	7,375
Employment, total [2]	thou.	3,006	4,823	7,038	10,004
Agriculture	do.	240	125	92	84
Manufacturing	do.	509	920	1,409	2,075
Other commodity producing	do.	448	597	755	972
Distributive industries	do.	853	1,362	1,818	2,324
Service industries	do.	957	1,819	2,963	4,549
Land base	thou. ac.	117,581	117,581	117,581	117,581
Agricultural	do.	109,204	107,554	105,594	103,584
Cropland, total [3]	do.	28,492	26,415	25,933	25,438
Used for crops	do.	24,120	22,131	24,151	24,128
Idle and fallow	do.	4,372	4,284	1,782	1,310
Pasture-permanent	do.	55,593	56,399	55,372	59,647
Forest and woodland	do.	25,119	24,740	24,289	18,499
Nonagricultural	do.	8,377	10,027	11,987	13,997
Irrigated land [4]	do.	[5] 5,100	5,500	5,500	[6] 5,500

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used for pasture.
[4] Includes cropland and pasture.
[5] In 1965 productive irrigated acreage was 5,500 thousand acres of which about 5,000 thousand acres were actually irrigated.
[6] Studies by the States of Texas and New Mexico indicate that nearly 11,000 thousand acres of irrigated land will be needed by 2020. Irrigation of this acreage is contingent upon major import of water.

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TABLE 6–11–5.—*Projected water requirements, Texas-Gulf Region*

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	40	70	120	160
Municipal (public-supplied)	1,055	1,890	3,110	4,540
Industrial (self-supplied)	5,465	9,340	15,500	22,100
Steam-electric power:				
Fresh water	2,100	5,500	22,000	41,000
Saline water	200	2,700	7,300	15,900
Agriculture:				
Irrigation	7,450	9,400	9,000	[1] 8,500
Livestock	100	180	300	440
Total	16,410	29,080	57,330	92,640
Consumptive use				
Rural domestic	40	65	110	145
Municipal	400	740	1,200	1,750
Industrial	880	1,160	1,650	2,160
Steam-electric power:				
Fresh water	57	180	495	590
Saline water	2	20	55	145
Agriculture:				
Irrigation	5,810	7,100	7,100	7,100
Livestock	100	170	280	410
Total	7,289	9,435	10,890	12,300

[1] Studies by the States of Texas and New Mexico indicate the necessity of importing 13,450 mgd (15 maf/yr) by 2020. With import the water use build-up will occur prior to 2020.

may reach about 96 mgd (107,000 af/yr) if and when inland navigation, as authorized and tentatively planned, occurs.

According to the State Comprehensive Outdoor Recreation Plan, in 1966 the Texas portion of the Region had a shortage of approximately 40,000 acres of related land development for water-oriented recreation to meet a current demand for 62.5 million visitor-days. By 2000, the shortage will have surpassed 165,000 acres for an estimated 208.4 million visitor-days unless additional developments are integrated into the Texas State Water Plan. Future needs include allowance for sport fishing and hunting demands associated with water development areas.

EMERGING WATER PROBLEMS

Water importation is urgently needed in western and in southern coastal parts of the Region. The feasibility of water transfers within the Region as well as of imports from outside will need to be considered. Coordinated planning will be needed between areas of surplus and of deficiency; once acceptable plans are developed, agreements, compacts, and other arrangements will have to be consummated.

The dynamic urban-industrial expansion along the Gulf, from the Houston-Galveston complex on the upper Texas coast to the Corpus Christi area in the Coastal Bend, demands a constantly increasing water supply. In addition, the municipal and industrial demands of a number of major inland centers are large and growing.

Faced with serious depletion of groundwater in storage, future supply of the same or expanded levels of irrigation, as well as expanded urban and industrial requirements, will be possible only if supplemental supplies are successfully imported in the Texas and New Mexico portions of the Region. Current and tentatively planned developments of groundwater and sur-

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face water can be expected to supply, on a sustained basis, only a little over 3 million irrigated acres with some 6.0 bgd (6.7 maf/yr) of water. Thus, the almost 8-million acre remainder of the total irrigated acreage projected by the States as needed by 2020 would involve importation of over 13.5 bgd (15 maf/yr).

In all areas where irrigation projects may be planned the farms must be large and adapted to a high degree of mechanization, requiring heavy capital investment. It would be impractical to apply the existing acreage limitation policy on Federal irrigation project development; modernized and broadened irrigation development policy is needed.

Purely as a physical problem, the job of planning, designing, and constructing of large-scale storage, transmission, and distribution systems is a tremendous one. The organizational and operational problems in receiving and handling large quantities of water will be greater than any heretofore experienced by water management bodies. Responsible local organization will be essential. Funding will probably require broad taxing authority to distribute costs over the full economic base of the use area. Thoughtful legislation will be needed to provide a satisfactory organizational and statutory framework.

Planning and development of projects to meet regionwide objectives need to be based on a clear understanding of local and regional needs, so that the understanding can in turn be reflected in cooperatively formulated comprehensive plans. If this can all be accomplished to the mutual advantage of local authorities, States, and the Federal Government, the comprehensive plans stand a good chance of being translated into strong, effective programs to implement water and related land resources development. In Texas, the established river authorities will be an appropriate implementing entity.

Weather modification is likely to receive intensive attention in the near future. If so, it will entail a new group of legal, institutional, and operational problems.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Only small segments of the Texas-Gulf Region extend into New Mexico and Louisiana, but the Region covers a major part of Texas. To support water resources planning and management activities, the State of Texas is establishing a central data bank system for water resources data. The following activities are urgently needed to keep planning and development moving forward at a satisfactory pace:

1. Amounts and locations of water potentially available for importation to certain New Mexico and Texas portions of the Region need to be identified.

2. Since the High Plains in Texas and New Mexico are and will be major water use areas, studies need to be accelerated to establish the amount of underground storage that is available, and any physical and economic limitations to its use.

3. The immediacy and complex nature of many State water planning and development problems indicates the need to gather staffs which are well-qualified and experienced in several professional fields.

4. Management of bays and estuaries of the Gulf Coast may involve large fresh water inflows from streams of the Region. At present, information concerning the relation of such inflows to the management of these waters is conflicting. The availability of water for other purposes could be greatly affected by bay and estuarine requirements, and more study is needed if optimum use is to be made of water in these areas.

5. Despite accelerated topographic mapping programs, the lack of adequate maps will severely limit effective planning for the next several years in some areas of the Region. The fastest possible topographic coverage should be achieved for these specific areas.

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CHAPTER 12

Rio Grande Region

SUMMARY

The Rio Grande Region is confronted by five major water problems: (1) in nearly every part of the Region the available water is not sufficient in quantity; (2) a significant amount of water is of poor quality because of high salinity; (3) heavy sediment loads are common in many tributaries; (4) excessive nonbeneficial consumptive use of water occurs; and (5) floods cause frequent and extensive damage to property and are threats to human life.

Progress has been and is being made in combatting the problems, but their ultimate solution requires the coordinated planning and action of local groups, States, and the Federal Government. Plans for the importation of water, desalination of brackish supplies, or both, are essential to the full development of the Region's potential for future urban, industrial, and irrigation expansion. If the problems are not at least well on the way to solution in the very near future, economic growth will lag.

DESCRIPTION OF THE REGION

The Rio Grande rises in the mountains of southern Colorado and flows south across New Mexico into Texas at El Paso. From El Paso to the Gulf of Mexico—700 airline miles and 1,244 river-miles—it forms the boundary between the United States and Mexico. The total area contributing runoff to the river contains 182,000 square miles, of which 89,000 are in the United States and 93,000 in Mexico. The Region embraces 136,000 square miles, including the 89,000 of the River's drainage, plus about 44,000 square miles that drain into several closed basins and about 3,000 square miles drained by coastal streams in the Lower Rio Grande Valley of Texas (fig. 6–12–1). The Continental Divide forms the western boundary of the Region. The eastern boundary trails off through rolling hills and the High Plains area without marked relief.

The principal tributaries of the Rio Grande are the Conejos River and Alamosa Creek in Colorado; the Rio Chama, Jemez River, and Rio Puerco in New Mexico; the Pecos and Devils Rivers in Texas; and the Rio Conchos, Rio Salado, Rio Alamo, and Rio San Juan in Mexico. The Pecos, the longest tributary, is separated from the Rio Grande in the upper basin by the Sangre de Cristo Mountain Range, an extension of the southern Rockies.

A semiarid to arid climate and low and/or erratic rainfall are characteristic of the Region. Average annual precipitation ranges from 30 inches in the high mountains and lower coastal plains to only 8 inches in the middle valley area, where most of the precipitation occurs in the form of heavy summer thunderstorms. Winters are severe in Colorado and in the high mountains of New Mexico, but generally mild throughout the lower areas.

Recorded history of the Rio Grande Region began with its exploration by Coronado in 1540. Spanish colonization in the 17th and 18th centuries along with pioneering by American settlers in the early 1850's resulted in rapid development of irrigation. In the early 1890's, however, irrigation water shortages began to occur, restricting the magnitude of further irrigation development.

The distribution pattern of population closely followed that of irrigated land. In recent years urban areas have grown rapidly as a result of nuclear research and governmental and military activities. Populations of the main New Mexico urban centers—Albuquerque, Alamogordo, Carlsbad, Las Cruces, Los Alamos, Roswell, and Santa Fe—have increased notably over the past three decades. More than one-third of New Mexico's population resides in these cities. The population of the Texas part of the Region was 880,000 in 1960. Largely urban, it is concentrated in the El Paso and Laredo metropolitan areas and the Lower Rio Grande Valley.

The regional economy is based chiefly on agriculture, with livestock production pre-

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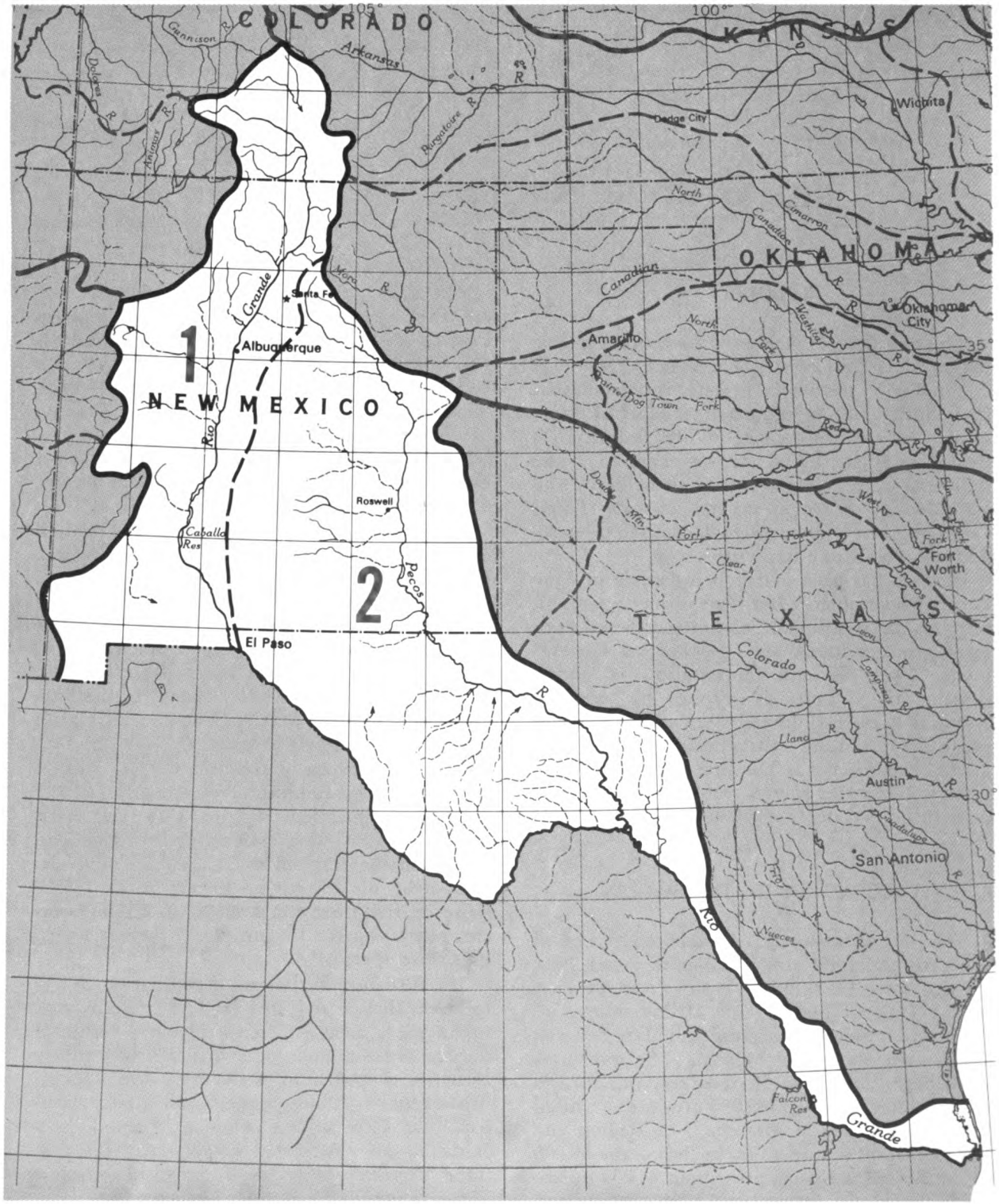

FIGURE 6–12–1.—*Map of the Rio Grande Region.*

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dominating. Manufacturing is of relatively minor importance. In parts of the basin, mineral extraction is significant. Recreation, tourism, and resort trade are increasing as sources of revenue.

THE WATER RESOURCE

The water resources of the Rio Grande Region may be considered as distinctly divided into two parts according to the present uses of water. From the headwaters of the Rio Grande to a point about 80 miles below El Paso, essentially all the streamflow is consumed. The supply in this reach is derived principally from snowmelt with some increase from summer rains. In the lower subregion, the Rio Grande is rejuvenated by the short-period flows of the Pecos River and other tributaries which flow in direct response to rainfall. The annual natural runoff from the two subregions is shown in table 6–12–1.

Subregion 1, the Upper Rio Grande, extends from the river's headwaters in Colorado to El Paso, Texas, and includes central New Mexico. It also includes the San Luis Valley closed basin in Colorado and five closed basins in New Mexico: the North Plains, San Augustin Plains, and Mimbres, west of the Rio Grande, and the Jornada del Muerto and Estancia, east of it.

The subregion's runoff comes from the mountainous areas above the valley floor and approximates the natural runoff unaffected by man's activities for the period 1896 through 1935. Possible runoff from precipitation on the valley flood was not taken into account.

The annual runoff in the Colorado portion of the subregion—1.43 bgd (1.60 maf)—is derived mainly from snowmelt; consequently, streamflows are high in spring and early summer. The runoff into the San Luis Valley closed basin represents about 12% of the total. The headwaters of the Rio Grande are relatively pure and the main dissolved constituent is calcium bicarbonate. Downstream, where the river passes through irrigated areas, return flows increase its salinity.

The annual runoff for the New Mexico portion, exclusive of closed basins, is 1.30 bgd (1.46 maf), and is also derived mainly from snowmelt; however, a greater portion than in Colorado originates from summer thunderstorms. As the Rio Grande flows southward, it becomes progressively more saline. This is due not only to return flows from irrigation, but also to inflow from the tributary Jemez River, Rio Puerco, and Rio Salado, which carry dissolved sulphates of calcium, sodium, and magnesium. The tributaries north of the Jemez are all of low salinity.

Excessive erosion and consequent sedimentation of river channels is a major problem in the Rio Grande in New Mexico above San Marcial. In many places, the riverbed is higher than adjacent lands. Historically, 60% of the sediment production was derived from the Jemez, Rio Puerco, and Rio Salado. The Rio Puerco alone contributed 35%; its maximum recorded daily suspended sediment concentration near Bernardo is 23%, and its maximum recorded daily suspended sediment load is 2.2 million tons. However, its sediment contribution is now adequately

TABLE 6–12–1.—*Annual natural runoff, Rio Grande Region*

Subregion	Drainage area [1]	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	42,700	2.73	1.34	2.70	1.47	1.17
2	93,200	2.18	.49	2.12	.99	.74
Regional value ...	135,900	4.9	.76	4.9	2.6	2.1

[1] Geological Survey Water-Supply Paper 1732 shows the contributing drainage area for subregion 1 is approximately 29,300 sq. mi. and for subregion 2 is approximately 59,700 sq. mi. making a total of 89,000 sq. mi. within the United States.

Note: Rio Grande above El Paso: Based on data from "Regional Planning, Part VI, Upper Rio Grande," National Resources Council, 1938, using base period 1896-1935. Pecos River: Based on data from "Regional Planning, Part X, Pecos River Basin," National Resources Council, 1942, using base period 1905-1939. Rio Grande between El Paso and Pecos River: Based on data from Water Bulletin No. 12, International Boundary Commission, 1942, using base period 1871-1942.

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controlled by Jemez Canyon Dam. The average sediment deposition in Elephant Butte Reservoir is about 10,000 af/yr.

There are at the present time six small imports from the Upper Colorado Region into the Colorado portion of subregion 1. They total about 4 mgd (less than 5,000 af/yr); however, another transmountain diversion, presently under construction in Colorado and New Mexico, will add about 100 mgd (110,000 af/yr) to the supply.

Subregion 2, the Lower Rio Grande, includes the Pecos River, the Tularosa and Salt closed basins in New Mexico and Texas, and the Rio Grande drainage in Texas. Its average annual natural runoff is 2.18 bgd (2.44 maf) and occurs primarily as flood flows produced by high-intensity rainfall. Small but important contributions to runoff occur from springs, but snowmelt is negligible except in New Mexico's high areas.

The Pecos River rises in the Sangre de Cristo Mountains, flows through eastern New Mexico into southwest Texas and joins the Rio Grande near Langtry, Texas. Its 35,300 square miles of contributing drainage area is divided into the upper and middle basins in New Mexico and the lower basin in Texas.

The average annual runoff of the Pecos in New Mexico is 0.65 bgd (0.73 maf). In this part of the subregion the runoff, as typified at Artesia, New Mexico, is fairly well distributed annually, with 57% occurring from May through September. Torrential rains, which move inland from the Gulf of Mexico from May through September, produce the major floods. The Pecos is highly mineralized, because great quantities of evaporites and limestone are within reach of circulating groundwaters; however, its sediment production is considerably less than the Rio Grande's. The Tularosa and Salt closed basins lie to the west of the Pecos.

The average annual natural runoff of the Texas portion of subregion 2 is 1.53 bgd (1.71 maf). In addition, the natural runoff from Mexico averages 1.75 bgd (1.96 maf/yr), of which about one-third is available for use in the United States under the provisions of the 1944 Water Treaty with Mexico. The Treaty also provides that, over a 5-year period, this one-third portion must average at least 312 mgd (350,000 af/yr). The flow of the lower Rio Grande is erratic—recorded flows at Laredo averaged 2.79 bgd (3.13 maf/yr), ranging from 6.29 to 0.86 bgd annually, from 37.4 to 0.0035 bgd monthly, and from 435 to 0 bgd daily. Estimates prepared by the International Boundary and Water Commission of historical and future flows of the Rio Grande at Falcon Dam are shown in table 6–12–2.

TABLE 6–12–2.—*Historical and future flows of the Rio Grande at Falcon Dam* [1]

(Billion gallons per day)

Flow conditions	Average annual	Maximum annual	Minimum annual
Historic conditions ...	3.62	7.42	0.73
Future conditions ...	2.59	6.14	0.59
Future conditions (U. S. share) ...	1.56	3.59	0.40

[1] Based on 1900-1956 period.

The flow of the Pecos is highly mineralized from Red Bluff Reservoir downstream nearly to the Rio Grande, at which point flows from springs greatly improve its quality. Because of high salinity, the quality of Rio Grande flows is poor from Fort Quitman to the mouth of the Rio Conchos near Presidio. The quality of Falcon Reservoir releases is generally acceptable for current uses, although low-flow releases are often contaminated by downstream return flows. This situation will be materially improved when the highly saline return flows of El Morillo Drain in Mexico are diverted into the Gulf of Mexico. Works to effect this diversion are now under construction by the Governments of the United States and Mexico.

New Mexico has large quantities of water in underground storage in both valley fill and bedrock aquifers, but most of it is brackish. The estimated storage in valley fill along the main stem of the Rio Grande plus the Jornada del Muerto, a large closed basin lying between the Rio Grande and the Pecos, is about 1,300,000 billion gallons (4,000 maf). It is generally believed that most of the State's economically usable groundwater has been located and that increase in groundwater use comparable to that of the last quarter century cannot be expected in the future.

The Texas Water Development Board estimates that the annual yield from aquifers in the Texas portion of the Region is about 0.53 bgd (0.59 maf) and that about 21,200 billion gallons (65 maf) of usable quality groundwater could be recovered economically from storage in these aquifers. Most of them are concen-

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trated in El Paso and Hudspeth Counties and the Pecos River basin. Only minor supplies of usable quality are available in the Lower Rio Grande Valley.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The predominant use of water in the Region is irrigation. Presently, about 6.67 bgd (7.47 maf/yr) are being withdrawn for the irrigation of about 1.95 million acres (table 6–12–3); approximately 60% of the withdrawal is consumed. Of the amount withdrawn, almost 60% is surface water; the remainder is groundwater. Irrigation withdrawal and consumption represent about 90% and 95%, respectively, of the total withdrawals and consumption within the Region.

About 4% of total regional withdrawal is used for self-supplied industrial purposes, including steam-electric power, but about 80% of it is returned to the streams or aquifers for reuse.

Urban and rural (domestic and livestock) uses account for most of the remaining withdrawals. About 60% of the water for urban use is presently being returned for reuse, but most of the water for rural use is consumed. Other uses of water include fish and wildlife habitat, recreation, and hydroelectric power, but water-use estimates are not presently available for them.

ADEQUACY OF PRESENT DEVELOPMENT

The water resources of the Region are fully appropriated and insufficient to meet present needs. In most of the areas of heavy groundwater use, withdrawals substantially exceed annual recharge rates. Thus, the groundwater in storage is being steadily depleted, frequently with accompanying deterioration in quality.

Periodic excessive stream discharges pose a serious and significant problem in many areas. Uncontrolled flood flows frequently spread over alluvial flood plains, damaging urban property, railroads, roads, and irrigation canals and diversions, by inundation, scour, and deposition of sediment and threatening and often taking human life. For example, the Texas flood of June 10 and 11, 1965, along Sanderson Canyon caused 24 deaths.

Subregion 1

Numerous significant water development projects have been carried out in Colorado and

TABLE 6–12–3.—*Present water use, 1965, Rio Grande Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
Water withdrawn							
1	4	121	37	0	3,291	56	3,509
2	6	133	178	70	3,380	13	3,780
Total	10	254	215	70	6,671	69	7,289
From:							
Groundwater	(9)	(160)	(75)	(40)	(2,808)	(38)	(3,130)
Saline	—	—	(133)	—	—	—	(133)
Water consumed							
1	2	68	18	0	1,637	55	1,780
2	5	40	28	9	2,528	13	2,623
Total	7	108	46	9	4,165	68	4,403

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 1,638,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

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New Mexico to provide irrigation water, sediment control, and flood protection. Nevertheless, additional improvements are needed to meet the subregion's present requirements. The San Juan-Chama Project, now under construction, will import water, primarily for municipal use, from the Upper Colorado Region. Several flood and watershed protection projects are also under construction. Additional developments in Colorado have been authorized or proposed, but action is being held up because of Colorado's Rio Grande Compact status.

Subregion 2

All areas of subregion 2 that use surface water are subject to periodic shortages due to extended periods of subnormal runoff. Irrigation in the El Paso Valley is largely dependent on releases from Elephant Butte Reservoir. However, deliveries to the reservoir by New Mexico prior to 1953 and by Colorado in recent years have been less than prescribed in the Rio Grande Compact, with the cumulative debit status now being about 414 billion gallons (1.35 maf). Such delivery shortages have accentuated deficiencies in surface water irrigation supplies. Irrigators have had to supplement their surface water supplies by pumping groundwater from shallow alluvium; because of its high salinity, a critical salt balance situation has been aggravated in some soils.

Along the Rio Grande above Falcon Reservoir, streamflow is highly variable and provides a fluctuating, undependable water supply. Streamflow regulation by Amistad Reservoir, which is now under construction, should largely correct this situation. Falcon Reservoir itself has materially improved the dependability of the surface water supply that supports the economy of the Lower Rio Grande Valley.

Red Bluff Reservoir provides water for irrigation of lands along the Pecos River, but the supply varies widely from year to year and is inadequate to irrigate more than a small part of the area that has been developed. The water is so highly mineralized that agricultural production on the irrigated lands falls far short of their capabilities.

Several other developments for irrigation, flood control, and watershed protection have been completed, with others authorized. Work has begun to reduce phreatophytic vegetation and its nonbeneficial uses of water. Some water-quality improvement of the Pecos is being accomplished by pumping an acquifer that has been contributing brine to the river. The concentrated brine solution is evaporated in a closed basin.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Division of the Rio Grande waters above Fort Quitman, Texas, between the United States and Mexico, is provided for by the 1906 Treaty with Mexico. Under the Treaty, the United States delivers to Mexico a total of 54 mgd (60,000 af) of water annually in the bed of the Rio Grande at the headworks of the Acequia Madre above the city of Juarez, Mexico. This delivery amount is subject to reduction in the event of extraordinary drought or serious accident to the irrigation systems in the United States. The United States' share of water is apportioned among Colorado, New Mexico, and Texas by the Rio Grande Compact, consented to by the Congress on May 31, 1939 (53 Stat. 785).

The Compact establishes schedules which specify the amount of water that the States of Colorado and New Mexico are to deliver to the downstream States each year. In recent years, Colorado has not been meeting the required scheduled deliveries and has accrued a debit of about 284 billion gallons (0.93 maf). New Mexico had previously accrued a considerable debit; but with the rehabilitation of the Middle Rio Grande Project and the recommencement of required deliveries the debit is being reduced and now stands at about 130 billion gallons (0.42 maf). As a result of Colorado's high debit accrual, Texas and New Mexico have filed suit in the Supreme Court of the United States against Colorado in an attempt to force compliance with the Compact.

Waters of the Rio Grande below Fort Quitman, Texas, are divided between the United States and Mexico in accordance with the International Treaty of 1944 which became effective November 8, 1945. The regulation and exercise of the rights and obligations of the two Nations under the Treaty were entrusted to the International Boundary and Water Commission. Both Falcon and Amistad Dams were authorized and will be operated under the provisions of this Treaty.

One of the most complex water problems of the Region is embodied in proceedings for adjudication of water rights. The Texas Water Rights Commission, under a new law enacted in the 1967 session of the Texas legislature, is initiating adjudication of water rights in the

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reach between Falcon and Amistad Dams to establish the portion of such supply to which holders of these rights will be entitled.

In June 1956, the United States' share of water stored in Falcon Reservoir was about 16 billion gallons (50,000 af), an amount sufficient to supply municipal, domestic, and livestock requirements in the Lower Rio Grande Valley for only about 3 months without additional inflow to the reservoir. Therefore, the Texas Board of Water Engineers (now divided into the Texas Water Development Board and the Texas Water Rights Commission) entered an order reserving all water then impounded in Falcon Reservoir for municipal, domestic, and livestock water purposes. Subsequent reservoir releases to supply downstream municipal, domestic, and livestock uses never reached their destinations, however, because irrigators intercepted the water. On June 28, 1956, the State of Texas, joined by 8 Valley cities, initiated a suit to restrain and enjoin water diversion for irrigation when the United States' share of water impounded in Falcon Reservoir was 50,000 af or less. Plaintiffs also sought appointment of a water master to regulate diversions from the Rio Grande. On June 29, 1956, the Texas District Court took judicial custody of Rio Grande waters from Falcon Dam to the river's mouth for so long as the United States' share of water impounded in the reservoir was 50,000 af or less. In subsequent proceedings the temporary order was extended to prorate water above 50,000 af for irrigation of lands that were in cultivation and under irrigation on October 17, 1956. Judgment was entered in the case on August 1, 1966, and is now being appealed to the State Appellate Court.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

In 1965, the population of the Rio Grande Region was estimated at 1,830,000. It is expected to increase to 2,649,000 in 1980, 4,173,000 in 2000, and 6,063,000 in 2020. The 1965 metropolitan population of two of the largest cities, Albuquerque, New Mexico, and El Paso, Texas, was each in excess of 300,000.

Manufacturing is increasing in importance in the Region. In the past, it has been largely associated with production for local markets and industries, including food processing, lumber products, printing and publishing, and concrete and stone products. Trends in manufacturing indicate a broadening of the industrial base with less dependence on resource-based industries. An example of this is the recent expansion in electronic manufacturing in Albuquerque. The manufacturing of petrochemicals is just beginning to be explored, and an increase in oil refining throughout the oil-producing areas is expected. Manufacturing related to food processing, fabrics, forest products, and minerals is expected to continue to increase.

The most important mineral resources are petroleum and natural gas, uranium, potash, and molybdenum. About 92% of the potash produced in the United States comes from the Region. The discovery of additional large deposits of molybdenum in New Mexico will stimulate the economy of that area substantially. Other significant minerals produced in the Region are copper, perlite, pumice, sand, and gravel. Coal is also an important mineral resource, but coal mining has decreased and at present is of little economic significance. However, two nonmetal industries—cement and gypsum products manufacturing—make an important contribution to the economy.

Tourism has become and will continue to be an important industry in the higher altitude areas of Colorado and New Mexico throughout the year, and in the lower areas in the winter. The Region has many attractions for visitors—among them its climate, exciting topography, Indian culture, and historic sites. In addition, the national forests offer wilderness camping and winter sports.

Projections of regional population, economic activity, and land use are presented in table 6–12–4.

The pattern of water use will change with the expected growth in regional population and economy. While irrigation will still represent the largest portion of the demand for water, the expected five- to sixfold increase in urban and industrial uses will probably restrict the growth of irrigation. In any case, without major import facilities, only a minor increase in irrigation can be expected. The increase that may take place will be due mainly to the salvage of water from nonbeneficial consumptive use and to presently authorized import projects. Projections of future water requirements are shown in table 6–12–5.

The water resources of the Rio Grande Region must be developed and managed in harmony with this expected economic growth. They must be an enhancing and not a limiting factor in the economic expansion of the Region. The use of groundwater has increased rapidly during

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TABLE 6–12–4.—*Economic and agricultural projections, Rio Grande Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	1,604	2,649	4,173	6,063
Per capita personal income	1954 dol.	1,964	3,175	4,950	7,600
Employment, total [2]	thou.	540	972	1,561	2,331
Agriculture	do.	57	36	29	28
Manufacturing	do.	46	110	200	329
Other commodity producing	do.	114	152	185	225
Distributive industries	do.	144	250	404	592
Service industries	do.	180	424	742	1,159
Land base	thou. ac.	87,533	87,533	87,533	87,533
Agriculture	do.	76,648	75,998	75,398	74,798
Cropland, total [3]	do.	2,805	2,447	2,428	2,409
Used for crops	do.	2,180	1,725	1,843	2,105
Idle and fallow	do.	625	722	585	304
Pasture-permanent	do.	59,735	59,562	59,092	58,622
Forest and woodland	do.	14,108	13,989	13,878	13,767
Nonagricultural	do.	10,885	11,535	12,135	12,735
Irrigated land [4]	do.	[5] 1,950	2,050	2,050	2,050

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used for pasture.
[4] Includes cropland and pasture.
[5] In 1965 irrigated land amounted to about 2,000 thousand acres.

TABLE 6–12–5.—*Projected water requirements, Rio Grande Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	10	10	10	10
Municipal (public-supplied)	254	450	720	1,090
Industrial (self-supplied)	215	910	1,800	3,570
Steam-electric power (fresh)	70	70	70	100
Agriculture:				
Irrigation	6,671	6,840	6,840	6,840
Livestock	69	70	70	70
Total	7,289	8,330	9,510	11,680
Consumptive use				
Rural domestic	7	7	7	7
Municipal	108	220	400	670
Industrial	46	90	180	350
Steam-eletcric power (fresh)	9	20	65	100
Agriculture:				
Irrigation	4,165	4,270	4,270	4,270
Livestock	68	69	69	69
Total	4,403	4,676	4,991	5,466

the past quarter century, and additional water supplies needed in the immediate future will probably be taken chiefly from groundwater sources, the location of which is generally believed to be known. Expanded use of groundwater, however, will increase the rate of its depletion.

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EMERGING WATER PROBLEMS

In the semiarid portion of the Region, projected requirements are much greater than the available water. As noted earlier, there is insufficient water even to meet present requirements as evidenced by continued groundwater depletions. Although the present supply will be augmented by importation from the Upper Colorado Region via the San Juan-Chama Project, this will not satisfy all of the expected future needs.

Problems will increase from the competition among present users having water rights, and between these users and new users who have no existing rights. Population increases and the expansion of the industrial and service sectors of the economy will create increasingly greater pressures toward change of existing physical and institutional arrangements. These same pressures will also affect future requirements for water-based recreation, fish and wildlife management, and aesthetic considerations.

Consequently, new needs must be met as they develop—through changes in present use, water salvage, importation, desalination, weather modification, vegetation management, or some combination of these. Increased recirculation and reuse will intensify the already serious water quality situation and will require increased quality control measures. Potential imports of supplemental water supplies will require development of carefully formulated local organizations to handle the deliveries effectively, to assure their efficient use, and to provide for payment of costs involved.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Improvements of the increasingly inadequate water supply is the most acute development need of the Rio Grande Region. The problem calls for a three-way attack: (1) through completing new import facilities and programs, (2) through enhancing the usefulness of the present supply, and (3) through implementing practices and devices to increase the efficiency of present and future water use.

The San Juan-Chama Project, including Heron Reservoir, is now under construction and will be an important adjunct to the water supply. Groundwater pumpage in the Middle Rio Grande Valley is depleting the river's flows, and deliveries from this project will help to replenish the groundwater source. The weather modification program now in the research stage may also be considered a form of water import that could have immense benefits to the Region.

The usefulness of the available water can be significantly improved through increased storage and regulation, reduced losses due to nonbeneficial consumptive uses, and improved water quality control measures. Channelization, phreatophyte control, and vegetation manipulation have already proved effective in the Region and warrant continued emphasis.

Huge brackish groundwater supplies—estimated at 1,300,000 billion gallons (4,000 maf)—exist within the Region. Adaptation of desalting technology could increase this supply for an indefinite period and also provide aquifer capacity for induced recharge from flood waters. The brine disposal problem may be alleviated by geological studies revealing hydrologically closed basins for such disposal.

Water-use efficiency can be improved by better water management practices, reallocation of uses, industrial and municipal recirculation and reuse, and improved conveyance and distribution systems.

The problems of water supply and water rights are complicated, but many of those in the middle valley could be solved if the Middle Rio Grande Conservancy District were to act as supplier for all water uses including municipal, industrial, and irrigation. The bulk of the water rights belongs to the District. An analog model of the groundwater aquifer might facilitate the coordinated management of surface water and groundwater resources.

Because irrigation accounts for about 17 times the consumptive uses of all other purposes, small improvements in irrigation efficiency and small conversions from irrigation would release sizable water supplies for other uses. Irrigated acreage is expected to decrease in the major irrigated areas: Middle Rio Grande, Rio Grande, Fort Sumner, and Carlsbad Projects. In these areas higher economic returns can be attained by converting agricultural land to other uses. However, irrigation is expected to increase moderately in the Colorado-New Mexico part of the Region.

Continued efforts should be made at all levels of government to reduce flood damages in the Region by means of flood control structures, land treatment measures, and wise flood plain use. Projects under construction will help the situation; however, serious flood threats will still exist, and numerous other authorized or

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proposed projects should be constructed by 1980. It is expected that the flood plain management program authorized by the Flood Control Act of 1960, as amended, will help to bring about a reduction in flood damages in the future.

Water for recreation and fish and wildlife purposes will have to come from the limited supplies available. In this water-short area, supplies are inadequate for sewage effluent dilution, and extensive treatment of these effluents will therefore be required.

All of the emerging water problems previously mentioned require immediate attention if they are to be resolved by 1980. The State of Texas is presently engaged in a comprehensive planning program to assure development of its water resource for the benefit of the entire State. Early initiation of a Federal-State comprehensive planning study (type 1) is considered imperative for the orderly development of a strategy to meet the entire Region's water resources needs. This study would also identify alternative strategies to achieve full development of the Region's economic potential.

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CHAPTER 13

Upper Colorado Region

SUMMARY

The 113,500 square miles covered by the Upper Colorado Region include those areas of Arizona, Colorado, New Mexico, Wyoming, and Utah that drain into the Colorado River above Lee Ferry, Arizona, plus the Great Divide closed basin of Wyoming. The Region is one of extreme contrasts, with high, snow-covered mountains and plateaus in the north and dry deserts in the south. Some 2% of the total land base is used for irrigated cropland, and about 75% for grazing. In all, agricultural areas occupy more than 85% of the Region and contain most of the 317,000 inhabitants. About 15% of the land total is privately owned. The remainder is owned by the governments of respective States or by the Federal Government, or is included in Indian reservations. Mining and agriculture, particularly livestock raising, are the principal industries, although oil refining, lumbering, transportation, trade, tourism, recreation, and construction are growing in importance. The entire economy of the Region is dependent upon a limited water resource.

The high plateau of the Great Divide closed basin supports minor livestock operations and practically no other agricultural crops. Its meager water supply disappears from intermittent streams into sinks.

The Colorado River's long-term virgin flow at Lee Ferry is estimated to be 13.45 bgd (15.06 maf/yr). For the period 1930-64, the virgin flow amounted to only 11.6 bgd (13.0 maf/yr). Since there is a tremendous variation in the river's annual flow, the Region depends on streamflow regulation for a firm water supply. The partially constructed Colorado River Storage Project will, to a large extent, provide this necessary regulation. However, the recent years of extensive droughts have indicated that, even with these huge storage facilities, the firm potential supply is less than the 6.7 bgd (7.5 maf/yr) of the Region's apportionment under the Colorado River Compact.

The present consumption of water is estimated to be 2.59 bgd (2.9 maf/yr), of which about 0.52 bgd (0.58 maf/yr) are exported to the more heavily populated industrial centers of Colorado, New Mexico, Utah, and Wyoming in other Regions. By 2020, consumptive use is expected to be 5.1 bgd (5.7 maf/yr), including exports of 1.46 bgd (1.63 maf/yr). Among the representatives of the States that are party to the Region there is considerable disagreement about the projections. Some claim that the rate of future water resource development, as exemplified by the above figures is much too slow, and that by the end of the present century all of the Colorado River water supply apportioned to the Region will be consumptively used.

Although most of the present water resources development has been financed privately, it has included several large Federal projects. Most future development, however, will require public funds, careful coordination, and multipurpose use of the remaining water supply. The application of unified policies will definitely be needed, and State and Federal agencies should be able to provide needed guidance. The States should also press for completion of their individual water plans.

Problems with respect to the coordinated operation of water storage and power facilities of the Upper and Lower Colorado Regions should be resolved. Numerous agricultural areas are in need of supplemental water; ability to produce more forage crops would make possible better use of range lands. Parts of the population exist in a chronically depressed economic condition. Opportunities exist for increasing the land under irrigation. increasing mining exploration and development of oil shale and other mineral resources, expanding the utilization and processing of forest products, and expanding recreation development. A broadened economic base is

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needed to provide employment opportunities which would permit a population growth from the present one-third million to nearly one-half million in 1980, and over 1 million by 2020. In addition, increased exports of water would contribute to the economies of the populous industrial areas outside of but adjacent to the Region.

Rapid filling of the Colorado River Storage Project reservoirs (Lake Powell, Flaming Gorge, Curecanti, and Navajo) and attendant power operations for funding new participating irrigation projects will involve problems calling for early solution.

DESCRIPTION OF THE REGION

The Upper Colorado Region includes parts of Arizona, Colorado, New Mexico, Utah, and Wyoming and covers about 113,500 square miles —109,500 in the upper Colorado River drainage area and 3,960 in the Great Divide closed basin in Wyoming. It is bounded on the east and north by mountains forming the Continental Divide and on the west by other Rocky Mountain ranges; on the south it opens to the Lower Colorado Region at Lee Ferry in northern Arizona. Figure 6–13–1 depicts the Region and its subregions.

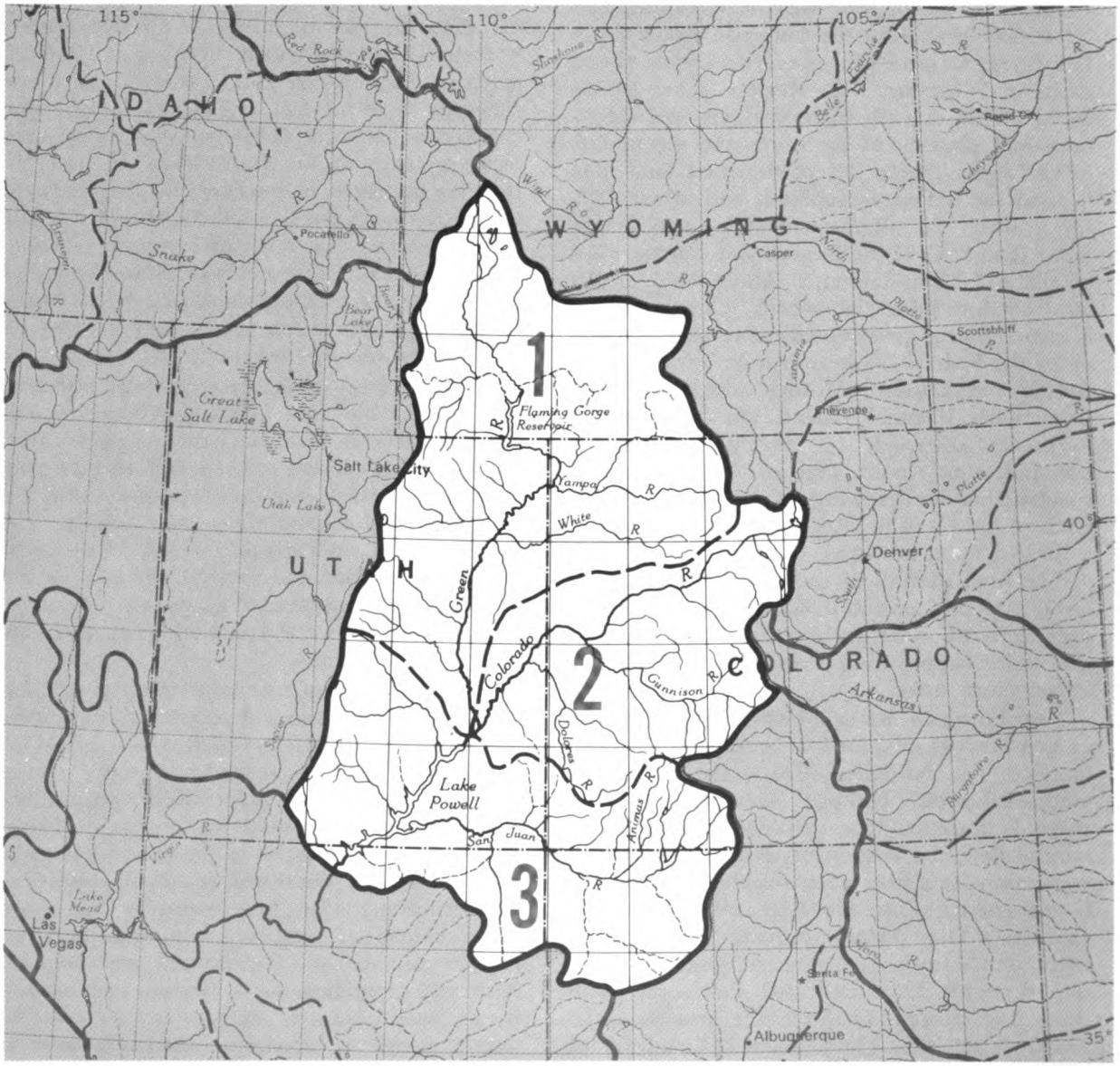

FIGURE 6–13–1.—*Map of the Upper Colorado Region.*

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The Colorado River rises in north-central Colorado among peaks more than 14,000 feet high, then meanders 640 river miles through the upper basin to Lee Ferry at elevation 3,100 feet msl. The Green River, its major tributary, rises in the Wind River Mountains of Wyoming and discharges into the Colorado River in southeastern Utah, 730 river miles from its origin and 220 river miles upstream from Lee Ferry. Other principal tributaries are the west-flowing Gunnison, Dolores, and San Juan Rivers. The Yampa and White Rivers from the east and the Duchesne from the west are the principal tributaries of the Green River.

The Region was divided into three subregions for analysis in this Assessment: (1) Green River: Green River and its tributaries and the Great Divide closed basin; (2) Upper Main Stem: Colorado River and its tributaries above Green River; and (3) San Juan-Colorado: San Juan River, the Colorado River between Green River and Lee Ferry, and their tributaries.

The wide range of climate is due to vast differences in altitude and latitude, and, to a lesser extent, to topographic features. Temperatures range from -52° at Kendall, Wyoming, to 109° at Shiprock, New Mexico. In the north, summers are short and warm, winters long and cold. In the south, summers are relatively longer; the winters are moderate at low altitudes, but colder temperatures prevail in the mountains.

In parts of western Colorado and New Mexico, where topographic features create favorable air drainage, frost damage is minimized, permitting cultivation of fruits and berries. Potatoes, sugar beets, vegetables, and small grains are grown in many parts of the Region. The dominant crops are alfalfa and other forage crops associated with the livestock industry.

Precipitation, mostly snow, is heaviest in the high east and north portions.

Settlement began in 1854 when Fort Supply, Wyoming, was established on the Mormon immigrant trail and water from Blacks Fork was diverted for irrigation. Breckenridge, Colorado, was settled in 1859 by miners from the older mining districts east of the Continental Divide. The less successful miners turned to farming, and settlement progressed from the mountains to the valleys, the advance being temporarily impeded by conflicts with the Indians who occupied the territory.

Most of the Uinta basin in Utah was designated as an Indian reservation in 1861. Lands unoccupied by Indians were opened to settlement in 1905. Nearly all areas of agricultural importance in the San Juan River basin in Colorado, New Mexico, and Arizona were once included in Indian reservations, and substantial portions are still Indian lands.

The Great Divide closed basin was avoided by the pioneers because it lacked water. Its favorable terrain was later used for sections of the first transcontinental railroad, and still later for the first coast-to-coast highway. A scattering of small settlements grew up near these facilities.

The Region is sparsely populated. In 1960, the population numbered about 317,000, and its average density was 2.8 persons per square mile compared with a national average of 60. The more than doubled growth for the period 1900-1960 was slightly faster than the national growth rate average, but much slower than the average for the Western States.

Some 80,000 people, or 25% of the regional total, made up the 1960 population of the seven largest towns. Farmington, New Mexico (the largest of the seven with close to 24,000 inhabitants), has recently expanded from an agricultural economy to become an important oil and gas center. The economies of Grand Junction (18,694), Montrose (5,044), Delta (3,832), and Durango (10,530), Colorado, are largely oriented toward irrigated agriculture. Mining and railroading are of importance to Durango, as well as to Rock Springs (10,371), Wyoming, and Price (6,800), Utah. On the other hand, only 200 people live in the Great Divide closed basin, of which about 110 are residents of Wamsutter, Wyoming.

Immediately east of the Region is the most densely populated part of Colorado, which includes Denver, Pueblo, Colorado Springs, and Fort Collins. Utah's heaviest population concentrations are immediately west of the Region in Ogden, Salt Lake City, and Provo. Other important nearby cities include Rawlins, Laramie, and Cheyenne, Wyoming; and Santa Fe, Los Alamos, and Albuquerque, New Mexico. Through transmountain diversions of water the Region serves municipalities, industry, and agriculture in many of these areas. Extensive increases are contemplated in these and other transmountain movements of water.

Mining, forest products, and agriculture, particularly livestock raising, are the principal industries of the Region. Oil refining, transportation, trade, tourism, recreation, and construction are growing in importance. Agricultural products are processed on a small scale. The

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Region's remoteness has retarded industrial development and exploitation of its abundant natural resources. However, many of its raw materials are used in important industrial centers such as Denver, Pueblo, Provo, and Salt Lake City.

Large coal fields are being worked extensively in several areas of the Region. Oil and gas are also produced, and the operation of pilot plants, to determine the best methods of extracting oil from shale, portends an important industry for the future. Since the conclusion of World War II, the Region has become the Nation's uranium mining and milling center.

Power-generating capacity, prior to the Colorado River Storage Project, totaled 120,000 kw, divided almost equally between hydroelectric and steam-electric plants. New hydroelectric installations under the storage project total 1,240,000 kw. In addition, about 3,100,000 kw of non-Federal steam-electric capacity have been or are being installed, and proposals for a substantial amount of additional capacity are under active consideration. A federally operated transmission grid system traverses the Region, providing interconnections with other systems, both private and Federal.

About 15% of the land base is privately owned; the remainder is owned by county, State, or Federal governments, or by Indians. National forests, parks, and monuments occupy 20% of the total lands. About three-fourths of the total is classed as grazing land and includes some grazing on forests and woodlands. Croplands, irrigated and dry-farmed, comprise only 3% of the total area. The Region contains about 6.15 million acres of irrigable land, of which about 1.44 million acres had been developed for irrigation by 1965.

Farming without irrigation is generally unsuccessful because rainfall is insufficient. In general, at elevations where rainfall is sufficient during the summer to grow crops without irrigation, the season is too short for most crops to mature.

THE WATER RESOURCE

The 1906-65 average virgin flow of the upper Colorado River drainage area, at Lee Ferry, Arizona, is estimated to be 13.45 bgd (15.06 maf/yr) (table 6–13–1). Because the virgin flow includes natural channel losses, the natural runoff of the Region is somewhat larger. The average annual natural runoff is estimated to be in excess of 13.7 bgd (15.3 maf).

From year to year there have been wide fluctuations in the virgin flow. Between 1896 and 1965 the virgin flow of the Colorado River at Lee Ferry varied from 21.4 bgd (24.0 maf) in 1917 to 5.03 bgd (5.64 maf) in 1934.

Most of the precipitation of the Region occurs as snowfall during fall, winter, and spring. As temperatures rise in the late spring and early summer, rapid snowmelt causes high streamflows. About 70% of the annual runoff occurs from April through July. Approximately 75% of the water yield of the Region comes from about 33% of the total land base; these areas are in forest and associated cover types or above timberline.

Groundwater in the Region is found in con-

TABLE 6–13–1.—*Annual virgin flow,*[1] *Upper Colorado Region*

Subregion	Drainage area	Average virgin flow		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1 [2]	48,700	4.95	2.13	4.95	3.16	2.67
2	26,500	6.06	4.80	6.06	3.65	2.96
3	38,300	2.44	1.34	2.25	1.38	1.17
Regional value	113,500	[3] 13.45	2.49	13.45	8.82	7.50

[1] At Lee Ferry, Arizona, for base period 1906-1965.
[2] Runoff from Great Divide closed basin considered negligible.
[3] Average annual natural runoff estimated to be about 13.7 bgd.

Note: Virgin flow proportioned among subregions on basis of average runoff indicated in "Water Resources of the Upper Colorado River Basin," Geological Survey Professional Paper 441, 1965.

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solidated rocks and alluvium. The consolidated rocks directly contribute water and sediment to the river system and also indirectly contribute water to the river system through the alluvium. The principal water-bearing rocks are sandstone and limestone which contain water of good chemical quality, but there are also large formations of highly soluble evaporites which contain saline water. The main stem of the Colorado River and the lower parts of the Green and San Juan Rivers are deeply entrenched in major water-bearing formations. In most places, the discharge of groundwater from the rocks to the streams has a significant effect on the chemical quality of the surface water only during periods of low streamflow.

The three subregions have quality-of-water records for the 1931-60 period at three gaging stations: Green River at Green River, Utah; Colorado River at Cisco, Utah; and San Juan River at Bluff, Utah. However, none of the records antedate the beginning of irrigation; consequently, water quality under natural runoff or virgin flow conditions must be estimated.

Of the total dissolved solids in the river system, very little is contributed by municipal or industrial users, and only about 10% by saline springs. Most of them derive from natural sources and from irrigated lands, about 1.4 million acres in recent years. The historical average total dissolved solids at Lee Ferry gaging station for the period 1931-60 was about 8.5 million tons per year with a concentration of about 550 ppm. Assuming that the historically irrigated lands contributed 2 tons of dissolved solids per acre, the total load under natural runoff conditions (without irrigation) for this period would have been about 5.7 million tons per year with a concentration of about 295 ppm. For the long-term period, the total load under natural runoff conditions would remain about 5.7 million tons per year, but, because the long-term natural runoff is higher, the concentration would have been about 275 ppm.

The waters of the three subregions vary considerably in their concentrations of dissolved solids. A major determinant of the chemical quality of each stream is the type of rocks that underlies each drainage basin. Thus, the headwaters close to the Continental Divide, underlain by rocks resistant to the solvent action of water, may contain less than 20 ppm of dissolved solids, whereas waters flowing over the more soluable Cretaceous and older rocks of some other parts of the watershed may contain about 2,000 ppm.

Fortunately, the large water-yielding areas are forested or covered with low vegetation and grass and contribute only minor amounts of dissolved solids. Large amounts, however, come from the vast lower, barren reaches of each subregion, which contain softer soluble rock formations and are continually eroded by smaller amounts of runoff.

A number of practices and situations produce water quality problems which may have implications for public health. These include disposal of uranium milling tailings and of liquid and solid waste; the presence of total dissolved solids in drinking water; the high levels of fluoride and arsenic in some of the Region's waters; and vector control problems in connection with impoundments and irrigation activities.

PRESENT WATER RESOURCES DEVELOPMENT—1965

A portion of the Region's share of surface water under the Colorado River Compact is used locally for domestic, industrial, power, municipal, irrigation, stock watering, fish and wildlife, and recreation purposes. Only a small amount of groundwater is being used. Other portions of the surface water are exported to adjoining Regions for similar uses. Estimates of the average water withdrawals and consumptive use in 1965 within the Upper Colorado Region are summarized in table 6–13–2.

Ninety-six storage reservoirs, each with a capacity greater than 326 million gallons (1,000 af) and having a combined capacity of about 11,500 billion gallons (35.2 maf), have been constructed in the Region. Of this capacity, 10,900 billion gallons 33.6 maf) are contained in four large reservoirs of the Colorado River Storage Project. The Project provides Compact deliveries at Lee Ferry; it also provides power generation, flood control, recreation, habitat for fish and wildlife, and, through participating irrigation projects, a variety of upstream uses.

A total of about 1.44 million acres were under irrigation in 1965, mostly by private enterprise. Federal projects, however, furnished water to about 93,000 acres of Indian lands and to about 270,000 acres of non-Indian lands, including some already irrigated lands which required supplemental water.

The water withdrawn by municipal supply systems served about 240,000 of the Region's population and was used for industrial, com-

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TABLE 6–13–2.—*Present water use, 1965, Upper Colorado Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture: Irrigation [5]	Agriculture: Livestock	Other [6]	Total
Water withdrawn								
1	1.0	18.0	10.5	5	1,460	5.4	117	1,617
2	1.9	27.9	23.4	6	1,700	3.6	418	2,181
3	2.8	14.2	6.3	9	720	2.2	63	817
Total [7]	6	60	40	20	3,880	11	598	4,615
From groundwater	(4)	(20)	(10)	—	—	(2)	—	(36)
Water consumed								
1	0.6	5.2	1.6	3	729	4.7	117	861
2	0.4	4.2	3.1	1	848	3.3	418	1,278
3	1.5	5.1	3.2	9	357	1.8	63	441
Total [7]	3	14	8	13	1,934	10	598	2,580

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 240,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by the industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling)
[5] Conveyance losses not included in consumption.
[6] Includes 96 mgd, 418 mgd, and 4 mgd exported from subregions 1, 2, and 3, respectively. Also includes net evaporation losses of 80 bgd from main storage reservoir areas.
[7] Rounded.

mercial, public, and domestic purposes. In addition, many industries supplied their own needs through their own facilities. The self-supplied water of steam-electric plants was used mostly for cooling purposes. Withdrawals for rural areas were used for domestic purposes in homes not served by public water supply systems and for livestock watering.

The Region exports 518 mgd (578,000 af/yr) to four other Regions as follows: Missouri Region (South Platte River), 372 mgd; Arkansas-White-Red Region (Arkansas River), 46 mgd; Rio Grande Region (San Luis Valley), 4 mgd; and Great Basin Region (Jordan River system), 93 mgd, and (Sevier River system), 3 mgd. In addition, the Colorado River itself serves the Lower Colorado and California Regions and Mexico.

Not included in table 6–13–2 are the instream uses of the Region's water supply. These can, for the most part, be discussed only qualitatively.

Hydroelectric power comprises an important use of the water resources of the Region. With the completion of the Colorado River Storage Project in the next few years, the installed capacity will be about 1,360,000 kw and about 15 bgd will pass through the plants. Most of the generation occurs at the Colorado River Storage Project reservoirs.

Use of the waters of streams, lakes, and reservoirs for preservation and enhancement of fish and wildlife resources and for public recreation is vital to the Region's economy.

Because the large storage facilities on the principal rivers effectively control most major floods, few areas experience serious flood damages. Occasionally, however, agricultural areas do suffer flood damages, and local flood prevention works of limited scope have been constructed by individuals and communities with aid from local, State, and Federal agencies.

ADEQUACY OF PRESENT DEVELOPMENT

The present level of development of the water and related land resources of the Region is generally adequate to meet present needs, but this does not mean that areas of maldistribution are nonexistent. The rate of development in the past, although sometimes affected to varying degrees by vagaries of financing and changing programs of government agencies, has usually been consonant with developing needs.

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The wide fluctuation in annual virgin flow and the tendency for years of low flow to occur in sequence made necessary the construction of large storage reservoirs to enable optimum use of the available water. Flow commitments at Lee Ferry, required by the Colorado River Compact, led to the planning and construction of the Colorado River Storage Project, which provides long-term carryover storage. However, even with this supplement, it is estimated that during extensive periods of subnormal flow the Region will not be able to obtain the full amount of water apportioned to it under the Colorado River Compact.

On the whole, the most pressing needs for water resource development have been met as they arose. (One exception is the need for rehabilitation of existing irrigation systems.) Some areas located in the upstream reaches above regulatory reservoirs suffer from seasonal water deficiencies; most of the lands in these areas are devoted to wet meadows, grass and legume, hay and pasture, or other forms of livestock forage and fodder production. Patterns of ranch operation and management have been developed that recognize the frequent water supply shortages.

Because the downstream agricultural areas are at lower altitudes, their characteristics and water needs differ considerably from those of the upstream areas. Frost-free periods are longer and seasonal temperatures higher (resulting in greater plant consumption of water) and effective precipitation during the growing season is less. During the late growing season, irrigation demands are frequently greater than available streamflows. The diversified crops are of high value. Thus the heavy economic loss associated with deficient water supplies justified development of projects for regulation of streamflows and adequate full-season water supplies. Water resource developments have been provided in nearly all of these areas or are currently being planned.

Water resource developments to meet municipal and industrial requirements are generally adequate. A few persisting localized problems are amenable to financial and engineering solutions that are available under a number of programs. However, insufficient water reserves will inhibit growth and development of some parts of the region; for example, a number of small communities need short-term water supply reserves, and in many cases the necessary financial resources are lacking.

The Upper Colorado Region has no large metropolitan areas. However, Denver, Colorado (Missouri Region), on the east, and Salt Lake City, Utah (Great Basin Region), on the west, both rapidly growing, now partially depend upon the Upper Colorado Region's water resources; two other Colorado cities, Colorado Springs (Arkansas-White-Red Region) and Aurora (Missouri Region) will soon begin drawing on them moderately. In adition, numerous projects for the export of water are either completed and in operation, or authorized and under construction. Among the larger of these are the Colorado-Big Thompson (Missouri Region), Fryingpan-Arkansas (Arkansas-White-Red-Region), San Juan-Chama (Rio Grande Region), and Strawberry and Central Utah (Great Basin Region) projects.

Existing water resource developments have contributed to waste dilution and the amelioration of troublesome sediment, salinity, and bioenvironmental problems. A few situations still exist, however, which produce water quality problems. In some areas irrigation water is applied to soils with inherent limitations; in others, the water available for domestic use is affected by groundwater containing excessive salts, alkalis, or total dissolved solids.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

For a long period of time, water resource development in the Region was directed toward rather specific problems and programs. The Colorado River Storage Project was the first regional attempt at unified, basinwide, comprehensive development. Recently, there has been increased emphasis on developing an integrated Federal-State water resources policy.

The States have developed local institutions and organizations, such as water conservancy districts, capable of complementing Federal activities in the water development field. These State and local activities are usually geared to specific types of development. The States are developing planning programs to supplement the national water resources program; these are being funded in part by grants under Title III of the Water Resources Planning Act of 1965. A type 1 comprehensive framework study is currently under way in the Region.

The several Indian reservations within the Region present problems for comprehensive regional water and related land resources management. Difficulties arise both from legal and

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institutional factors of the land's historical occupancy and from aspects of the special relationship between the Indian people and the Federal Government.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

Opportunities exist for enlarging the area of land under irrigation, increasing mining exploration and the development of oil shale and other mineral resources, expanding the use and processing of forest products, and developing recreation. A broadened economic base through development of new and expanded industries and associated service enterprises is needed to provide employment opportunities.

Projections of income, employment, population, and land-use are presented in table 6–13–3. The projections are based principally on past trends within the Region. In areas of limited water supply, for example, it is assumed that water will restrict future economic production to approximately the same degree as in the past. Some States in the Region believe the projections reflect an unreasonably slow rate of growth.

In addition to the projected increases of total irrigated land, supplemental water developments are projected for 153,000 acres by 1980 and an additional 101,000 acres by 2020.

The two factors which most directly affect estimates of future water requirements are population and irrigated land. Substantial areas of land are suitable for irrigation, but they are widely dispersed and constitute an undetermined number of project potentials. Many have been investigated and some are being currently considered for authorization. On the basis of these factors, projected withdrawal requirements and consumptive uses have been estimated and are shown in table 6–13–4.

The course of natural resource development will influence future water requirements. If oil shale and pulp and paper developments proceed on the scale predicted by many, future water requirements will increase significantly.

It is estimated that the net evaporation and salvage from the major regulatory reservoirs will total 500 mgd (560,000 af/yr) in the future. Transmountain diversions will total about 800 mgd (895,000 af/yr) in 1980 and about 1.46 bgd (1.63 maf/yr) in 2020. Depletions, including exports from the Region, will, therefore, total about 4.0 bgd (4.5 maf/yr) in 1980 and 5.1 bgd (5.7 maf/yr) in 2020.

Outdoor recreation is an important and growing activity for a large segment of the national

TABLE 6–13–3.—*Economic and agricultural projections, Upper Colorado Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	317	454	700	1,025
Per capita personal income	1954 dol.	1,897	2,775	4,325	7,075
Employment, total [2]	thou.	111	160	256	383
Agriculture	do.	16	8	6	6
Manufacturing	do.	5	7	10	12
Other commodity producing	do.	25	24	32	41
Distributive industries	do.	31	50	72	99
Service industries	do.	34	71	136	225
Land base	thou. ac.	65,008	65,008	65,008	65,008
Agricultural	do.	56,551	56,401	56,321	56,231
Cropland total [3]	do.	2,041	1,716	1,714	1,711
Used for crops	do.	1,729	1,446	1,563	1,683
Idle and fallow	do.	312	270	151	28
Pasture-permanent	do.	32,173	32,407	32,361	32,309
Forest and woodland	do.	22,337	22,278	22,246	22,211
Nonagricultural	do.	8,457	8,607	8,687	8,777
Irrigated land [4]	do.	[5] 1,370	1,800	2,000	2,000

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965 irrigated land amounted to 1,440 thousand acres.

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TABLE 6–13–4.—*Projected water requirements, Upper Colorado Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	6	10	10	10
Municipal (public-supplied)	60	120	160	240
Industrial (self-supplied)	40	200	1,000	1,500
Steam-electric power (fresh)	20	30	35	50
Agriculture:				
Irrigation	3,880	5,300	5,350	4,900
Livestock	11	15	20	25
Export	518	800	1,200	1,460
Evaporation [1]	80	500	500	500
Total	4,615	6,975	8,275	8,685
Consumptive use				
Rural Domestic	3	4	5	5
Municipal	14	30	35	50
Industrial	8	35	140	150
Steam-electric power (fresh)	13	17	20	35
Agriculture:				
Irrigation	1,934	2,600	2,880	2,880
Livestock	10	14	20	20
Export	518	800	1,200	1,460
Evaporation [1]	80	500	500	500
Total	2,580	4,000	4,800	5,100

[1] Net evaporation and salvage from main storage units.

population. Partly for this reason, recreation and associated services constitute a significant and rapidly growing part of the total regional economic activity, and are related closely to the use and conservation of both the water and the related lands. Present water development proposals would serve to relieve some of the shortages in recreation facilities. Studies of requirements, opportunities, and extent of recreation-oriented developments and their relation to the water resources of the Region, together with economic development potentials, are needed.

EMERGING WATER PROBLEMS

In this arid and semiarid area, optimum use of the vast land resources is dependent on the availability of water. Crop production without irrigation is possible in only a few areas. A stabilized and increased irrigation supply would permit a shift to more intensive types of farming in some sections, and thus provide agricultural opportunities for more people. The practical limit of water resources development for this purpose by private enterprise has been reached. Although many facilities have recently been constructed under the Colorado River Storage Project Act, many attendant community improvements must be undertaken before full utilization of the Region's water-oriented resources can be realized.

Some of the major emerging water problems of the Upper Colorado Region are stated briefly below.

In the past, stream pollution has been minor, although isolated instances have occurred. It is possible, however, that administration and enforcement of the Water Pollution Control Act, as amended, may become a problem for local, State, and Federal officials as well as for municipalities and industries.

The following matters are causing increasing concern among the States: the rapid utilization of potential water supply to its limit under existing practices and procedures; the authorized temporary utilization of upper basin compact-ap-

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portioned water in the lower basin with its attendant implications; the differences of opinions as to proper river management under the "law of the river"; and the implications of proposals involving weather modification, river channelization, phreatophyte control, and desalination.

Potential claims for unknown quantities of runoff from Federal and Indian lands could pose problems for future water resource development. In this semiarid Region, such claims could adversely affect other present and potential users of water.

Opinions differ very widely in the Colorado River basin regarding the magnitude of the water delivery burden, including conveyance losses, of the Mexican Water Treaty and its division between the upper and lower basins.

The financial feasibility of future water development programs in the Region may be jeopardized if the practice of diverting revenues from the Upper Colorado River Basin Fund continues. These revenues are being used to pay for the diminutions in generation of electric energy at Hoover Dam caused by the filling of Colorado River Storage Project reservoirs. The diversions from the Fund already amount to over $30 million, including accrued interest.

More specific, emerging problems are enumerated and explained briefly below.

There is a growing demand for transmountain diversion of water from the Upper Colorado Region to the four adjacent Regions—Missouri, Arkansas-White-Red, Rio Grande, and Great Basin. The potential intra- and interregional demands for water far exceed the amount physically available, even if the restrictions on use and downstream commitments imposed by the Colorado River Compact were excluded. This poses a difficult distribution problem for the States to solve in their respective State water plans.

Several existing projects provide adequate supplies for the intensive irrigation of farms in various parts of the Region. Additional projects need to be constructed, however, to supplement supplies for inadequately irrigated lands, permit more lands to be irrigated, and improve domestic water facilities.

Some problems involve land use. The inability to produce sufficient hay to winter-feed livestock has prevented optimum use of the fine rangelands of Wyoming, Colorado, and northern Utah. In southern Utah, New Mexico, and northeastern Arizona, where the mild climate allows a longer grazing season, lack of winter feed has forced range use for an excessive portion of the year, so that certain areas have been overgrazed. As a result, land has been eroded and natural resources have been destroyed.

Increases of regional population and economic activity will call for additional flood protection and flood plain management in urban and rural areas and along transportation routes.

Foremost among the present water problems are the sustained periods of drought with consequent low safe-water yields. No longer can the Region anticipate full use of 6.7 bgd (7.5 maf/yr) apportioned to it under the Colorado River Compact. Consumptive uses of Colorado River water in Colorado and New Mexico will approach their regional allotments under the Upper Colorado River Compact when authorized projects are constructed. This problem can be solved only by a major augmentation of the regional water supply. The need for streamflow augmentation has become more apparent in the light of authorized uses in the lower basin of water apportioned to the upper basin but presently not being used there. Utah and Wyoming are particularly concerned because of their large proportionate share in the water authorized in recent legislation for temporary use in the lower basin.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Planning studies authorized by the Colorado River Storage Project, supplemented by additional participating projects; programs of the Water Resources Council and its Member Agencies; and State and private water plans under current consideration should provide sufficient means to meet the Upper Colorado Region's 1980 water needs. Local, State, and Federal institutions should be able to provide the coordinated management necessary for the accomplishment of these programs.

Other development and management needs of paramount importance are directly related to the resolution of the major and specific emerging water problems enumerated earlier. Some solutions will require legislative action; others can be accomplished through administrative decisions. Still others are susceptible to an approach involving negotiation and arbitration among interested and affected parties.

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CHAPTER 14

Lower Colorado Region

SUMMARY

The Lower Colorado Region includes substantially all of Arizona and portions of New Mexico, Nevada, and Utah. Its climate ranges from desert to alpine. The economy is based on manufacturing, mining, tourism, irrigated farming, and livestock. The Region is sparsely settled, but the present population growth rate is one of the highest in the Nation. Much of this growth is occurring on lands previously developed for irrigation.

The water supply available for use in the Region is inadequate to meet the needs of the existing economy. Virtually all dependable surface water resources, exclusive of the mainstream of the Colorado River, are fully utilized, and groundwater resources are being depleted. At present, the Colorado River provides water for nearby irrigation, municipal, and industrial uses. It also serves similar uses in a substantial portion of the California Region and provides water for delivery to Mexico under the Treaty of 1944.

Water withdrawals in 1965 totaled about 6.9 bgd (7.7 maf/yr), greatly exceeding the replenishable supply. Surface water sources, including the Colorado River, provide about 2.8 bgd (3.1 maf/yr), groundwater resources, 4.1 bgd (4.6 maf/yr), and reclaiming sewage, about 57 mgd (64,000 af/yr). Estimates vary as to how much groundwater withdrawal is in excess of replenishment. The quantity used in this Assessment is 2.7 bgd (3.0 maf/yr).

The water-supply deficiency of the Region will increase in the future. Projections indicate that the 1965 population of 1.7 million will increase to about 7.2 million by 2020, with a consequent increase of about 2.0 bgd (2.2 maf/yr) in total water withdrawals. Meeting increased demands for irrigation would add substantially to these requirements.

Construction of recently authorized facilities to fully utilize the Arizona and Nevada entitlements of Colorado River water would reduce the regional deficiency. Other possibilities for increasing the usable water supply or its beneficial use include increased efficiency of use and reuse; wastewater reclamation; watershed management, including phreatophyte control; evaporation suppression; and weather modification. There is, however, no assured indication that such measures can meet any major portion of the increasing deficiencies. Very probably, the only solution—for both present and future water requirements—is augmentation from outside the Region through desalting of sea water or fresh water import.

In summary, the Region's groundwater storage is being exhausted to meet the increasing water demands. Unless it can be augmented from other sources, the repercussions on both the national and regional economies will be serious. Further, both the Nation and the Region would be adversely affected by the loss of the type of crops (for example, winter vegetables and citrus fruit) that are a regional specialty. To assure that the specialized agricultural production of the Lower Colorado Region's irrigated farming is sustained and increased may be highly desirable in view of the Nation's expected future food and fiber needs.

DESCRIPTION OF THE REGION

The Lower Colorado Region's area of approximately 134,000 square miles includes most of Arizona and parts of southeastern Nevada, southwestern Utah, and western New Mexico (fig. 6–14–1). Geographically, it includes all drainages into the Colorado River below Lee Ferry, Arizona, except those in California and Mexico; several closed basins in Arizona, Nevada, and New Mexico; and some drainage basins in southern Arizona that flow into Mexico.

Physiographically, the Region is comprised of (1) the basin and range province and (2) the plateau province. The first is a hot and arid area of lower elevations containing a series of

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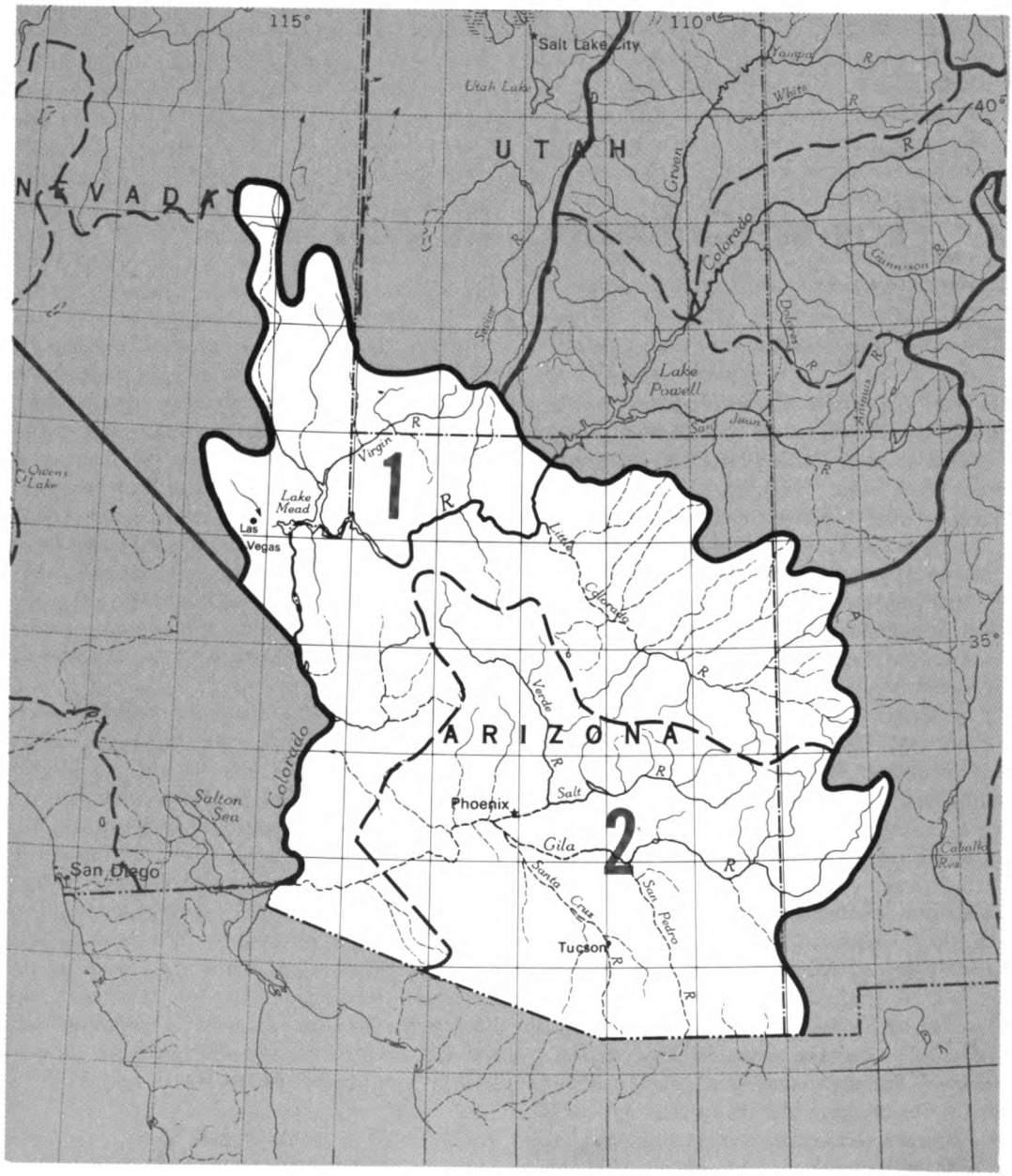

FIGURE 6–14–1.—*Map of the Lower Colorado Region.*

northwest-trending mountain ranges, intervening basins, and desert. The geographic dividing line between it and the plateau includes the Mogollon Rim, a spectacular escarpment traversing central Arizona, and a series of other minor escarpments running from the head of Lake Mead, impounded by Hoover Dam, in a southeasterly direction to the Continental Divide in western New Mexico. The plateau areas are at fairly level higher elevations with relatively moderate temperatures; in the main, they make up the north and northeastern portions of the Region.

Temperature, elevation, and land use vary widely. Annual precipitation—mostly rain except for some snow at the highest elevations—ranges from 3 inches at Yuma, Arizona, to more than 25 inches on Mt. Baldy in eastern Arizona. The annual frost-free period is 30 days or less in the higher mountains and 348 days at Yuma. The extremes of elevation include the 76 feet msl at the Mexican border 15 miles south of Yuma and the 12,670 feet on Humphreys Peak near Flagstaff, Arizona.

For purposes of this Assessment, the Region

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has been divided into two subregions: Colorado Main Stem (subregion 1) and Gila (subregion 2). For future studies, however, it is anticipated that additional subregions will be established. The Little Colorado River basin, in the northeastern part of subregion 1, comprises about 20% of the Region. It is primarily a livestock grazing area, although extensive stands of merchantable timber are available along the southern edge adjacent to the Mogollon Rim. Recreation is becoming an increasingly important source of income. The subregion's remaining portion encompasses the northern and western 33% of the Region. It is predominantly desert, but there are scattered farmlands along the Virgin, Muddy, Bill Williams, and Colorado Rivers.

Subregion 2 comprises the southern 47% of the Region. The area contains about 80% of the Region's irrigated lands, including those in central Arizona that are among the most productive in the world. In the 11th century, there was a flourishing Indian culture of approximately 170 cities and villages along the Salt and Gila Rivers. It is estimated that their canals, which were at least 150 miles long, could have irrigated 250,000 acres and supported over 100,000 people. Because these Indians mysteriously disappeared about 1300, they have been called Hohokam, "those who have gone."

The first known white man to enter the Region was Friar Marcos de Niza, a Spanish priest who came from Mexico City in 1539 looking for the legendary "Seven Cities of Cibola." Irrigation was first used by white settlers in the mid-1800's. Following the passage of the Reclamation Act of 1902, irrigation-based agriculture expanded rapidly in the Salt River Valley and at Yuma.

Expansion of urban areas began to pick up speed in the 1940's. So far, however, there is nothing that resembles the "strip cities" of the East and West Coasts. The Region's cities are characteristically at great distances from each other.

The present Phoenix metropolitan area, ranking first in size, developed on the basis of its irrigated farming into a diversified agricultural and industrial economy. Tucson, once a territorial trading post and stagecoach center, has become a very modern city, with mining, tourism, education, and defense-oriented industry as important factors in its economy. Las Vegas expanded its entertainment and tourist services into population-attracting industries. Flagstaff, originally a trading post, now thrives as a tourist and educational center. The population total of the Region increased nearly threefold from 1940 to 1960, reaching almost 1.5 million in 1960.

Total value of agricultural products—crops, livestock, livestock products, and forest products—increased from slightly under $300 million in 1940 to over $580 million in 1965. Nearly all cropland is irrigated, with 1.66 million acres developed for irrigation in 1965. An additional 30 million acres are considered suitable for irrigation. Major sources of agricultural income are cotton, feeder livestock, range livestock, vegetables, citrus, and melons.

Mining has long been one of the most important industries and still ranks among the top income producers. Over 50% of the Nation's copper is mined here. During the 20 years since 1945 the value of manufactured goods increased almost tenfold—reaching a total annual income of $1 billion in 1965. Most of the manufacturing industries are of the light, diversified, smokeless type which use a minimum amount of water.

In that same 20 years, tourism and recreation also increased nearly tenfold, reaching a total annual income value of about $460 million in 1965. A sizable portion of this recreation economy is water-oriented.

THE WATER RESOURCE

The water supply available for use in the Lower Colorado Region consists of three major components: natural runoff within the Region; a portion of the main stem Colorado River water released from the Upper Colorado Region at Glen Canyon Dam above Lee Ferry under the provisions of the Colorado River Compact; and groundwater reserves which have accumulated over geologic ages.

The average annual natural runoff within the Region is shown in table 6–14–1. Natural runoff is defined as being unaffected by man-made depletions; nevertheless, runoff does reflect changes in the character of watersheds resulting from the activities of man. The Region's annual runoff shows wide variations. In the desert areas, where it is directly dependent on rainfall, most of the flow occurs from July through September. In the mountainous areas, its peak generally occurs during the March through May snowmelt period.

In subregion 1, only a small portion of the runoff is directly diverted from the streams. The

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TABLE 6–14–1.—*Annual natural runoff, Lower Colorado Region*[1]

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	70,300	1.08	0.32	0.81	0.31	0.24
2	63,800	2.11	0.69	1.64	0.68	0.54
Regional value	134,100	3.19	0.50	2.51	1.07	0.85

[1] Excludes inflow from Upper Colorado Region.

Note: Base period 1897-1943, as given in *The Colorado River*, USDI, 1946.

major portion joins the Colorado River and is controlled by the mainstream reservoirs, principally Lake Mead. In subregion 2, nearly all of the runoff is diverted at Granite Reef Diversion Dam near the confluence of the Salt and Verde Rivers, and at Ashurst-Hayden Diversion Dam upstream from Florence, Arizona. Storage above these sites, totaling about 1,100 billion gallons (3.3 maf), substantially controls and regulates the runoff except for infrequent floodflows.

A portion of the flow of the Colorado River, regulated and depleted in the Upper Colorado Region, is available for use in the Lower Colorado Region. This flow also serves lands in the California Region and in Mexico. The 1906–65 average virgin flow of the river at the Compact point (Lee Ferry, Arizona) is estimated at 13.45 bgd (15.06 maf/yr). However, large variations in flow have occurred both annually and over long periods of years. In the past 35 years (1931–65), the estimated virgin flow at the compact point has averaged only 11.65 bgd (13.05 maf/yr) while in the preceding 25 years (1906–30) it averaged 15.96 bgd (17.88 maf/yr). Net depletions in the Upper Colorado Region were about 2.6 bgd (2.9 maf/yr) in 1965, resulting in an average annual available flow at Lee Ferry of about 10.9 bgd (12.2 maf/yr) under 1906–65 virgin flow conditions and 1965 development conditions.

Groundwater currently provides about 4.1 bgd (4.6 maf/yr) of the Region's total water withdrawal. Groundwater is being pumped at a rate that greatly exceeds the estimated recharge. This is most critical in the central Arizona area, where average groundwater depths are increasing at an annual rate of 10 feet and in excess of 20 feet in some localities. Estimates of the amount of groundwater mining have ranged from 1.5 to 3.6 bgd (1.7 to 4.0 maf/yr), and detailed studies are under way to better define the extent, storage, specific yield, and annual recharge of the significant groundwater basins. Excessive pumpage is lowering levels in some areas faster than the rate of travel of recharging waters. Thus, the downward percolating waters remain in transit through the dewatered zone and are therefore essentially unavailable for use as long as the pumpage so greatly exceeds the rate of recharge. For this Assessment, it was estimated that total pumpage in excess of recharge is 2.7 bgd (3.0 maf/yr).

The quality of surface water is acceptable for most agricultural, municipal, and industrial uses. However, further development of upstream areas, particularly on the Colorado River, will contribute to the degradation of water quality for downstream uses. The quality of groundwater is dependent upon the degree of reuse and the geologic source, and is extremely variable throughout the Region. As reuse increases and levels continue to fall, quality is expected to decline accordingly.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The Region's water resources are utilized primarily for irrigation. Minor amounts are used consumptively for municipal, industrial, steam-electric power, livestock watering, fish and wildlife, and recreation purposes. Consumption is influenced significantly by climate; more than 90% of the total beneficial consumptive use occurs in semiarid to arid areas with relatively high average temperatures.

The Lower Colorado Region withdrew 6.9 bgd (7.7 maf) during 1965, of which 6.4 bgd (7.2 maf) was for irrigation use. About 3.5 bgd

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(3.9 maf), or 50% of the total withdrawal, was consumed. Some of the remainder constitutes return flows and groundwater recharge; however, an undetermined amount of irrigation conveyance loss is irrecoverable. Municipal, industrial, and steam-electric power withdrawals in 1965 totaled 0.5 bgd (0.6 maf), and their consumptive use was 0.3 bgd (0.3 maf). This represents 7% and 8%, respectively, of the Region's withdrawals and consumption (table 6–14–2).

Use of the waters of streams, lakes, and reservoirs for preservation and enhancement of fish and wildlife resources and recreation is important to the Region's tourist and recreation industry. Over 300,000 fishing licenses were sold in 1966. Though it is recognized that there is a consumptive use of water for fish and wildlife purposes, an evaluation of this use is difficult from available data.

ADEQUACY OF PRESENT DEVELOPMENT

The Region's water resources—both surface and ground—are highly developed. The groundwater resource is actually overdeveloped; about 60% of withdrawals are from this source. A critical annual overdraft threatens to destroy the usefulness of this valuable resource—if not the resource itself. Some lands in central Arizona that were developed for irrigation have already gone out of production because of deficient water supplies. (These lands are not herein reflected in water deficiency figures, but they remain evidence of the problem's imminence and gravity.)

In subregion 1, there are many small reservoirs at high elevations which develop flows of Colorado River tributaries for localized use. Since flows originating in the subregion are tributary to the Colorado River, the major main stem reservoirs capture almost all of these flows and return flows. In subregion 2, present developments conserve substantially the entire surface flows of the Gila River system for use within the subregion. However, additional storage on the Salt, Verde, Santa Cruz, San Pedro, and Gila Rivers could provide some additional water for beneficial use in local areas by regulation of major floodflows.

As pointed out in the next section, a number of documents affect the utilization of the Colorado River. One of these—the Colorado River Compact—requires, among other things, that the States of the Upper Division (Colorado, New Mexico, Utah, and Wyoming) will not cause the flow of the river at Lee Ferry (a point near the

TABLE 6–14–2.—*Present water use, 1965, Lower Colorado Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
Water withdrawn							
1	3	77	30	2	1,800	4	1,916
2	3	265	110	8	4,600	11	4,997
Total	6	342	140	10	6,400	15	6,913
From:							
Groundwater	(5)	(250)	(115)	(7)	(3,760)	(10)	(4,147)
Wastewater	—	—	—	—	(57)	—	(57)
Water consumed							
1	3	43	15	2	1,050	3	1,116
2	2	160	35	6	2,120	9	2,332
Total	5	203	50	8	3,170	12	3,448

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 1,735,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.

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Arizona-Utah border) to be depleted below an aggregate of 75,000,000 acre-feet (24,400 billion gallons) for any period of 10 consecutive years. In very general terms, an average of 6.7 bgd (7.5 maf/yr) of surface flow is required to be delivered at Lee Ferry. For the near future, these releases will exceed that amount for legal and physical reasons.

Moreover, a treaty consummated in 1944 guarantees Mexico 1.34 bgd (1.5 maf/yr), with provisions for increase when surpluses are available and for reductions in times of extreme drought. The States of the Colorado River basin disagree as to the meaning of the Compact with regard to the Upper Division obligation to supply a portion of the Mexican Treaty water in addition to the 7.5 maf/yr.

In 1952, Arizona brought suit in the Supreme Court against California to establish the States' respective entitlements of water from the Colorado River. The Supreme Court Decree of March 9, 1964, provides, among other items, that, if the first 6.70 bgd (7.5 maf/yr) of mainstream water below Lee Ferry is available for release for annual consumptive use within the United States, there shall be apportioned 2.50 bgd (2.8 maf) to Arizona, 3.93 bgd (4.4 maf) to California, and 0.27 bgd (0.3 maf) to Nevada.

In 1965, use in California was about 4.6 bgd (5.1 maf), in Arizona about 1.0 bgd (1.1 maf), and in Nevada about 20 mgd (22,000 af) from the main stem of the Colorado River, and deliveries to Mexico were about 1.5 bgd (1.7 maf).

In view of the critical overdraft of groundwater in central Arizona, efforts have been under way for many years to obtain authorization of a Federal reclamation project to convey Arizona's unused entitlement of Colorado River water to areas of need. This project, the Central Arizona Project, was recently authorized in the Colorado River Basin Project Act (PL 90-537). The Southern Nevada Water Project, upon which construction is starting, will ultimately develop the major portion of Nevada's entitlement. Recently completed storage facilities at the Senator Wash Reservoir in southern California will enable the deliveries to Mexico to be more closely controlled, and deliveries much in excess of treaty requirements will be held to a minimum. When the authorized diversion works of the Central Arizona Project are constructed, Arizona will be able to develop its entitlement and the Lower Colorado Region will obtain additional water from that source (the California Region will, however, face reductions in its present uses). The construction of the Central Arizona Project will mitigate somewhat the present critical overdraft of the groundwater basins of the Phoenix and Tucson areas by supplying an average of 1.1 bgd (1.2 maf/yr) of Colorado River water for both municipal and irrigation uses. The project will also provide four additional reservoirs to more completely control the tributaries in the Gila River basin.

Efforts to augment existing water supplies are having variable measures of success. Treated sewage effluent is used for the irrigation of certain crops and golf courses. Efforts to increase runoff through treatment of watershed lands and manipulation of vegetation have shown signs of being effective. Evaporation suppression on reservoirs and stock ponds has been attempted with somewhat less success. Phreatophytes along rivers are being removed, and there are additional opportunities in this regard. Impervious lining of irrigation canals has been proceeding rapidly, and on-farm irrigation efficiencies are being increased through improved water management practices. Some brackish water is being desalted in local areas for municipal uses.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

The utilization of the waters of the Colorado River is governed by a series of documents collectively known as the "Law of the River." Among the documents are the Colorado River Compact; the Boulder Canyon Project Act; the Mexican Water Treaty; the 1963 decision and 1964 decree of the Supreme Court in the case of *Arizona v. California, et al.;* numerous contracts between users and the Secretary of the Interior; various agreements among water users in the Colorado River basin; and now the Colorado River Basin Project Act. A full and complete explanation of any of the components of the Law of the River is beyond the scope of this Assessment, but the general import of some of them can be briefly stated as follows: The Colorado River Compact divides waters of the Colorado River between the upper and lower basins; the Boulder Canyon Project Act, among other things, makes provision for use of the waters of the river within the lower basin; the Mexican Water Treaty provides for delivery of certain waters to Mexico; the 1963 decision and 1964 decree of the Supreme Court in the case of *Arizona v. California, et al.,* interprets the Boul-

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der Canyon Project Act; and the Colorado River Basin Project Act, among other things, makes additional provision for use of the waters of the river within the lower basin and provides guidelines for operation of existing storage reservoirs on the river.

The States of the Region follow the appropriation doctrine of water rights for surface water, and, except for Arizona, generally for groundwater. The current Arizona code restricts expansion of pumping facilities in critical areas, but does not limit the pumping rate as long as the owner's actions conform to the principle of reasonable use. Heavy overpumping persists in the critical areas.

The Region also faces numerous other institutional problems. Rights to water originating on Federal or Indian lands are in question. Restrictions on the drilling of wells in critical groundwater areas prevent new irrigation development. As an example of competing uses, recreation and fish and wildlife developments compete with other uses for the available water supply.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The record economic growth experienced in the Lower Colorado Region between 1945 and 1965 is expected to continue into the future at rates well above the national average. Growth will be induced through development and utilization of the Region's natural resources and through further exploitation of the favorable climate. Table 6–14–3 presents a summary of projected regional population and economic activity.

While population in the Region is expected to increase over 300% from 1965 to 2020, water withdrawal and consumptive uses will increase only about 29% and 36%, respectively (table 6–14–4). Municipal, industrial, and steam-electric power withdrawals will increase from 1.5 bgd in 1965 to 2.3 bgd in 2020, and in so doing will become a major demand, accounting for about 26% of the total annual requirement.

Irrigation withdrawals are estimated to increase from 6.4 bgd in 1965 to 7.7 bgd in 1980 and then to decline to 6.5 bgd in 2020. This subsequent reduction in withdrawals will result in very little change in water consumption. The combined effect of this and the increase in other uses will represent a drop from over 90% to about 70% of the Region's total annual water requirements. The projections assume very little change in the amount of irrigated land in the Region, except on Indian lands, and the decrease in demand results from projections of increased farm and conveyance efficiencies.

TABLE 6–14–3.—*Economic and agricultural projections, Lower Colorado Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	1,480	3,038	4,768	7,194
Per capita personal income	1954 dol.	1,736	2,950	4,800	7,675
Employment, total [2]	thou.	525	1,159	1,827	2,766
Agriculture	do.	40	33	30	30
Manufacturing	do.	62	172	310	500
Other commodity producing	do.	91	152	198	264
Distributive industries	do.	141	318	455	646
Service industries	do.	192	484	833	1,324
Land base	thou. ac.	98,784	98,784	98,784	98,784
Agricultural	do.	88,191	87,791	87,311	86,831
Cropland total [3]	do.	1,806	1,771	1,761	1,751
Used for crops	do.	1,416	1,524	1,555	1,688
Idle and fallow	do.	390	247	206	63
Pasture-permanent	do.	57,783	57,548	57,233	56,918
Forest and woodland	do.	28,602	28,472	28,317	28,162
Nonagricultural	do.	10,593	10,993	11,473	11,953
Irrigated land [4]	do.	[5] 1,520	1,750	1,800	1,800

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture.
[5] In 1965 lands developed for irrigation amounted to about 1,660 thousand acres. Of this amount about 1,460 thousand acres were considered productive irrigated lands and about 1,220 thousand acres were actually served with water. Considerably more land could be irrigated if more water were available.

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TABLE 6–14–4.—*Projected water requirements, Lower Colorado Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	6	7	8	9
Municipal (public-supplied)	342	520	860	1,400
Industrial (self-supplied)	140	210	280	340
Steam-electric power (fresh)	10	40	250	600
Agriculture:				
Irrigation	6,400	7,700	7,000	6,500
Livestock	15	20	30	40
Total	6,913	8,497	8,428	8,889
Consumptive use				
Rural domestic	5	5	5	5
Municipal	203	310	515	840
Industrial	50	80	130	200
Steam-electric power (fresh)	8	35	210	470
Agriculture:				
Irrigation	3,170	3,630	3,760	3,760
Livestock	12	15	25	35
Total	3,448	4,075	4,645	5,310

Other projections developed by local, State, and other responsible groups have produced substantially different values and corresponding differences in projected water requirements.

EMERGING WATER PROBLEMS

The Lower Colorado Region has experienced a population growth rate over the past 25 years which is unparalleled in the Nation. The basis for the growth—migration of industries and individuals attracted by the climate and other environmental aspects of the area—continues to exist. Aside from the imminent water shortage, there appears to be no reason why explosive population growth should not continue.

Projections indicate that the 1960 population and employment will increase about 4 times by 2020. An increase of this magnitude will place tremendous demands upon the Region's already overtaxed water resources.

Increasing municipal and industrial water uses will compete with agricultural uses for the increasingly scarce supply. About 20% of the 1965 income of the Region was received directly from agriculture, with about half of this coming from cultivation of irrigated farmlands. Agriculture has been historically a mainstay of the Region's economic growth and is vital to the stability of the present economy.

The amount of available water to satisfy the Region's entitlement to Colorado River water is based upon a number of conditions. To estimate the quantities of water available, assumptions were made regarding the rate of development on the River and also future river regulation procedures. On the basis of these assumptions, water available to the Lower Colorado and California Regions from the Colorado River have been projected (table 6–14–5). These projections indicate that the water available to the two Regions will decrease from 7.0 bgd (7.8 maf/yr) in 1980 to 6.3 bgd (7.0 maf/yr) in 2020. Other estimates have been prepared by the States of the Colorado Regions. One basic disagreement concerns the dependable virgin flow at Lee Ferry which representatives of some States consider to be lower than that used in this chapter.

Groundwater overdraft cannot continue at its present level. Increased pumping costs are making water from some aquifers prohibitively expensive for agricultural use, and water from others is of unsuitable quality at the greater depths. In some aquifers the storage has already been exhausted.

The continued and accelerated elimination of

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TABLE 6–14–5.—*Projected water available from the Colorado River,*[1] *Lower Colorado Region*

(Billion gallons per day)

Item	Level of development			
	1965	1980	2000	2020
Upper Colorado Region:				
Average virgin flow[2]	13.5	13.5	13.5	13.5
Regional consumption	2.6	4.0	4.8	5.1
Glen Canyon Dam operation:[3]				
Regulated release	(9.7)	(8.3)	(7.7)	(7.5)
Spills	(1.2)	(1.1)	(1.0)	(0.9)
Inflow to Lower Colorado Region	10.9	9.4	8.7	8.4
Net gain to Lake Mead	0.8	0.7	0.7	0.7
Lake Mead evaporation	0.8	0.8	0.8	0.8
Hoover Dam operation:				
Regulated release[4]	(10.0)	(8.8)	(8.4)	(8.1)
Spills	(0.9)	(0.5)	(0.2)	(0.2)
Net loss below Lake Mead	0.6	0.5	0.5	0.5
Available to Lower Colorado and California Regions[5]	5.6	7.0	6.6	6.3
Outflow from Lower Colorado Region	[6]4.7	1.8	1.5	1.5
Mexican Treaty deliveries	1.5	1.3	1.3	1.3
Flow to Gulf of California[7]	3.2	0.5	0.2	0.2

[1] Based on simulated operation studies for the four levels of development shown, with each utilizing the historic trace of annual virgin flows for the period 1906-1965. Figures represent average quantities of water over the simulated operation period, individual years vary significantly. (Values rounded.)

[2] Period 1906-1965. Virgin flow 11.6 bgd in period 1931-1965.

[3] Includes regulation by other CRSP reservoirs.

[4] Includes diversions from Lake Mead.

[5] Asumes construction of CAP before 1980

[6] Actual outflow for period 1951-1965 was 3.1 bgd and for period 1961-1965 was 1.6 bgd.

[7] Consists only of system spills by 1980.

irrigated agriculture will have grave implications for both the Region and the Nation. Within the Region, the rapid loss of a major segment of the economy will result in severe readjustment problems; as has been shown in other sections of the Nation, people and economies do not adjust readily to major changes even though alternative opportunities are available. In addition, the loss of the Region's specialized agricultural products—types of crops that are already being imported in quantity—would be felt nationwide.

Problems of water quality are also emerging in the Region, and will be of increasing concern as developments in the Upper Colorado Region occur. A major problem has already developed in regard to deliveries of water to Mexico. Further quality degradation of the Region's water supply will occur with increased intensity of regional water use and reuse. Minimization of degradation without unreasonably restricting beneficial uses is mandatory.

It is apparent that further development of the Region's water resources cannot cope with all of the emerging problems. The only solution appears to be augmentation of the supply; weather modification, desalination, and importation from other Regions have been suggested as potential means of accomplishing this. In any case, feasible means of some kind must be developed and implemented at the earliest date possible if a major crisis is to be averted.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

The present planning and other efforts of Federal and State agencies to initiate construction of facilities whereby the Region could utilize Arizona's and Nevada's unused apportionment of Colorado River water will reduce the deficiencies somewhat. However, this water would satisfy less than 50% of present deficiencies and would not provide for future growth. The consideration of present and future water resource problems of the Pacific Southwest and possible alternative programs for their solution will be facilitated by the type 1 comprehensive framework studies currently under way.

Development Needs

The construction of authorized facilities to utilize Arizona's unused apportionment of Colorado River water are critically needed. The Salt,

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Verde, Santa Cruz, San Pedro, and Gila Rivers, as well as some of their tributaries, are subject to floods resulting from summer storms and winter runoff. Storage is needed to conserve these flood waters for beneficial use and to provide flood protection. The multipurpose conveyance, storage, and channelization features of the authorized Central Arizona Project will help to fulfill these needs.

Because of its recent very rapid population increase, the Las Vegas area needs additional water immediately, as well as provision for future expansion. The first stage of the authorized Southern Nevada Water Project will satisfy the immediate requirement by construction of facilities with a capacity of 12 mgd (134,000 af/yr).

In western New Mexico, regulation of flows of the upper Gila River is needed to provide for irrigation, municipal, and industrial uses and for the enhancement of fish and wildlife and recreation. Construction of Hooker Dam or suitable alternative, a feature of the Central Arizona Project, would accomplish this. The authorized Dixie Project on the Virgin River will serve water needs in the southwestern Utah area.

Small watershed projects and major flood protection works can reduce floodwater damage and make possible the orderly release of floodwater for beneficial uses. Several such flood control projects have been constructed, many more are authorized, and still others will be constructed prior to 1980. Considerable development of reservoir and stream shoreline areas and of lake and stream fisheries is needed to accommodate present and 1980 recreation and fish and wildlife demands.

Since municipalities and industries will be withdrawing an increasingly larger part of the total water used, reclamation of their wastewaters can provide an increasingly significant supplement to the usable water supply. Additional research and development in this area should be undertaken. And other means of augmenting the water supply of the Region—such as phreatophyte control, channelization, desalination, manipulation of vegetative cover, and weather modification—must be accelerated.

Management Needs

Plans to control water quality are being formulated by various governmental bodies within the Region. As municipal and industrial uses become a larger part of the total uses, factors of quality will become more important. Standards must be continuously reviewed and updated to allow reclaimed wastewaters to supplement local water supplies.

New irrigation methods and equipment to control evaporation and percolation will reduce not only these direct losses and other non-beneficial consumptive use, but also salt buildup, with attendant reduction in the need for leaching water. A departure from the open ditch or flooding method is indicated.

The current pumping rate of groundwater basins in the central Arizona and southern Nevada areas exceeds estimated natural recharge. Introduction of additional Colorado River water will permit a reduction in the overdraft, but regulations or economic incentives are needed to reduce pumping rates.

At present, Federal and State agencies employ different bases for their respective measurements of water availability and use. To insure the consistency of all water resource data, standard measurement criteria should be established.

The ongoing type 1 framework study should provide guidance in these regards.

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CHAPTER 15

Great Basin Region

SUMMARY

The Great Basin Region has an area of about 137,000 square miles. About 132,100 square miles are in Utah and Nevada, and 4,900 in Idaho and Wyoming. Much of the area is desert; only on the eastern and western borders of the Region and in the Humboldt River basin is the water supply adequate to support a thriving economy. The mountains adjacent to these areas produce an estimated 80% of the Region's total runoff.

Agriculture and mining have traditionally been principal sources of income and are still important to the economy of the Region. In recent years manufacturing, transportation, tourism, and service industries have increased in importance.

In 1960, the population of the Region was about 970,000, and projections indicate an increase to 1.8 million in 1980; 2.8 million in 2000; and 4.3 million in 2020. This projected growth rate exceeds the national growth rate. The regional growth rate of per capita personal income is expected to be even greater than that of population.

Inadequate water supply in many parts of the Region has limited economic growth, particularly in agriculture and related industries. Generally, water supplies have been adequate in areas served by mountain streams during the spring snowmelt runoff period, April through June. In most years, water flows into the terminal lakes. Storage facilities are needed to conserve stream runoff and better distribute the supply throughout the year; in recent years, some storage facilities have been constructed, and studies are now under way on others. Also under way are several watershed protection projects that will maintain and improve water quality and control sediment.

In addition to surface supplies, the Region has 230 known groundwater basins, some 150 of which contain substantial water reserves that are only slightly developed. The recharge rate in most of them is low, and full utilization of the resources will result in a continual lowering of groundwater levels. Withdrawals are governed by statutes of the various States.

The use of water for irrigation is expected to remain essentially unchanged to 2020. However, increased irrigation efficiency is expected to allow use of existing supplies on 13% more land by then. On the other hand, domestic and industrial water requirements are expected to increase nearly fourfold from 1960 to 2020. With proper development and management of the water available to the Region, including authorized imports and anticipated authorizations for already-identified developments, it is estimated that sufficient water will be available to meet demands in the more rapidly growing areas until about 2000. In certain areas, however, significant water shortages will occur before this date. After 2000, additional water imports will be needed to sustain the projected economic growth of the Region.

The water resources of the Region will be confronted with a growing demand for water for many uses. With the population burgeoning, developments for municipal, industrial, and recreational uses will almost certainly divert some water from agriculture. Population centers will further concentrate on the Region's eastern and western boundaries where the primary water sources are located.

DESCRIPTION OF THE REGION

The Great Basin lies between the Wasatch Range in Utah and the Sierra Nevadas in California. From north to south, it extends between the Malheur closed basin in Oregon to the Mojave Desert in California. For purposes of this Assessment, those parts of the basin in Oregon and California are excluded. The Region's area of 137,000 square miles includes 88,300 (nearly two-thirds) in Nevada, 43,800 in Utah, 3,400 in Idaho, and 1,500 in Wyoming (fig. 6–15–1).

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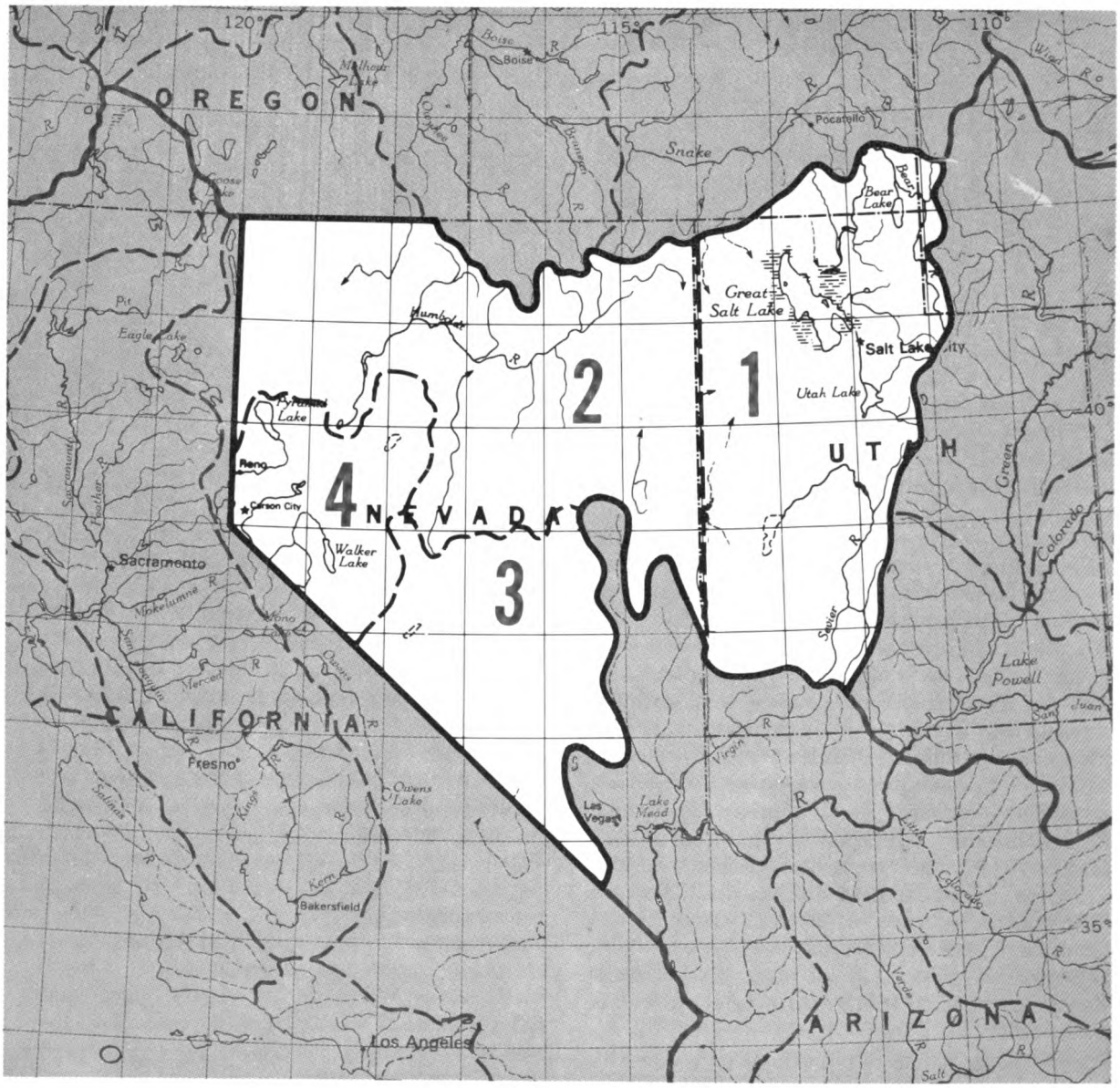

FIGURE 6–15–1.—*Map of the Great Basin Region.*

Geographically, the Great Basin is characterized by a series of desert valleys separated by north-south-oriented mountain ranges. This parallelism of mountain chains is a physiographic feature peculiar to the Great Basin. Much of the Region was once covered by prehistoric Lake Bonneville and Lake Lahontan. The streams terminate in lakes or sinks with no outlet to the sea. Elevations range from about 2,000 feet in southern Nevada to over 12,000 feet in the higher mountain ranges. Annual precipitation ranges from less than 4 inches in the desert areas to 50 inches or more in the high mountains. In much of the Region the average annual growing season lasts several months but in the mountains is less than 30 days.

Some of the West's first settlements sprang up in the Great Basin. Mormon communities based on irrigation agriculture in Utah, Idaho, Wyoming, and the Comstock mining camps of western Nevada set the stage for growth from 1847 to 1890. The growth rate during this period exceeded that of Pacific coastal areas.

Population is currently about 1,155,000, having tripled since 1940. Nevada's growth rate now exceeds that of all other States, and Utah's

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exceeds the national average. Most of the population resides along the eastern and western margins of the Region.

Mining, manufacturing, agriculture, services and tourism are major economic activities. Mining declined in importance after World War I, surged during World War II, and has a promising future once again because of the growing demand for minerals, rising mineral prices, and technological advances in ore processing. The Region contains about 7.4 million acres of irrigable land, of which 1.86 million acres were irrigated in 1965. Major agricultural products are cattle, sheep, dairy products, poultry, hay, wheat, sugar beets, fruits, and truck garden produce. Tourism with its related service industries has expanded manyfold in the past decade, and its value is expected to double again by 1975.

THE WATER RESOURCE

The availability of water varies widely throughout the Region. Natural runoff is greatest in the high mountains near the eastern and western margins; at least 80% of it has its source in these higher watersheds. Year-round runoff from mountain watersheds and water pumped from groundwater basins have supplied the water for industrial development. In the desert areas, runoff is characteristically low and the streams are often dry except for short periods following heavy precipitation.

Average annual natural runoff for the Region and its subregions is shown in table 6–15–1. This table does not include natural runoff from California of about 960 mgd (1.1 maf/yr) or from Oregon of about 18 mgd (20,000 af/yr). In addition, about 96 mgd (108,000 af/yr) is imported from the Upper Colorado Region to the eastern portion of the Region.

The maximum annual runoff has been about twice the average, and the minimum about half of the average. The extremes in streamflow are due largely to variations in precipitation, but variations in temperature, vegetation, geology, and topography are also influential, since they affect infiltration, evaporation, and flow rates. Nearly half the annual runoff, largely from melting snow, occurs from April through June. Natural streamflows diminish drastically in July and August.

Of the 230 known groundwater basins within the Region, about 150 contain large and underdeveloped water reserves. Due to the arid climate, the average annual recharge of many of these basins is relatively small and full utilization of the resources will necessitate groundwater mining. Availability and quality of the water resources in many of the basins is unknown.

In general, surface water from the mountain streams is of excellent quality, suitable for all irrigation and industrial uses and, with a minimum of treatment, for domestic use. Quality deteriorates downstream, however, as return flows and poorer quality flows enter the streams. Deterioration in some lakes and streams is attributable to increasing urbanization.

All of the streams in the Region terminate in closed basins, some of which contain permanent lakes. Among these are Pyramid and Walker Lakes in Nevada, and the Great Salt Lake in Utah. Salts have been concentrated in the lakes by evaporation over a period of many years. Although the waters of Pyramid and Walker Lakes still support a substantial fresh water fishery, the salt content of the Great Salt Lake is now about 25% by weight as compared with 3.5% for the oceans.

TABLE 6–15–1.—*Annual natural runoff, Great Basin Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	48,700	3.60	1.55	3.59	2.11	1.73
2	48,100	1.24	.54	1.10	.34	.22
3	24,100	.12	.10	.10	.02	.01
4	16,100	.93	1.21	.88	.35	.25
Regional value	137,000	5.89	.90	5.82	3.12	2.46

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PRESENT WATER RESOURCES DEVELOPMENT—1965

Most of the water use in the Region is for irrigation; other uses, although essential to the regional economy, are relatively minor. Present withdrawals and consumption are discussed below and summarized in table 6–15–2.

Water for domestic purposes in homes not served by public water supply systems comes mainly from groundwater sources. Municipal water is provided by public supply systems for domestic, public, commercial, and industrial purposes. These systems presently serve a municipal population of about 957,000, resulting in a rate of withdrawal of 285 gcd, among the highest in the Nation. Mining, related manufacturing, and steam-electric power generation are the principal users of self-supplied industrial water.

The Region has about 1.86 million acres of irrigated land. Groundwater is the primary source of supply for about 460,000 acres. Total withdrawal for irrigation is about 4.6 bgd (5.1 maf/yr), and 2.1 bgd (2.3 maf/yr) is consumed. This represents about 90% of all regional withdrawals and 93% of the consumption. Managed waterfowl habitat represents nearly 20% of the use in subregion 1. Although the livestock industry is a major segment of the agricultural economy, it uses a very small amount of water.

Not included in table 6–15–2 are the instream uses of the available water which can, for the most part, be discussed only qualitatively. Hydroelectric power is generated on many streams of the Region, the most significant installation being on the Bear River in Idaho and Utah.

The streams, lakes, and reservoirs of the Region serve as nuclei for outdoor recreation activities. Water surfaces are being used intensively, particularly near the larger population centers. The major water-oriented recreation activities include fishing, boating, swimming, water skiing, picnicking, and camping.

Use of streams, lakes, and reservoirs for preservation and enhancement of fish and wildlife resources is important to the regional economy, since it provides sportsmen from widespread

TABLE 6–15–2.—*Present water use, 1965, Great Basin Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total [6]
					Irrigation [5]	Livestock	
			Water withdrawn				
1	7.7	229.3	193.7	8	3,060	9.2	3,508
2	1.8	7.5	17.5	0	1,000	4.5	1,031
3	0.2	1.4	3.5	0	107	0.4	113
4	5.5	35.7	10.3	2	408	1.8	463
Total [6]	15	274	225	10	4,575	16	5,115
From groundwater	(9)	(111)	(71)	—	(740)	(4)	(935)
			Water consumed				
1	3.1	71	22.8	2	1,420	6.5	[7]1,525
2	1.4	4	7.1	0	448	2.7	463
3	0.2	1	3.0	0	48	0.3	53
4	4.5	18	4.2	0	184	1.1	212
Total [6]	9	94	37	2	2,100	11	2,253

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 957,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.
[6] Rounded.
[7] Does not include 315 mgd consumed by managed waterfowl habitat.

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areas of the United States with a variety of recreation opportunities. The maintenance of such areas for fish is an important water use.

Water used for managed migratory waterfowl habitat accounts for a substantial part of the total water consumed in the Region. There are approximately 86,500 acres of managed marshland and waterfowl habitat along the eastern shores of the Great Salt Lake and an additional 125,000 acres in Nevada.

Watershed management is important in managing runoff so as to prevent damage from floods and erosion. Various public programs are available to support such work. Completed watershed improvements, channel projects, and storage facilities help alleviate or reduce flood hazards in some of the developed areas of the Region. However, occasional floods from intense winter rains or heavy snowmelt runoff still damage agricultural and urban areas along the Truckee, Carson, and Walker Rivers in subregion 4; the Humboldt River in subregion 2; and the Bear, Weber, Jordan, Provo, and Sevier Rivers in subregion 1. Cloudburst storms, characteristic of the Region, also produce extremely high floodflows in small areas and affect both urban and rural developments.

ADEQUACY OF PRESENT DEVELOPMENT

Water for municipal and industrial uses is generally adequate in quantity and quality to meet present needs. In many cases, however, domestic water supplies for rural communities, farms, and ranches are insufficient or of poor quality.

Irrigation is essential to the Region's agricultural economy. Although some irrigated areas have sufficient water for their needs, others do not. Many others suffer recurrent annual and cyclical shortages because of extremely variable runoff or inadequate physical works. Withdrawals and consumption of water for irrigation amounted to about 80% of actual requirements for irrigated lands in 1965.

To date, the development of the Region's water-oriented recreation potential has lagged behind that of other western Regions. Exceptions to this lag, however, are found in the Wasatch-Uinta Mountains of northeastern Utah and the eastern Sierra Nevada-Lake Tahoe area along the Region's western rim.

Additional flood protection is needed in many areas, particularly in the urbanizing areas in western Nevada and those along the Wasatch Range in Utah. Urban growth has increased both land values and potential storm runoff.

Although water quality problems are not yet critical regionwide, problems associated with wastewater disposal have arisen in local areas, particularly below major cities and industrial complexes.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Water resource planning and development in the Great Basin Region has a long history. For the most part, the planning has been on the local and Federal levels. In recent years, however, the States have been more active, particularly in the development of water quality standards and comprehensive State water plans. That they have a key role in water resources planning is now recognized, but they are seriously handicapped by insufficient funds and staff.

Water laws within the Region are administered by the States and are based on the appropriation doctrine and priority of use. Beneficial use is the basis for, the measure of, and the limit to the use of water. Problems involving water rights and water laws have existed and probably will continue to exist and to be worked out throughout the course of comprehensive water planning and development.

Interstate problems concerning equitable divisions of the available water exist between Idaho and Utah and between California and Nevada. The Bear River Compact, agreed to by Wyoming, Idaho, and Utah, consented to by Congress and approved by President Eisenhower in 1958, is adequate for the administration of the waters of the Bear River above Bear Lake. Problems still exist below Bear Lake. The California-Nevada Interstate Compact Commission has been working since 1956 to negotiate a compact which would equitably divide the waters of Lake Tahoe and the Truckee, Walker, and Carson Rivers.

Responsibilities for the ownership, management, and use of land and water resources are vested in many private and local, State, and Federal Government interests. Overlapping responsibilities and conflicting policies, goals, and objectives cause some problems of coordination and communication. In Utah, for instance, the assurances of local cooperation with water resource projects involving Federal flood control measures must be obtained from counties and local water districts. Desirable projects have

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been deferred for extended periods because these jurisdictions could not meet administrative requirements to provide the assurances. The problem is not quite as critical in Nevada, where the Director of the Department of Conservation and Natural Resources is authorized to give the required assurances when and as directed by acts of the State legislature. Nevada, however, is having some problems in turning over operation and maintenance of completed projects to local sponsors. Good Federal-local cooperation exists on small agricultural water management and flood prevention projects which are instigated, constructed, and maintained by local sponsors.

In recent years cooperation among land administrators and planners, both public and private, has been emphasized. For example, the Public Land Law Review Commission, established in 1964, is now studying existing land laws to determine how Federal lands could contribute more fully to the economy.

To further coordinate water and related land resources planning and development, each of the four States in the Region has designated an agency to be responsible, statewide, for such planning and development. The agency also acts as the coordinating agent of the State for programs involving Federal agencies.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

Major economic indicators point to continued high rates of economic growth for the Region. Projections for major sectors of economic activity and land use are summarized in table 6–15–3.

The population in the Region in 1960 was about 970,000. By 2020, it is expected to increase more than fourfold to 4.3 million, an annual growth rate of 2.5%. The States of the Region, however, believe this growth rate to be high and project a 2.3% rate of increase, or a population of 3.9 million by 2020.

Personal income for 1965 was about $2.8 billion; by 2020, it is estimated to be $33.4 billion. This relatively high amount reflects expected increases in both population and per capita income. Per capita personal income averaged about $1,981 in 1960. By 2020, it is expected to increase to $7,800, reflecting an annual growth rate of about 2.4%. Total employment in 1965 averaged 435,000, up 26% from 1960. Growth rates of employment generally parallel growth rates of population, although employment in agriculture has decreased in recent years.

The Region has 80.8 million acres of agricultural land and 6.4 million of nonagricultural

TABLE 6–15–3.—*Economic and agricultural projections, Great Basin Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total [2]	thou.	970	1,790	2,822	4,285
Per capita personal income	1954 dol.	1,981	3,250	5,050	7,800
Employment, total [3]	thou.	355	690	1,089	1,655
Agriculture	do.	22	13	10	10
Manufacturing	do.	53	116	178	263
Other commodity producing	do.	43	67	95	128
Distributive industries	do.	100	180	262	379
Service industries	do.	136	315	544	874
Land base	thou. ac.	87,189	87,189	87,189	87,189
Agricultural	do.	80,780	80,480	80,240	79,970
Cropland, total [4]	do.	2,857	2,646	2,638	2,629
Used for crops	do.	2,138	1,960	2,089	2,477
Idle and fallow	do.	719	686	549	152
Pasture-permanent	do.	56,996	56,985	56,815	56,624
Forest and woodland	do.	20,927	20,849	20,787	20,717
Nonagricultural	do.	6,409	6,709	6,949	7,219
Irrigated land [5]	do.	[6] 1,700	1,950	2,000	2,000

[1] Some data for 1959.
[2] Independent population study by State agencies projects population to be 1,865,000 by 1980, 2,910,000 by 2000, and 3,900,000 by 2020.
[3] May not check due to rounding.
[4] Includes cropland used as pasture.
[5] Includes cropland and pasture.
[6] In 1965 irrigated land amounted to 1,860 thousand acres.

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land for a total land base of 87.2 million acres. Probably the most significant future change in agricultural land use is the expected increase in cropland used for crops and the decline in idle and fallow cropland. From 1965 to 2020, irrigated land is expected to increase from about 1.86 million acres to 2.0 million, and nonagricultural land from 6.5 million to 7.2 million.

The two factors which most directly affect water requirements in the Region are population and irrigated land. Using the projections for these factors and various water use rates, future water requirements have been projected to 2020 (table 6–15–4). The water consumed is that which was lost through evaporation, transpiration, or other irrecoverable losses.

Substantial water-oriented recreation needs are foreseen, but have not been evaluated. The need for additional flood control, drainage, water quality control, and watershed management will also increase with regional growth.

EMERGING WATER PROBLEMS

Developing usable water supplies to meet the rapidly increasing demands is the major water problem of the Region. An associated problem, that of placing priorities on alternative water uses, is also increasing as the various demands for water intensify.

Assuming no significant increase in irrigation water use, the essential needs to 1990 can, in general, be met from presently available water sources. These include authorized projects to import water from the Upper Colorado Region and natural inflow from the California and Columbia-North Pacific Regions, provided that (1) surface water is fully developed, (2) groundwater is more fully utilized, (3) conveyance and on-site use losses are reduced, (4) excess losses due to evapotranspiration are controlled, and (5) transfers of water from one use to another and from one area to another are allowed. Since all of these provisions are costly, an overriding regional problem will be financing and repaying such developments.

Vast tracts of arable land in Utah and Nevada will never be irrigated unless new sources of water can be developed. Whether it will ever be economically feasible or practical to serve most of this land has not been determined.

Considering the entire Region, average annual flood damages have not been large in the past

TABLE 6–15–4.—*Projected water requirements, Great Basin Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	15	15	15	15
Municipal (public-supplied)	274	450	745	1,005
Industrial (self-supplied)	225	340	560	740
Steam-electric power (fresh)	10	30	100	200
Agriculture:				
Irrigation	4,575	6,200	6,100	5,800
Livestock	16	20	30	40
Total	5,115	7,055	7,550	7,800
Consumptive use				
Rural domestic	9	9	9	9
Municipal	94	154	255	345
Industrial	37	56	92	123
Steam-electric power (fresh)	2	25	75	160
Agriculture:				
Irrigation	2,100	3,040	3,110	3,110
Livestock	11	15	21	29
Total	2,253	3,299	3,562	3,776

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because of limited economic development in flood-prone areas. Since many of these are now being urbanized, future flood damages will be much greater. Federal policy for flood plain management will reduce future industrial and urban expansion in such areas.

With tourism and leisure time increasing, the demand for recreation waters is also increasing. In response, more emphasis is being given to water conservation and to preservation of fish and wildlife habitat. The problems of the Region's four major terminal lakes—Utah's Great Salt and Sevier, Nevada's Pyramid and Walker —are closely related to these increasing demands.

Great Salt Lake is the largest and most saline of the four. It will not support fish life, but the extraction of minerals from the lake is becoming a major industry. However, recreation activity on and along the lake is increasing. Sevier Lake has become a mudflat since irrigation development of upstream water supplies. Pyramid Lake, which lies within an Indian reservation, is somewhat saline but supports fresh-water fish, including Lahontan cutthroat trout. Its recreation potential is considerable, and currently a portion of the shoreline is being advertised for development; however, its decline will continue until equilibrium is reached between inflow and outflow. A similar decline is taking place at Walker Lake. Although saline, it presently supports the more salt tolerant fresh-water fish.

The problem in regard to all three of the remaining lakes is that streamflows are not sufficient to meet upstream conservation needs and at the same time maintain lake levels. Increases in upstream consumptive uses will continue to cause recession and increased salinity of the lakes. The question is whether or not a water level can or should be maintained to realize the apparent benefits.

Some of the emerging problems are specific to individual States:

Utah: Municipal and industrial demands along the Wasatch will be met by local developments and importation of water from the Upper Colorado Region until 1990—and longer if existing groundwater supplies are mined. Industries and people are concentrating in this area, and with them come problems of supplying water of adequate quantity and quality. This growing concentration of water use for municipalities and industry presents a challenge for effective reuse of water discharged as municipal and industrial wastes. Although treatment facilities have increased, water quality in the lower sections of streams is deteriorating.

Nevada: In the more populous area along the eastern fringe of the Sierra Nevada, the problem is one of distributing very limited water supplies among users whose demands are increasing and will continue to do so. Even now competition is keen among agricultural, municipal, industrial, recreation, and fish and wildlife uses. The Washoe Project, under construction in western Nevada, will provide future municipal and industrial water supplies for the Reno-Sparks metropolitan area sufficient to meet the anticipated growth until about 2000.

Idaho: Agriculture and the phosphate industry are the main potential users of water in the Idaho portion of the Region. It is anticipated that these water requirements will be supplied from within the Bear River system.

Wyoming: Agriculture is the main user of water in this portion of the Region, and the Bear River is expected to supply this need.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

In Utah, water is locally available for development to meet municipal and industrial water requirements in the populous areas until 1980. This is contingent, however, upon completion of the Bonneville Unit of the Central Utah Project that is currently under construction. The unit will import about 122 mgd (137,000 af/yr) from the Upper Colorado Region, salvage about 89 mgd (100,000 af/yr) through modification of Utah Lake, and provide more control of local streamflows with additional storage and facilities.

In Nevada, the municipal and industrial requirements in the populous areas can be met until after 1980 with supplies developed as a part of the Washoe Project (under construction) and by reassigning water from irrigated lands which become urbanized. The project will also provide supplemental irrigation service for about 40,000 acres, flood control, recreation facilities, and protection for fish and wildlife. However, there will be some deterioration of the fishery in Pyramid Lake. Within the Humboldt River drainage, there is another authorized project that would reduce flooding and also provide supplemental water for agriculture, recreation, and fishery purposes. Undeveloped groundwater, mainly in central Nevada, holds some promise of expanding the irrigated agricultural base by about 200,000 acres.

The 1980 water requirements in the Region, both supplemental and full supply, will be reasonably satisfied if the following manage-

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ment opportunities are exploited: (1) storage of remaining unused surface water, (2) more extensive development and use of groundwater, (3) more use of municipal and industrial waste flows, (4) more efficient water use through reducing nonbeneficial consumptive uses and increasing irrigation efficiencies, and (5) where feasible, watershed management to improve water yield.

State and regionwide water plans to guide water resources management are primary needs. Utah is now preparing a State water plan which is scheduled for completion by 1971, and the Idaho Water Resource Board and Wyoming State Engineer have recently initiated preparation of similar plans. A cooperative State-Federal type 1 framework study of the Great Basin Region has just been initiated and will provide the means for coordinating the various State plans and including regional and national considerations.

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CHAPTER 16

Columbia-North Pacific Region

SUMMARY

The Columbia-North Pacific Region occupies a diversified area of 274,400 square miles, commonly known as the Pacific Northwest. Elevations range from sea level to over 14,000 feet, and rainfall varies from less than 8 inches to over 200. Summers, however, are consistently dry.

The Region's economy is based on its land, mineral, and water resources. Agriculture is a major activity, but, of the commodity-producing industries, manufacturing provides the largest source of income. Fish and wildlife resources and the abundant recreation opportunities are also important. The population—5.4 million in 1960—is expected to reach 7.6 million by 1980 and 14.4 million by 2020. Employment is expected to increase by 180% from 1960 to 2020. Land use projections reflect a small but continuing transfer of land from agricultural to nonagricultural uses.

Although the water supply in total is abundant, areal distribution varies widely and seasonal flows are low in many of the smaller streams. The available average annual natural runoff is 258 bgd (289 maf/yr), of which 19% (48 bgd) originates in Canada. With few exceptions, the quality of the water is good.

Total present withdrawals average 29.7 bgd (33.3 maf/yr), of which 10.5 bgd (11.8 maf/yr) are consumed. About 95% of the consumption is accounted for by irrigation. The main instream uses are hydroelectric power generation, fish and wildlife habitat, recreation, navigation, and assimilation of wastes. The present water supply is generally adequate, but localized seasonal shortages for virtually all uses occur because development of water and related land resources (including proper control measures) has not kept pace with demands for the resources.

Total consumptive use is projected to increase to 16.0 bgd (17.9 maf/yr) by 1980 and 31.3 bgd (35.0 maf/yr) by 2020. Withdrawals for these uses will increase, respectively, to 47.4 and 178.9 bgd (53.1 and 201 maf/yr). One of the largest uses will continue to be irrigation, which is projected to increase from 6.6 to 17 million acres by 2020. Another large user will be steam-electric powerplants. In the near future, over 1 million additional kilowatts of installed steam-electric capacity will be required each year, and by 2020 withdrawals for cooling water are expected to be 97.2 bgd (109 maf/yr). Municipal and industrial demands will also increase substantially. Instream demands for fish and wildlife, recreation, navigation, and quality control are expected to increase with increases in population and industrialization. All lands are expected to be utilized more intensively to meet the increasing needs of the people. This will necessitate improved management, development, and control of the Region's water and land resources from the upper watersheds covered with timber and grass to the major river valleys.

Although regional water supplies are generally adequate to meet projected consumptive uses for the year 2020, serious depletions will occur in some of the interior basins of eastern Washington and Oregon and southern Idaho. Such depletions will have adverse effects on water quality and instream uses.

In general, the growth of the Region is dependent on its water and land resources. As population and industry grow, needs and demands for additional development and better management of these resources will increase. To meet these needs, the level of Federal and State investment in water and related land resources development and management must increase substantially over the present level—some $250 million annually. Information is not available for other public and the many private interests, but their future investments will also greatly increase.

DESCRIPTION OF THE REGION

Within its 274,400 square miles, the Columbia-North Pacific Region encompasses all of Wash-

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ington, most of Oregon and Idaho, and parts of Montana, Nevada, Wyoming, and Utah. It includes the drainage area of the Columbia River basin within the United States, the portion of the Great Basin within Oregon, and the coastal areas of Oregon and Washington. (See fig. 6–16–1, which also shows the 12 subregions adopted for study purposes.)

Physiographically, the Region is diverse. The Coast Range of hills and low mountains parallels the ocean a few miles back from the shore. East of the Coast Range is the Willamette-Puget Trough, a broad structural valley extending from Cottage Grove, Oregon, into Puget Sound, Washington. Farther east rise the Cascades, a range of more formidable mountains with several peaks above 10,000 feet. East of the Cascades lie the basin and range area, the Columbia Basin, the lava plateaus, the Snake Plain, and the numerous ranges and intermontane valleys of the Rocky Mountain system. The regional drainage pattern is dominated by the Columbia River and its principal tributaries, the Kootenai, Pend Oreille, Spokane, Yakima, Snake, and Willamette Rivers.

The climate reflects the physiographic diversity. West of the Cascades it is characteristically maritime; winters are mild, summers cool, and humidity and rainfall are relatively high, except during the summer when prolonged droughts are usual. East of the Cascades, temperature extremes are greater and rainfall is generally less. Precipitation varies greatly with exposure and elevation. Some areas in the central plains are extremely arid with average annual precipitation as little as 8 inches. Throughout the Region, precipitation is greatest in the winter and scant during the summer months except along

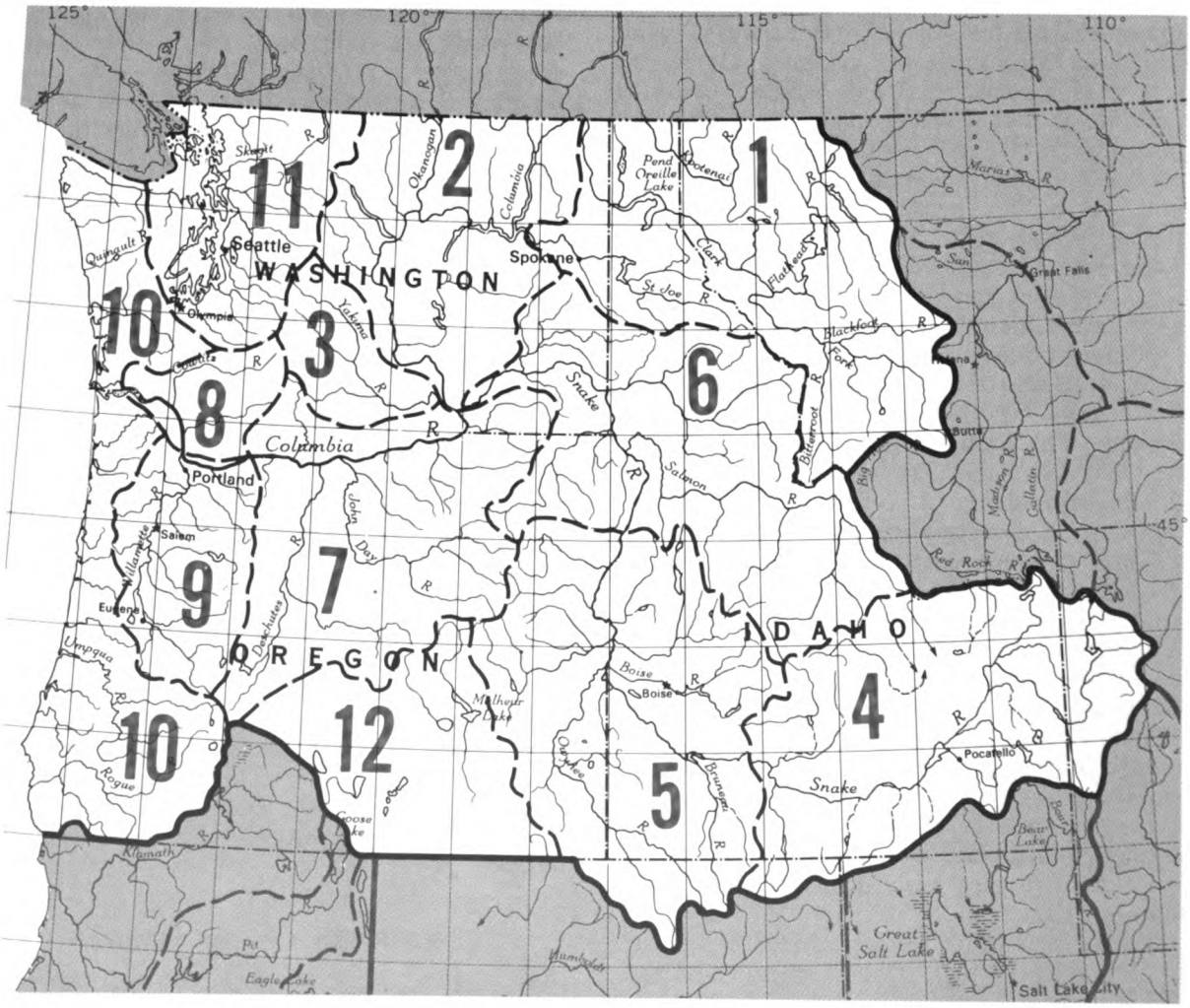

FIGURE 6–16–1.—*Map of the Columbia-North Pacific Region.*

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the Continental Divide where it is about uniform.

Population in 1960 was 5,359,000. Almost 60% of the people live in the Willamette-Puget Trough. Rural population densities are related to the intensity of agriculture; thus, desert, forest, and mountain areas are generally sparsely peopled.

The Region's economy is based chiefly on its land, mineral, and water resources. Agriculture is a major economic activity, and its productivity is due in great part to successful irrigation. Tourism has grown rapidly with utilization and development of the abundant fish and wildlife resources and recreation opportunities.

Manufacturing, however, is the largest source of income. Lumber and wood products and the related pulp and paper industry account for about one-third of total manufacturing employment, but transportation-equipment manufacturing, food processing, and production of metals and chemicals are also important. Factors influencing this industrial growth and economic development include the large quantities of low-cost hydroelectric power, the abundance of water for industrial use, and the excellent deep-draft port facilities.

THE WATER RESOURCE

The average annual natural runoff of the Region is 210 bgd (236 maf/yr). Its distribution, together with the 48 bgd (54 maf/yr) originating in Canada, is shown in table 6–16–1. As can be seen in the table, runoff varies greatly among the subregions. Estimates of natural runoff available 50%, 90%, and 95% of the time for each subregion and for the Region as a whole are also given to indicate annual dependability.

Reservoirs and natural lakes of more than 40 acres and streams more than one-eighth of a mile wide provide almost 2 million acres of water surface.

Streams west of the Cascade Range are characterized by high flows in winter and low flows in summer. The main Columbia River and its tributaries east of the Cascades are generally high in spring and early summer and low in fall and winter.

TABLE 6–16–1.—*Annual natural runoff, Columbia-North Pacific Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years			Total average runoff available to subregion [1]
				50	90	95	
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*	*bgd*
1	36,400	26.40	15.23	26.40	16.58	13.81	33.22
2	22,400	6.73	6.31	6.73	4.49	3.85	80.63
3	6,100	2.90	9.98	2.90	2.01	1.75	2.90
4	35,900	8.69	5.08	8.60	4.69	3.73	8.69
5	36,800	7.09	4.05	6.96	3.50	2.70	15.78
6	35,100	20.58	12.31	20.58	13.73	11.77	36.36
7	29,600	9.91	7.03	9.91	7.03	6.11	129.72
8	5,100	13.29	54.72	13.29	9.37	8.27	167.65
9	12,000	24.64	43.12	24.64	17.37	15.33	24.64
10	23,800	53.90	47.56	53.90	38.00	33.53	53.90
11	13,300	35.00	55.26	35.00	26.46	24.04	35.58
12	17,900	0.88	1.03	0.81	0.29	0.20	0.88
Regional value	274,400	210	16.07	210	154	138	258
Annual Canadian contribution to Columbia-North Pacific Region							
1	8,100	6.82	17.67	6.82	4.28	3.57	
2	31,400	40.60	27.17	40.60	27.69	21.23	
11	400	0.58	28.88	0.58	0.40	0.30	
Canadian value	39,900	48.0	25.26	48.0	32.7	25.1	

[1] Total average runoff available to subregion includes Canadian water and all other water that originates upstream from but flows through the subregion in question. The sum of subregions 8, 10, 11, and 12 equals 258 bgd, the total water available to the Region.

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Major groundwater aquifers capable of yielding moderate to large supplies of water for irrigation, municipal, and industrial use underlie about one-fourth of the Region. In most of the remainder, small to moderate supplies can be obtained from groundwater. The quality is generally good, although hard water is common east of the Cascade Range.

In contrast to conditions in many parts of the Nation, quality of this Region's surface water is generally very good. Significant quality problems do exist in some areas, however. Dissolved solids concentrations average less than 300 ppm in major water supply sources, although there are exceptions in some isolated areas. Some areas of eastern Washington and Oregon and southern Idaho contribute large amounts of sediment to watercourses. Nitrate and phosphate concentrations from both natural and man-made sources are resulting in excessive algal growths in the Yakima and Snake River basins and in areas of the Columbia Basin Project. During the summer months, water temperatures in many streams rise to levels undesirable for fish life. Low dissolved oxygen concentration is a seasonal problem in segments of some rivers, including the Upper Snake and the main stem Willamette. Bacterial concentrations seasonally exceed desirable levels in the Yakima, Willamette, and lower Columbia and in stream reaches below a number of major communities throughout the Region. Deterioration of the biological and chemical qualities of groundwater supplies has been noted in and around some major population centers. Discharge of radioisotopes from Hanford, Washington, although in small quantities, is a matter of concern within the lower Columbia River.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The approximate quantities of water withdrawn and consumed in 1965 for rural domestic, municipal, industrial, irrigation, livestock, and recreation uses are summarized in table 6–16–2.

The main instream uses of water in the Region are hydroelectric power generation, recreation, fish and wildlife habitat, waste assimilation, and navigation. These uses are essentially nonconsumptive and do not require the removal or diversion of water from its natural course. Water used to produce hydroelectric power and the water surface area used for recreation in 1965 are shown in table 6–16–3.

Navigation is generally limited to the coastal areas of Oregon and Washington, the Columbia River below Pasco, and the lower Snake and lower Willamette. The deep-water ports on the coast and the lower Columbia below Vancouver handle all types of cargo for national and international trade. The lower Columbia channel has a controlling depth of 35 feet and a width of 500 feet at a flow of 77,000 cfs. By 1971, a slack water channel with a controlling depth of 14 feet will exist on the Columbia to the head of McNary Pool and on the Snake to Lewiston, Idaho. The Willamette River, several of the larger lakes and reservoirs, and many tidal streams are used for hauling rafted logs.

Interest and participation in water-oriented recreation activities has increased rapidly throughout the Pacific Northwest. The waters and other natural assets of the Region make it one of the most important recreation and vacation areas of the Nation.

The important fish and wildlife resources of the Region require proper water temperature, quality, and flow patterns. The anadromous fish resource produces annually a sport harvest of 1,380,000 fish; a commercial harvest of 3,630,000; and a spawning escapement of 2,500,000. These estimates are actually low, because they do not include contributions to international waters, spawning escapements for some small streams, and figures for anadromous cutthroat trout. In addition, shad, striped bass, eulachon, and sturgeon landings amount to 2 million pounds annually.

Projects existing, under construction, and assured, including Canadian projects, will provide about 10,100 billion gallons (31 maf) of flood control storage. Of this storage capacity, 650 billion gallons (2 maf) will be for control of winter floods on the Willamette River, and 7,170 billion (22 maf) will be used to control spring floods on the Columbia River. A flood the size of the historical maximum flood on the Columbia would be reduced from 1,240,000 cfs to about 700,000 cfs at The Dalles.

ADEQUACY OF PRESENT DEVELOPMENT

On a regionwide basis, water supplies for municipal, industrial, and rural domestic uses are adequate. However, there are seasonal problems in some local areas, but they are usually related to system capacities rather than available supplies.

Most of the 6.6 million acres of irrigated land

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TABLE 6–16–2.—*Present water use, 1965, Columbia-North Pacific Region*

(Million gallons per day)

Subregion	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Other [6]	Total
					Irrigation [5]	Livestock		
			Water withdrawn					
1	17.9	131.2	102.3	4	1,417	5.2	4.0	1,682
2	8.6	40.5	12.9	—	2,586	4.2	1.0	1,653
3	14.0	34.5	8.1	—	2,138	2.8	1.5	2,199
4	11.9	44.7	57.2	—	11,388	10.5	2.0	11,514
5	12.4	38.9	78.4	—	5,296	9.4	1.5	5,437
6	4.3	25.1	109.7	—	706	5.0	1.0	851
7	2.8	56.1	166.1	—	1,666	5.5	1.5	1,898
8	0.8	17.6	330.5	—	28	1.2	1.0	379
9	32.8	181.0	515.4	4	347	4.4	8.0	1,093
10	14.1	118.2	264.3	—	234	3.4	2.5	636
11	27.7	415.4	235.9	—	154	5.0	11.5	850
12	0.9	2.1	30.0	—	445	2.1	0.1	480
Total	148	1,105	1,911	8	26,405	59	36	29,672
From:								
Groundwater	(124)	(399)	(409)	—	(3,320)	(37)	—	(4,289)
Saline	—	—	(31)	—	—	—	—	(31)
			Water consumed					
1	16.2	21.2	11.3	—	570	5.2	0.8	625
2	8.4	9.7	1.0	—	1,202	4.1	0.2	1,225
3	12.5	8.2	0.6	—	850	2.7	0.3	874
4	10.6	2.6	4.4	—	3,695	9.5	0.4	3,723
5	11.2	2.7	8.7	—	2,063	8.5	0.3	2,095
6	3.9	3.2	1.6	—	286	4.6	0.2	300
7	2.5	20.0	6.1	—	602	5.0	0.3	636
8	0.7	1.8	3.5	—	13	1.1	0.2	20
9	29.7	36.0	22.5	—	243	4.0	1.6	337
10	12.6	18.6	13.5	—	141	3.2	0.5	189
11	25.2	57.0	25.8	—	94	4.8	2.3	209
12	0.8	1.0	0.5	—	287	2.0	0.0	291
Total	134	182	100	—	10,046	55	7	10,524

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 4,458,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Water supplied by industries themselves; also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).
[5] Conveyance losses not included in consumption.
[6] Recreation uses only.

are adequately supplied except during the most critically dry periods. However, at least 1 million acres, generally along smaller tributary streams, suffer perennial late-season water shortage. In many areas, achieving an adequate irrigation supply has required the use of all the natural streamflow during the summer irrigation period, as well as use of regulatory and holdover storage. Regionwide, over 100 reservoirs have individual active capacities of more than 1.63 billion gallons (5,000 af), and a total active irrigation capacity of over 5,530 billion gallons (17 maf). In addition, some 1 million acres of the total irrigated area depend all or in part upon groundwater.

Up to the present time, hydroelectric developments have been able to meet most of the Region's electric power needs. This situation is rapidly changing. The few feasible hydro sites that remain are being developed, and as needs continue to increase rapidly, more steam-electric plants will be required.

The existing channel in the Columbia River from the mouth to Vancouver, Washington, lim-

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TABLE 6–16–3.—*Water used for hydroelectric power and recreation, 1965, Columbia-North Pacific Region*

Subregion	Hydroelectric power		Recreation	
	Generation	Average water use	Boating and water skiing use	Water surface used
	mil. kwh	*bgd*	*thou. visits*	*thou. ac.*
1	6,622	94.6	1,800	452
2	33,107	282.3	600	288
3	176	1.5	700	28
4	2,066	33.3	900	266
5	4,629	38.2	850	171
6	2,056	22.9	500	81
7	17,429	229.0	650	95
8	2,420	11.1	400	74
9	1,996	16.6	4,140	106
10	1,466	4.3	1,230	154
11	4,065	14.3	5,850	101
12	0	0	40	94
Total	76,032	748	17,660	1,910

its the size of vessels and commerce carried by the waterway. Deepening to 40 feet and widening to 600 feet are under way. Other navigation waterways throughout the Region are generally adequate for existing traffic.

At present, the water surface area available for recreation is generally adequate, although localized shortages may exist. Deficiencies of water surface near the larger metropolitan areas are not a serious problem at this time. Stream fisheries for resident species are generally inadequate to meet needs. Also, the quantity and quality of some streamflows are inadequate for the optimum production of anadromous fish. Water for the production of waterfowl is insufficient in some refuges and other wetland areas.

Some 60% of the 1,600 small watersheds in the Region are in need of improved management, more development, or better protection to adequately protect the water and related land resources. The agricultural land base of 158 million acres is presently producing food and fiber for both regional consumption and export. Of the present 19.5 million acres of cropland, approximately 3.4 million have a problem with excess water due to continuing wetness or flooding. More than 6.5 million acres have significant erosion problems, as do portions of the grasslands and forests.

During the floods of December 1964 and January 1965, existing projects prevented damages of $640 million; but flood damage totaling nearly $290 million did occur, indicating that additional control is needed. Additional upstream storage capacity under construction in the United States and Canada will go far toward fulfilling the objective for flood control on the Columbia River. However, floods from uncontrolled streams will still damage local areas throughout the Region.

Levels of water quality are less than desirable in some locations during certain times of the year. This is attributable to one or both of the following factors: (1) less than adequate waste reduction or treatment; (2) an insufficient quantity of water resulting from seasonal low flows, upstream consumptive uses, or regulation for power, irrigation, or other uses.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Institutional arrangements for comprehensive river basin planning, development, and management in the Region are reasonably well suited to the current conditions and problems of water supply and use. At the regional level, there is a long history of intergovernmental study and cooperation in water and related land resources fields. Operation of the Columbia River for power is controlled by three interrelated institutional arrangements: (1) The Columbia River Treaty with Canada, (2) arrangements for use of the Pacific Northwest-Southwest transmission interconnections, and (3) the Pacific Northwest Coordination Agreement. For more than 20 years, the Columbia Basin Inter-Agency Committee carried program coordinating activities forward on a voluntary Federal-State intergov-

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ernmental basis. In 1966, the Pacific Northwest River Basins Commission was established under the Water Resources Planning Act of 1965 with broader and more definite responsibilities in comprehensive basin planning.

At the State level, water resources boards or departments, with broad responsibilities in water resources planning, development, and control have been established. All of the States are formulating cooperative State water planning programs with financial assistance under the Water Resources Planning Act. State water resources research centers or institutes are also active in each State, with financial assistance under the Water Resources Research Act of 1964. The States have prepared water quality standards under provisions of the Water Quality Act of 1965.

The new Basins Commission is expected to improve one situation in the Region which has to some extent impeded efficient planning—i.e., the often overlapping responsibilities and sometimes limited jurisdictional authority of the many Federal, State, and local government units that have been concerned, directly or indirectly, with the area's water and related land resources development.

A number of problems involving regulation, management, and water rights will arise in the course of comprehensive water planning and development. However, these do not represent serious obstacles; rather, they are matters to be routinely worked out to suit specific conditions and needs as the development program progresses. Some of the States favor a compact that would allocate the waters of the Columbia River system, but attempts to establish it have so far been unsuccessful. A general problem of importance to both the States and the Federal Government concerns the differences in viewpoint and uncertainty about water rights associated with withdrawals and reservations of Federal and Indian lands. Such uncertainty, if it persists, could hinder water and related land resources development.

Some States have a major problem in that their water laws do not recognize water use for fish and wildlife, recreation, or water quality control as beneficial. Also, certain State laws prohibit a State agency from reserving water for instream or future uses, as determined by long-range water plans. Implementation of plans including all presently authorized functions may require legal action and institutional changes at State and local levels.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

Economic projections for the Region are shown in table 6–16–4. Population is expected to mount from 1960's 5.4 million to 14.4 million

TABLE 6–16–4.—*Economic and agricultural projections, Columbia-North Pacific Region*

Item	Unit	1960 [1]	Projections		
			1980	2000	2020
Population, total	thou.	5,359	7,581	10,463	14,444
Per capita personal income	1954 dol.	2,045	3,250	4,975	7,725
Employment, total [2]	thou.	1,990	2,921	4,032	5,570
Agriculture	do.	169	114	94	91
Manufacturing	do.	447	678	904	1,198
Other commodity producing	do.	208	292	380	511
Distributive industries	do.	548	812	1,101	1,480
Service industries	do.	618	1,024	1,552	2,290
Land base	thou. ac.	169,321	169,321	169,321	169,321
Agricultural	do.	158,066	156,816	155,536	154,186
Cropland, total [3]	do.	19,468	18,739	18,587	20,138
Used for crops	do.	13,752	15,250	15,878	17,514
Idle and fallow	do.	5,716	3,489	2,709	2,624
Pasture-permanent	do.	54,101	54,249	53,806	51,627
Forest and woodland	do.	84,497	83,828	83,143	82,421
Nonagricultural	do.	11,255	12,505	13,785	15,135
Irrigated land [4 5]	do.	[6] 5,700	9,204	12,780	17,056

[1] Some data for 1959.
[2] May not check due to rounding.
[3] Includes cropland used as pasture.
[4] Includes cropland and pasture, but excludes about 6 million acres of forest lands potentially irrigable for forests.
[5] WRC projection differs (see chapter IV-4).
[6] 1965 acreage was estimated as 6,555 thousand acres.

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by 2020, an increase of nearly 170%. Per capita income is expected to increase almost 280%.

Total employment is projected to increase by approximately 180%, from about 2.0 million in 1960 to 5.6 million in 2020. Employment in service industries, at present the largest sector relative to total employment, will grow from 31% of total employment in 1960 to 41% in 2020. Employment in manufacturing and in other commodity producing and distributive industries is projected to increase substantially by the year 2020, but will account for a slightly smaller percentage of total employment at that time. From 1960 to 2020, agricultural employment, in contrast to other employment sectors, is projected to decrease by 46%; however, this does not indicate a decrease in agricultural output. The number of farms is expected to decrease by half, but size of farms will increase.

The projections of major land uses reflect a continued relatively small loss of agricultural land to nonagricultural uses. From 1960 to 2020, total cropland will increase by about 3.5% and slight decreases will occur in permanent pasture and forest and woodland.

Projected water requirements for the various withdrawal and consumptive uses are shown in table 6–16–5; the total requirements for the uses (except steam-electric power) are shown by subregions in table 6–16–6. Factors considered in the projections included changes in the Region's population, income, employment, number of farms, livestock production, land use, and per capita and unit water use.

The largest consumptive use of water is irrigation. By 1965, there were about 6.6 million acres of irrigated land in the Region, an increase of nearly 2 million acres since 1944. By 2020, irrigated land is projected to be about 17 million acres, an increase of 160%. In projecting irrigation increases, consideration was given to changes in population, regional trends in needs for food and fiber, regional trends in irrigation development, availability of water,

TABLE 6–16–5.—*Projected water requirements, Columbia-North Pacific Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	148	148	148	148
Municipal (public-supplied)	1,105	1,304	2,100	3,240
Industrial (self-supplied)	1,911	4,478	8,880	13,500
Steam-electric power:				
Fresh water	8	4,000	22,200	44,600
Saline water	0	0	19,200	52,600
Agriculture:				
Irrigation [1]	26,405	37,380	50,400	64,500
Livestock	59	77	107	147
Recreation [2]	36	60	101	158
Total	29,672	47,447	103,136	178,893
Consumptive use				
Rural domestic	134	134	134	134
Municipal	182	219	350	537
Industrial	100	244	481	738
Steam-electric power:				
Fresh water	0	13	180	630
Saline water	0	0	180	740
Agriculture:				
Irrigation [1]	10,046	15,300	21,500	28,400
Livestock	55	71	100	137
Recreation [2]	7	12	21	32
Total	10,524	15,993	22,946	31,348

[1] WRC projection differs (see chapter IV-4).
[2] Managed recreation areas.

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TABLE 6–16–6.—*Projected water requirements by subregions, Columbia-North Pacific Region*

(Million gallons per day)

Subregion	Water use [1]	Withdrawals			Consumptive use		
		1980	2000	2020	1980	2000	2020
1	Irrigation	2,210	2,683	4,660	989	1,241	2,285
	Other	411	723	1,085	74	116	170
2	Irrigation	6,711	9,691	10,981	3,102	4,535	5,151
	Other	94	161	244	28	41	58
3	Irrigation	2,428	3,098	3,767	1,000	1,299	1,598
	Other	83	139	211	28	40	56
4	Irrigation	13,035	15,319	17,187	4,403	5,435	6,282
	Other	227	407	616	38	56	74
5	Irrigation	7,802	11,070	13,980	3,132	4,531	5,776
	Other	268	494	754	47	74	105
6	Irrigation	902	1,660	3,258	402	795	1,616
	Other	300	568	856	19	27	38
7	Irrigation	2,169	3,383	4,857	893	1,540	2,326
	Other	451	854	1,295	45	71	105
8	Irrigation	76	76	446	42	45	254
	Other	780	1,532	2,323	13	23	33
9	Irrigation	817	1,719	3,111	561	1,094	1,910
	Other	1,513	2,853	4,334	148	240	351
10	Irrigation	375	696	1,089	227	357	513
	Other	847	1,635	2,487	80	138	204
11	Irrigation	304	393	442	181	232	259
	Other	1,019	1,831	2,783	155	253	372
12	Irrigation	553	616	678	378	411	437
	Other	74	143	218	5	7	12
Subtotal [2]	Irrigation	37,400	50,400	64,500	15,300	21,500	28,400
Subtotal [2]	Other	6,000	11,300	17,200	700	1,100	1,600
Total [2]		43,400	61,700	81,700	16,000	22,600	30,000

[1] "Other" water use includes rural domestic, municipal, self-supplied industrial, livestock, and recreation. Requirements for steam-electric power are not included.
[2] Rounded.

and the availability of about 25 million acres of irrigable land. (No projections were made for an estimated 6 million acres of potentially irrigable forest lands.) In 1965, irrigation accounted for 95% of the consumptive use of water in the Regions; in 2020, it is projected to account for somewhat over 90%.

The transition from an essentially all-hydroelectric system to an integrated steam and hydro system is just beginning in the Region. Preliminary estimates of the electric energy loads indicate a growth from 80 billion kwh in 1966 to 183 billion by 1980, 579 billion by 2000, and 1,600 billion by 2020. Nearly all the growth in energy requirements after 1980 will be met from thermal sources. Although the generation of energy at hydroelectric plants is not expected to increase materially, the installed capacity will continue to increase. This is a result of the complementary role of hydro power for peaking purposes in an integrated system and is expected to result in hydro plant factors of 15% to 20% as compared with about 55% at present.

Detailed studies are under way concerning the locations, magnitude and number, and cooling methods of steam-electric plants. The cooling methods adopted will no doubt be a combination of cooling towers, cooling ponds, once-through flows, and other methods. Moreover, limited knowledge is available for estimating to what extent sea water will be used for cooling.

Estimated instream use for hydroelectric generation in 1980 is 1,360 bgd (1,520 maf/yr), and the figure includes reuse of water by successive plants on many streams. Subregions 1, 2, 6, and 7 account for 1,255 bgd (1,410 maf/yr) of the 1980 use, or 92%, but their use is expected to grow only slightly by 2000.

A comparison of projected recreation uses and presently available water-recreation areas within the reach of motorists indicates that water

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needs for recreation will continue to be concentrated in urban and urban-fringe areas. This will be particularly true in the heavily populated subregions where population pressures for open space and urban parks are becoming increasingly crucial. The broad regional and subregional availability picture may tend to mask local deficiencies that demand attention.

A number of by-products of the expected economic development of the Region will affect the instream use of fresh water by fish and wildlife. These by-products include pollution, diversion, siltation, alteration of temperatures, and inundation. The fish and wildlife values of the Region will diminish or be destroyed unless means can be found to combine water development projects with maintenance of conditions satisfactory for the production of fish and wildlife. Future instream water requirements for this use will at least equal present requirements and probably will increase.

By 2020, the Region will have to increase its output of food and fiber for its contribution toward an expected 170% increase in its population and for its proportionate share of exports. This will have to be accomplished, however, with an agricultural land base that has been reduced by 2.5%: to meet projected demands, for example, 25% more sawlogs and 3 times the present pulpwood must be produced on 2.5% less forest land, and 180% more livestock must be produced with 4.5% less grassland. This means that all land must be managed and used more intensively, and that management and development for water and erosion control must be greatly increased. About 3.4 million acres of farmland must be drained and protected from floods to permit more intensive use. To realize the desired level of flood control, some additional storage will be required for both the Columbia River system and several rivers tributary to the Pacific. Additional storage approximating 815 billion gallons (2.5 maf) will also be required by 2020 to maintain the water quality necessary for fish, municipal supply, recreation, and other beneficial uses. Any plans for storage, however, must be closely coordinated with other potential water uses to insure the realization of optimum benefits.

EMERGING WATER PROBLEMS

Future water problems of the Region will vary with location, supply, anticipated multiple uses, and magnitude of specific demands. In general, the coastal streams of Oregon and Washington and the Puget Sound area have total supplies greatly in excess of present or anticipated consumptive need; however, most of these streams have extreme seasonal variations in flow. In the interior subregions, many streams are already subject to consumptive uses that seriously deplete the flows. In fact, nearly all streams in the Region currently have at least one instream use that places demands on streamflow.

A comparison of average available water supplies with estimated withdrawals and consumptive uses by subregions for 2020 conditions is shown in table 6–16–7. It should be emphasized that the figures indicate average flows and uses without regard to seasonal variations and that the subregional totals give no indication of individual stream conditions or use. Moreover, the table does not include estimated water requirements for steam-electric power purposes.

The table indicates that withdrawals on a once-through basis will exceed average water supplies available in subregions 3, 4, 5, and 12 by 2020, and consumptive uses will deplete average available supplies in these subregions by over 70%. Such depletions will have adverse effects on such instream uses as fish and wildlife habitat, recreation, and hydroelectric power and could seriously affect water quality for both instream and withdrawal uses.

An emerging problem of increasing magnitude and concern is the higher water temperature which results from the cooling of steam-electric plants. The use of cooling towers (suggested as an alternative method) would increase the consumptive use of water and could cause atmosphere fogging, heavy condensation, and possibly a contaminated effluent.

There are substantial land and water resources available for irrigation development. However, many of the remaining developments will be costly because most underdeveloped irrigable lands lie at considerably higher elevations than the prospective water supplies and in some areas extensive water regulation facilities will be required. Water exchanges, now practiced in some irrigated areas, must be further extended; examples include the use of reservoir storage for expanded irrigated acreages in good water years in exchange for guaranteed groundwater pumping in dry years, or the substitution of groundwater pumping for natural streamflow to free the natural flows for further extension of the irrigated areas. Such exchanges will require

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TABLE 6–16–7.—*Water availability, withdrawals, and consumption, 2020, Columbia-North Pacific Region*

(Billion gallons per day)

Subregion 1	Average runoff 2	Total average runoff in subregion [1] 3	Total runoff less upstream consumption 4	Withdrawal in subregion [2] 5	Consumption in subregion [2] 6	Total runoff from subregion [3] 7	Net runoff in subregion [4] 8
1	26.40	33.22	33.22	5.74	2.46	30.76	23.94
2	6.73	80.63	78.17	11.23	5.21	72.96	1.52
3	2.90	2.90	2.90	3.98	1.65	1.25	1.25
4	8.69	8.69	8.69	17.80	6.36	2.33	2.33
5	7.09	15.78	9.42	14.73	5.88	3.54	1.21
6	20.58	36.36	24.12	4.11	1.65	22.47	18.93
7	9.91	129.72	106.51	6.15	2.43	104.08	7.48
8	13.29	167.65	139.75	2.77	0.29	139.46	13.00
9	24.64	24.64	24.64	7.44	2.26	22.38	22.38
10	53.90	53.90	53.90	3.58	0.72	53.18	53.18
11	35.00	35.58	35.58	3.22	0.63	34.95	34.37
12	0.88	0.88	0.88	0.90	0.45	0.43	[5] 0.43

[1] Includes Canadian water and all other water that originates upstream.
[2] Does not include steam-electric power uses.
[3] Column 4 minus column 6.
[4] Column 2 minus column 6.
[5] Represents water discharged into water bodies from which there is no outflow.

many agreements and additional cooperation on the part of the present water users.

The anticipated growth in population and industrial activity will intensify the problems of coping with residual wastes. Improved methods of limiting the nutrient content of residual municipal, industrial, and agricultural wastes must be implemented to prevent intensification of aquatic growth problems. In subregions 3, 4, and 5, and in several individual river basins in other subregions, increases in water use may significantly reduce streamflow available for residual waste assimilation.

Larger withdrawals of water will have less effect on hydroelectric power and navigation than on other instream uses. Anticipated flows appear adequate for commercial navigation on the main waterways, which are generally confined to subregions 2, 6, 7, 8, 9, 10, and 11. However, greater amounts of waterborne general cargo and further increase in the use of super bulk carriers will create needs for additional port and shore facilities and for increased channel dimensions. In addition, currents in the Columbia River in the vicinity of Bonneville Dam and the size of the Bonneville navigation lock will restrict this potential future navigation, unless corrective measures are applied.

While the Region has excellent recreation opportunities and facilities, planners must consider the projected increased demands for water-based recreation and search for new and imaginative approaches to the problem. The problem will be particularly critical in the more populated subregions 3, 9, and 11.

The fishery resource is an instream use of water that is directly affected by nearly all other uses. Hydroelectric plants, diversions, navigation, and other nonconsumptive uses all affect fish and wildlife, as do consumptive uses and structural control measures. Despite the fact that these resources have substantial tangible values and even greater aesthetic values, the economic demands of competing water uses could destroy them if dollar evaluation should become the only directive criteria for water resource development.

To meet the future increased demands for control functions in the Region and, at the same time, protect the water and related land resources, it is imperative that the watersheds be properly managed, developed, and protected. About 60% of them require group project-type action for water conservation, flood protection, drainage, vegetative control, and other land treatment measures. In achieving this goal, the major emerging problems will center around the need to develop local interests, organization, and financial support in regard to privately owned lands.

The projected expanding population and attendant increased economic growth in the

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Region especially emphasizes the need for a well-conceived and balanced program of flood control and flood plain management. If optimum use is to be made of water and related land resources, flood plain encroachment must be regulated and effective flood prevention measures must be instituted.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

To attain the projected regional growth in population, industry, and agriculture, while still maintaining a desirable environment, will require improved planning and management of the Region's water and related land resources and a greatly accelerated rate of development.

Water supplies are generally adequate for rural domestic, municipal, and industrial requirements projected for 1980, but the local shortages that exist now will become more acute. Watersheds now providing municipal supplies should be managed to insure the desired quantity and quality of future water.

In the 1970's, steam-electric powerplants will be increasingly used in the Region as a primary source of power to meet base loads. The availability of water for cooling and for disposal of thermal wastes will be an important factor in locating the plants. During the same period, the capacity of hydroelectric plants will be increased to meet peaking requirements. The total installed capacity of all plants is expected to grow at an average rate of over 1 million kilowatts per year. This rate of growth will require an annual investment of over $125 million for generation capacity.

Irrigated acreage is expected to increase from 6.6 million acres in 1965 to 9.2 million by 1980, an increase of 2.6 million or 175,000 acres per year. Additional water storage of about 1,850 billion gallons (5.7 maf) will be required. This rate of irrigation development will necessitate an annual investment of about $110 million.

Flows are generally adequate for present navigation. However, extension of Columbia River navigation to Wenatchee, enlargement of the Bonneville lock and improvement of the approach channel, deepening of the lower Columbia River channel below Vancouver, and additional terminal facilities may be required by 1980.

Water-oriented recreation is rapidly expanding. Additional water surface area and an estimated annual investment of $1.5 million in facilities will be needed to meet 1980 demands. Some of the increased need for surface area could be met if reservoirs presently unavailable for recreation purposes were utilized.

An essential step in the further development of fish and wildlife as a resource is State recognition of water for this purpose as a beneficial use. Basic research is needed on many aspects of protection and enhancement, including tolerable minimum flows and water temperatures, estuarine environment, reservoir management, and passage for anadromous fish. Development should also include provisions for better access to fish and wildlife areas, as well as for pollution abatement, improved streamflow, and pond and marsh development.

Watershed protection and land management programs must be accelerated to meet the 1980 demands. Projections show that while the Region's cropland will increase only 3%, the population will increase 41% and livestock production 46%. To keep pace, watershed protection and management programs on private and public lands should be accelerated to an annual level of about $100 million.

Effective flood plain management programs must be implemented to insure best use of lands and reduce future flood damages. In addition to the United States and Canadian projects existing and under construction, the smaller multiple-purpose projects now authorized on the Snake, Grand Ronde, Rogue, and other rivers should be completed by 1980. Additional storage in the Willamette River basin is needed, as well as on many smaller streams throughout the Region.

The need for storage and treatment facilities to ensure desirable levels of water quality is widespread. Storage for this purpose can be developed in conjunction with that for other purposes.

State laws for the protection of such instream uses as fisheries and recreation must be strengthened and enforced. These laws will necessarily deal with quality control, which is important in differing degrees to all water uses.

A type 1 framework study is well under way in the Region under the leadership of the Pacific Northwest River Basins Commission. This study will provide broad strategies for meeting the Region's water and related land resources development and management needs.

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CHAPTER 17

California Region

SUMMARY

The remarkable economic growth experienced by the California Region over the last several decades is expected to continue. Projections indicate that by 2020 the population will increase by more than 200% to about 64 million, and that irrigated land will expand more than one-fourth to over 11 million acres.

The 2020 economic status will require water supplies for withdrawal uses totaling about 245 bgd (274 maf/yr), of which 50 bgd (56 maf/yr) will be for uses other than steam-electric power. Water consumed will total about 38 bgd (43 maf/yr), of which some 34 bgd (40 maf/yr) will come from fresh-water sources. Steam-electric power uses are expected to require withdrawals of 195 bgd (220 maf/yr) and consumption of 2 bgd (2 maf/yr), primarily from saline water sources.

Natural water supplies within the Region are sufficient to meet these requirements, but additional surplus supplies in the northern portion would have to be transported to the water-deficient southern portion. Other sources of water—such as desalination and wastewater reclamation—may prove to be economically favorable alternatives. By 2020, the supplies required to supplement the yield capabilities of feasible local water-supply sources and of existing or authorized features of major State and Federal interbasin transport projects will be approximately as follows (bgd with maf/yr in parentheses): San Francisco Bay subregion, 0.2 (0.2); Central Coastal subregion, 0.5 (0.6); Central Valley subregion, 3.5 (3.9); and South Coastal subregion, 1.5 (1.7).

The following major conveyance and regulation facilities of the Central Valley Project are high-priority developments that will help the Region meet the portion of these requirements that is expected to materialize by 1980: West Sacramento Canal, Peripheral Canal, Kellogg Reservoir, San Felipe Division, and East Side Division.

Provision of the foregoing supplemental water supplies, together with necessary flood protection, water quality control, drainage, water-related recreation, fish and wildlife protection and enhancement, watershed management, protection against health hazards, and other related services will provide many of the physical elements necessary for sound economic growth in a favorable environment for future residents of the California Region.

DESCRIPTION OF THE REGION

The California Region includes the State of California plus that part of Oregon included in the drainage basins of the Smith and Klamath Rivers and of Goose Lake (fig. 6–17–1). Its total area is 164,700 square miles.

European settlement of California began in the final third of the eighteenth century with the establishment of Spanish missions and garrisons. During the 1830's and 1840's, when California was part of Mexico, American and European settlers began arriving at a slowly increasing rate. Two events of 1848 increased the settlement sharply—the discovery of gold near Sutter's sawmill on January 24, and Mexico's cession of California to the United States by the Treaty of Guadalupe Hildalgo on February 2. By 1849 the rush for gold had touched off a mass westward migration of people who came to mine or to engage in supportive commercial and agricultural activities. After California became a State in 1850, agriculture gradually replaced mining as the principal industry.

Settlement of the Oregon portion of the Region started in the 1840's. Growth there was much slower than in California, and fur trapping and cattle raising were the principal industries for many years.

The population of the Region currently approximates 20 million people, about two-thirds of whom reside in the San Francisco Bay and

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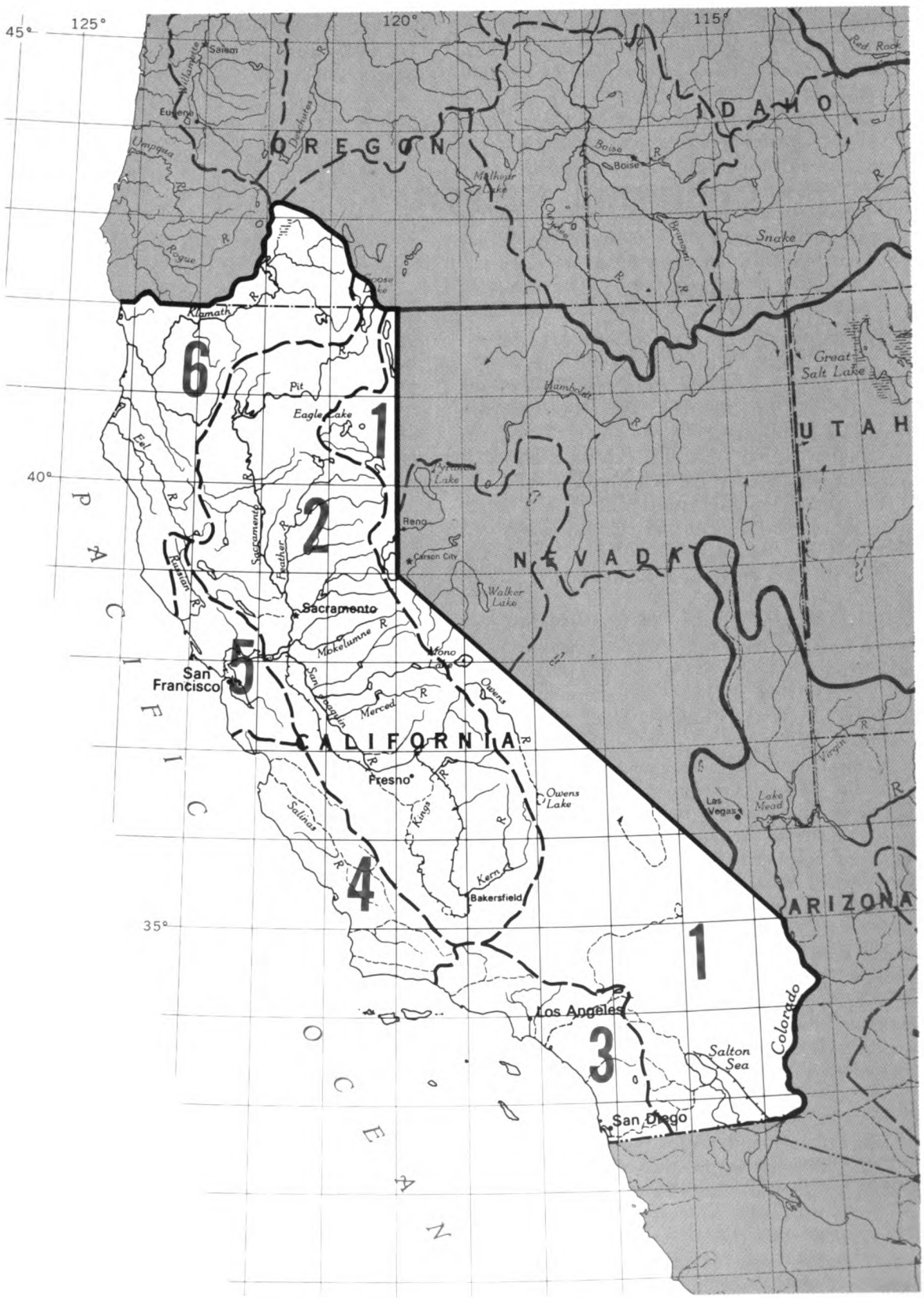

FIGURE 6–17–1.—*Map of the California Region.*

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southern California areas. Regional economic statistics are impressive. Personal income increased from $38 billion in 1959 to $60 billion in 1965. Value added by manufacturing totals about $18 billion. Agriculture production leads the Nation with an annual value of more than $3 billion. The gross irrigable area is about 22.7 million acres; field surveys of land use reveal that about 8.42 million acres were developed for irrigation in 1960, and it is estimated that in 1965 the total developed acreage had reached 8.85 million.

Variations in geography and climate are rather marked from one part of the Region to another. The extreme northern portion, subregion 6, begins in the forested, volcanic uplands, lakes, and reclaimed lakebeds of south central Oregon, includes a transitional area of valleys in northern California, and ends in the rough, mountainous northwestern corner of California. Precipitation here is the heaviest in the Region. The principal rivers are the Smith, Klamath, Trinity, Mad, and Eel.

The center of the Region, subregion 2, is occupied by the great Central Valley, the western slopes of the Cascade Range and the Sierra Nevada, and the eastern slope of the Coast Range. Precipitation is heavy in the mountainous areas of the north, and gradually diminishes to the south until, in part of the southern San Joaquin Valley, it averages less than 5 inches per year. The Central Valley is drained principally by the Sacramento and San Joaquin Rivers, which join southwest of Sacramento and flow to the Pacific Ocean through San Francisco Bay.

The San Francisco Bay area, subregion 5, consists primarily of rolling hills and small valleys. Precipitation is very heavy in the mountains of the southern coastal portion and of moderate intensity elsewhere. The principal streams are the Russian and Napa Rivers and Alameda Creek.

The Central Coast, subregion 4, lies south of the San Francisco Bay area. Mostly mountainous, it also includes a number of fertile valleys. The Santa Lucia Range, in the central part of the western edge, receives heavy rain, but precipitation elsewhere is moderate. The Salinas River is the principal stream.

The South Coast, subregion 3, is bounded on the north and east by the ridges of rugged mountain ranges. Its coastal valleys contain the vast Los Angeles and San Diego metropolitan areas. Urban development is gradually displacing the valuable citrus areas in Los Angeles, Orange, San Bernardino, and Riverside Counties. Precipitation is moderate along the coast, more substantial in the mountains. Many intermittent streams, the largest of which is the Santa Ana River, drain the area.

The portion of the Region east of the ridges of the Cascade Range, the Sierra Nevada, and the southern California mountains comprises parts of the Lahontan Basin and Colorado Desert, subregion 1. Although precipitation in the mountainous central portion near Lake Tahoe is normally abundant, desert conditions prevail in much of the subregion; in some areas of the southeastern portion precipitation averages only a few inches per year. The largest streams are the Truckee, Carson, Walker, and Owens Rivers.

THE WATER RESOURCE

Variation in natural runoff in the Region corresponds generally to the variation in precipitation mentioned previously. Table 6–17–1 presents runoff statistics for each of the six subregions. Average runoff for the Region totals about 65 bgd (73 maf/yr). The maximum seasonal runoff has been about twice the average runoff and the minimum about one-quarter of the average.

The availability of large quantities of water from groundwater sources has been a prime factor in the economic growth of the Region. Groundwater occurs principally in the sedimentary fill of more than 250 valleys which range in area from about 17,800 square miles in the Central Valley to a minimum of about 5 square miles. Studies indicate that a groundwater storage capacity of more than 300,000 billion gallons (1,000 maf) is available throughout California; 25% of this is estimated to represent economically usable storage.

The proportion of storage capacity that is currently occupied by groundwater varies areally. In the northern part of the Region, the annual groundwater pumpage is replenished by recharge to the basins, and a large proportion of the storage capacity is filled. In many of the central and southern basins, however, annual withdrawals exceed annual recharge—groundwater is being mined, and the basins are in overdraft. In the San Joaquin Valley, for example, more than 22,800 billion gallons (70 maf) of water have been mined, resulting in continuous lowering of the water table, saline connate water intrusion, and land surface sub-

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TABLE 6–17–1.—*Annual natural runoff, California Region*

Subregion	Drainage area	Average runoff		Annual flow exceeded in indicated percent of years		
				50	90	95
	sq. mi.	*bgd*	*in/yr*	*bgd*	*bgd*	*bgd*
1	52,600	3.00	1.20	2.94	1.45	1.11
2	60,100	30.20	10.55	29.60	14.56	11.17
3	11,000	1.10	2.10	.70	.21	.15
4	11,300	2.19	4.07	1.75	.39	.22
5	6,200	2.67	9.04	2.23	.62	.38
6	23,500	25.90	23.14	25.38	12.48	9.58
Regional value [1]	164,700	65.1	8.30	64.1	32.8	25.6

[1] The values do not include a supply of 4.5 to 4.6 bgd (5.0 to 5.1 maf/yr) diverted into southern California from the Colorado River.

Note: Base period 1895-1947 for California portion of the region, as used in "Water Resources of California," Bulletin No. 1, State Water Resources Board, California, 1951.

sidence. Many of the basins in the South Coastal subregion are in overdraft, and groundwater levels in a year of average precipitation and pumpage continue to fall. In general, however, a large proportion of the usable groundwater throughout the Region is still economically obtainable, although much of it is located in areas of little demand.

In the major water supply areas—the North Coastal subregion and the Sacramento basin of the Central Valley subregion—water is of excellent mineral quality and suitable for all uses. In areas that are water deficient to some extent, the quality of natural surface waters varies greatly. In the Sierra Nevada, for example, and the higher mountains of the Coast Range south of San Francisco Bay, water is of excellent quality; in the more southerly areas, particularly in the lower portions of closed drainage basins, water is of poorer quality.

PRESENT WATER RESOURCES DEVELOPMENT—1965

The Region's agricultural and urban development could not have taken place unless water supplies had been moved from their natural places and times of occurrence. Precipitation occurs largely in the cool fall, winter, and spring months, and during the summer growing season is almost nonexistent throughout the Region. Thus, irrigation is essential for agriculture and for maintenance of lawns and gardens in residential areas. Domestic water use has increased with the installation of home laundry systems, dishwashers, and similar appliances. Many industries depend upon essentially constant water supplies for washing, processing, or cooling.

Generally, the same quantities of water are used for a given purpose from year to year, regardless of the relative wetness of the years. Most supplies are firmed by surface water or groundwater storage. In the northern part of the Region, however, some variations in water use occur from year to year because of the area's greater dependence upon variable spring precipitation for crop production and for maintaining urban green areas. Annual use also varies where irrigation of mountain pastures depends upon fluctuating uncontrolled runoff, but the quantities are minor.

Estimates for water withdrawal and consumption in 1965 are presented in table 6–17–2. For both withdrawal and consumption, irrigation is the dominant water use, accounting for some 70% of withdrawals and over 90% of all consumption. The table does not include instream uses and management consideration. These, for the most part, can be discussed only qualitatively.

Hydroelectric power comprises an important instream use of the water resources of the Region and its value for flexible peaking service is well recognized. In 1965, it was estimated to have supplied about 5 million kilowatts (including the Colorado River generation), or about 25% of the total peaking power requirements in that year. The total quantity of water used in the Region in 1965 for hydroelectric power generation averaged 102 bgd (114 maf/yr). Of this amount, approximately 82 bgd (92

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TABLE 6–17–2.—*Present water use, 1965, California Region* [1]

(Million gallons per day)

Subregion	Rural domestic [2]	Municipal [3]	Self-supplied industrial [4]	Steam-electric power [5]	Agriculture		Total
					Irrigation [6]	Livestock	
			Water withdrawn				
1	5	100	35	0	4,680	5	4,825
2	55	780	215	10	18,000	45	19,105
3	5	2,250	385	4,320	770	15	7,745
4	5	120	55	830	830	5	1,845
5	5	720	470	480	210	5	1,890
6	15	40	90	30	1,710	5	1,890
Total	90	4,010	1,250	5,670	26,200	80	37,300
From:							
Groundwater	(80)	(1,860)	(620)	(20)	(11,000)	(30)	(13,610)
Saline	(0)	(0)	(540)	(5,600)	(0)	(0)	(6,140)
			Water consumed				
1	5	30	5	0	2,630	5	2,675
2	35	270	45	10	14,260	25	14,645
3	5	790	35	93	710	5	1,638
4	5	40	5	7	560	5	622
5	5	180	15	4	150	5	359
6	5	10	5	0	980	5	1,005
Total	60	1,320	110	114	19,290	50	[7] 20,944

[1] Includes use of water imported from Colorado River.
[2] Water used for domestic purposes not served by public systems.
[3] Serves a population of 17,317,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[4] Water supplied by industries themselves. Also includes military establishments.
[5] Public utility uses by steam-electric powerplants (predominantly for cooling).
[6] Includes conveyance losses.
[7] The estimated "net water requirement" in the State of California during 1965, based on information in Department of Water Resources' Bulletin No. 160-66, "Implementation of the California Water Plan," totals approximately 22,100 mgd. This, however, includes irrecoverable losses, such as sewage flow to the ocean and percolation of applied water to saline groundwater, as well as consumptive use of applied water.

maf) was used by plants which returned the water to the original stream within 10 miles of the point of diversion.

The principal navigation activity, other than in coastal waters and waters of the San Francisco Bay system, is in the Sacramento-San Joaquin Delta and on the Sacramento River. Oceangoing vessels are able to reach Stockton and Sacramento through deepwater channels. Barge traffic can utilize other channels of the Delta and navigate the Sacramento River as far north as Colusa, some 85 river-miles upstream from Sacramento. Navigation depths are maintained by dredging and, in a critical part of the river between Colusa and Sacramento, by water releases from the Central Valley Project.

Much of the Region's outdoor recreation activity is related to streams, lakes, and reservoirs. In California alone, this water-related activity is estimated to total more than 200 million visitor-days per year. Use of the waters of streams, lakes, and reservoirs for preservation and enhancement of fish and wildlife resources is of great importance. Such resources are highly desirable as recreation assets; they are also vital to the regional economy because they help support the tourism industry and provide the basis for the commercial fishing industry. One problem that will become increasingly important is the return to the streams or the ocean of water that has been heated in the steam-electric power process. Unless this is given consideration, fisheries may be adversely affected.

Management and control of water and related land are also important. Typical watershed management programs being carried on in various parts of the Region are aimed, for example, at maximizing economic returns of commodities produced, preventing reduction of land fertility, controlling sediment in streamflow, improving

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aesthetic conditions of the areas involved, and enhancing habitat for fish and wildlife.

Effective flood protection is essential for continued sound economic growth. Flood hazards have been reduced by construction of levees, channel improvements, and flood control reservoirs. Both Federal and State flood plain management laws are encouraging local governments to zone areas subject to flooding so as to reduce flood damages.

Agricultural drainage is an essential adjunct to effective irrigation. Farmers in the Imperial Valley, for example, have installed 1,000 miles of open drains and over 10,000 miles of tile drains. Such installations, on a lesser scale, are also found in other parts of the Region.

Water quality control in California is under the auspices of the State Water Resources Control Board. A similar agency functions in Oregon. Standards for waste discharges have been or are being established to protect the valuable resources of receiving waters. The Central Valley Project, incidental to its operation for water supply purposes, controls water quality through releases of water from storage in summer months. These releases prevent the incursion of sea water into the Sacramento-San Joaquin Delta waters which are used for irrigation and other purposes in that area and for export.

ADEQUACY OF PRESENT DEVELOPMENT

Present water resources development in the Region is adequate to meet most present-day needs for consumptive uses of water if developments now authorized or under construction go into operation as planned. Land resources are more than adequate to meet current needs for cities and agricultural areas. In California, for example, about 14 million acres of irrigable land have not yet been utilized. Additional undeveloped usable land is found in the Oregon portion of the Region.

In other respects, the present status is less satisfactory. The principal deficiencies stem from the changing and competing nature of water uses for industries, crops, cities, and recreation. It is this competition that has generated the present increased awareness of the need for pollution control, protection and enhancement of fish and wildlife, increased recreation opportunities, preservation of natural values, protection of public health, and improved land use.

The water supplies of most local areas are adequate to meet today's needs. More and more frequently, however, limitations in reservoir storage or distribution system capacities cause temporary shortages in periods of drought or peak demand. Conditions will of course not remain static, and the implications of projected growth in water demands will be discussed later.

Much of the Region, and particularly the southern two-thirds, is highly dependent upon groundwater. Although in many areas the groundwater basins are of large volume, there are also areas where the basins are shallow or their yields are limited during periods of drought. In portions of the San Francisco Bay, Central Coastal, South Coastal, Central Valley, and Lahontan Basin-Colorado Desert subregions, present groundwater pumpage exceeds the average annual recharge, resulting in storage depletion. In a number of areas, this overdraft condition is still able to sustain economic activity, and it can continue to do so as long as there are no adverse effects. In some localities, however, overdrafts have led to deterioration of groundwater quality, by causing inflow of connate brines or of salt water from the ocean, and to land subsidence. In other areas, the lowering of the water table is such that the economically feasible limits of well construction and pumping are being approached.

In general, construction of conveyance and distribution facilities for municipal, industrial, and irrigation water is following construction of multiple-purpose storage facilities, as dictated by the economics of construction and the timing of special-purpose storage needs, such as those for flood control and power. Interim storage releases have thus been available, in some cases, to alleviate immediate demands for water quality control, fishery, or recreation.

Existing developments are adequate to meet current navigation requirements. Developments for hydroelectric power are insufficient to provide adequate peaking capacity to supplement base-load stream-electric generating capacity.

The adequacy of water-associated recreation and related fish and wildlife resources is difficult to determine precisely because there are alternative outlets for recreation needs. Visitors flock to completed reservoirs by the millions, and recreation facilities are hard pressed to meet current demands. However, many of the sites best suited for recreation and fish and wildlife use are located in areas remote from population centers. As a result, most of the users spend less time at the recreation area than they would prefer, while many city dwellers are unable to reach these areas at all for day use. Southern

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California, particularly, is short of fresh-water recreation areas. Reservoirs in that area are among the few means of providing fishing for the public since stream fisheries are limited.

Alteration of the natural regimen of streams through diversions, construction of storage facilities, and other measures has affected the habitat for fish and wildlife in many streams of the Region. Fishery interests consider that water supplies in the San Joaquin River and other portions of the San Joaquin Valley are inadequate. In some locations, stream channelization, dredging for flood control and navigation, phreatophyte control, and levee clearing have had adverse effects. In other areas, such as the reach of the Sacramento River downstream from Keswick Reservoir of the Central Valley Project near Redding, fishery resources have been maintained and enhanced. Substantial reservoir-type fisheries have been established in the waters impounded by a number of dams.

While the practice of watershed treatment or management is widespread in the Region, improvements in techniques and scope are needed. Experiments in the Sierra Nevada with systematic harvesting of timber to obtain optimum snowpack and snowmelt have shown some promise of increasing the water crop and lengthening the period of spring runoff. These measures have not, however, been evaluated from an economic standpoint. The results of experiments with brush removal from foothill lands to increase the potential for livestock feed, to reduce storm erosion, and to increase the water crop have also been encouraging. Similar studies on methods of preventing land deterioration and of rehabilitating land damaged by overuse or by wildfire will contribute to land protection.

Much has been accomplished in the field of flood control, but developed areas in parts of the Region are still exposed to flooding. Much of the North Coastal subregion is subject to great periodic damage, as evidenced by the Christmas 1964 flood. In the San Francisco Bay subregion, some flood control facilities have been built, but further protection is needed for urban and agricultural improvements along the Russian and Napa Rivers and for urban areas adjacent to restricted natural channels, particularly in the zones of tidal influence near the Bay. Although flood protection is at a relatively high level in the South Coastal subregion, development in some areas has proceeded more rapidly than the provision of flood control measures.

In the Central Valley subregion, reservoirs in the mountains and foothills and levees and bypass channels on the valley floor provide a significant level of protection; but such major streams as the Yuba and the upper Sacramento Rivers still pose flood hazards. Bank erosion, which in places threatens levees of the Sacramento River Flood Control Project, calls for continual maintenance and additional bank revetment. There are problems in the Sacramento-San Joaquin Delta area during major flood periods. Flood damage in the Lahontan and Mojave basins occurs chiefly in the vicinity of Lake Tahoe and along the Truckee and Mojave Rivers. Flooding of the few highly developed urban portions of the Colorado Desert results chiefly from intense summer thunderstorms.

Storm water drainage in some urban areas of the Region is a problem. Large paved areas, which increase the intensity of runoff, urban encroachment on alluvial fans below the outlets of mountain canyons, and inadequate lowland drainage facilities all contribute to flooding. Examples of these conditions may be found especially in southern California. While many drainage problems have been overcome, much remains to be done in direct drainage of the land and in improvement of irrigation practices. For example, only with construction of the proposed San Joaquin Valley drain will the problem of water logged land in the trough of that valley show promise of solution.

Although water quality control is adequate in many parts of the Region, the disposal of surface and subsurface wastes is becoming a significant problem. Algal blooms adversely affect the waters of Upper Klamath Lake and are carried into the Klamath River downstream. Adverse salt balance conditions and saline drainage from uplands on the west side of the San Joaquin Valley have deteriorated the quality in some of the Valley's waters. There is an increasing need to prevent undesirable effects of pollution caused by the discharge of man-made wastes into streams and water bodies such as Lake Tahoe, channels of the Sacramento-San Joaquin Delta, San Francisco Bay, and even the ocean—especially in public beach areas.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

The most significant water rights issues involve the determination of the relative rights of large public water development agencies. The differences of opinion are being settled by negotiation in water rights hearings, which precede granting of permits for construction of

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major storage and diversion projects. A current issue, for example, is the manner in which the Federal Central Valley Project and the State Water Project are to be operated in relation to each other; several problems remain to be worked out, but progress is being made toward logical and equitable solutions.

The major rights and institutional problems in the southern portion of the Region involve the use and augmentation of the waters of the Colorado River. These problems obviously overlap State boundaries and must, therefore, be worked out through cooperation among the States and the Federal Government.

Given the large number of private and local, State, and Federal government agencies involved in water development in the Region, competition, overlapping jurisdictions, and areas of conflict are difficult to avoid. The activities of the four major Federal and State agencies dealing in water resources are now coordinated through the California State-Federal Interagency Group to eliminate overlap of studies and possible conflicts in planning. The four agencies are working together on a single plan of development in a cooperative planning effort now in progress in the California portion of the North Coastal subregion. Collaboration of Federal and State agencies in the type 1 comprehensive framework study will permit further progress in this direction.

The legislation which authorized and funded the State Water Project adjusted the controversy between northern and southern California interests with respect to water export from the north to meet the needs of the south. This was accomplished through the financial measure known as the "Delta Pooling Concept," which set aside authorized bonds for construction of additional conservation projects in the north when they will be needed to meet growing water demands.

As previously stated, a number of water quality control problems have been met and largely solved through the water quality control agencies in Oregon and California. The Water Quality Control Act of 1965 was intended in part to assist and induce State and local agencies to identify and find solutions to such problems. There are potential future problems in water quality management, however, because of possible differencies between Federal and State points of view.

The problems caused by the expanding population on the shores of Lake Tahoe and San Francisco Bay are leading to consideration of regional metropolitan agencies to supplement present local governments for the control of pollution and waste disposal.

The Federal statutory provision that water from Federal reclamation projects shall not be delivered to those portions of holdings that exceed 160 acres in single ownership or 320 acres in joint ownership is causing some problems in the Region. The intent of the law is to insure that benefits of the Federal investment be widespread. However, agricultural interests consider that under present economic conditions larger farms are essential; therefore, review and revision of the law is being called for.

Within Federal project areas, landowners with holdings in excess of the statutory limits must sign contracts agreeing to dispose of their excess holdings within 10 years in order to receive water. Moreover, in the Imperial Valley of Southern California, which is served by the All-American Canal from the Colorado River, the Federal Government recently reversed an opinion holding that the acreage limitation did not apply. Most water service from these projects supplements local resources of non-Federal origin.

Federal land laws are currently being reviewed by the Public Land Law Review Commission on a national basis, but conclusions are not yet available. Specific items being considered by the Commission of concern to the California Region include local zoning, land exchanges, trespass, illegal occupancy, and access. Land management generally reflects the increasing public desire for measures which would encourage more attention to aesthetic and environmental values while planning for the accommodation of the burgeoning regional population.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

Growth of the California Region is expected to continue unabated until beyond 2020. Projections of factors pertaining to economic growth are shown in table 6–17–3.

The two factors which most directly affect estimates of water requirements are population and irrigated land. Using the projected values of these factors, as well as unit water use and other information projected by the State of California, as a basis, the withdrawal requirements for various uses have been estimated, as shown in table 6–17–4. Also shown in the table are projections of net water requirements

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TABLE 6–17–3.—*Economic and agricultural projections, California Region*

Item	Unit	1960 [1]	Projections 1980	2000	2020
Population, total	thou.	15,584	28,167	43,317	[2] 64,003
Per capita personal income	1954 dol.	2,410	3,750	5,450	8,175
Employment, total [3]	thou.	6,120	11,296	17,148	25,150
Agriculture	do.	284	223	194	193
Manufacturing	do.	1,462	2,748	3,891	5,262
Other commodity producing	do.	740	1,000	1,304	1,703
Distributive industries	do.	1,556	2,683	3,762	5,179
Service industries	do.	2,077	4,642	7,998	12,813
Land base	thou. ac.	104,031	104,031	104,031	104,031
Agricultural	do.	81,884	77,834	73,354	68,764
Cropland total [4]	do.	13,566	12,577	11,856	11,117
Used for crops	do.	11,306	9,800	9,865	11,021
Idle and fallow	do.	2,260	2,777	1,991	96
Pasture-permanent	do.	22,900	22,087	20,815	19,511
Forest and woodland	do.	45,418	43,170	40,683	38,136
Nonagricultural	do.	22,147	26,197	30,677	35,267
Irrigated land [5]	do.	[6] 8,420	10,150	10,750	[7] 11,100

[1] Some data for 1959.
[2] Estimated 2020 population of the State of California, published in State Department of Water Resources' Bulletin No. 160–66, "Implementation of the California Water Plan," is 54,300 thousand. This was based on U. S. Bureau of the Census Series C projections. Due to recent lower birth rate trends, the State is now revising these estimates to reflect the Series D projections.
[3] May not check due to rounding.
[4] Includes cropland used as pasture.
[5] Includes cropland and pasture.
[6] In 1965 irrigated land amounted to 8,850 thousand acres.
[7] Estimated 2020 irrigated area in the State of California, published in Bulletin No. 160–66, is 10,775 thousand acres.

for these uses. The values include consumptive uses of applied water and irrecoverable losses, such as those portions of applied water that percolate to groundwater of unusable quality, or surface return flows or sewage outflows that cannot be reused. (These net requirements are based on factors used by the State of California in Bulletin No. 160–66, "Implementation of the California Water Plan".)

Projections of subregional water requirements are shown in table 6–17–5. The figures in this table do not include future cooling water requirements for steam-electric powerplants that may largely be obtained from saline water sources. Most of such developments requiring large quantities of cooling water will probably be located next to the sea or bodies of brackish water, resulting in no demand upon the Region's fresh-water supplies. Water temperature changes resulting from water use for cooling purposes could have serious effects upon biotic communities and their environment.

Future instream water requirements and management and control needs have not been quantified. It is probable, however, that additional navigation requirements in the major streams will not be extensive, but recreation and fish and wildlife needs will increase substantially. The California Department of Parks and Recreation has estimated that visitor use in that State of all outdoor recreation facilities in 2020 will amount to nearly 5 billion visitor-days. Also, the population growth of the Region could place additional millions of people in areas susceptible to flooding.

With a greater proportion of the available water supply being utilized a number of times, the need for water quality control in certain areas will increase. Protection of water quality in the San Joaquin River, the Delta, and San Francisco Bay will become increasingly difficult, since these waterways would normally carry wastes to the ocean. Continual vigilance will be required to prevent degradation of quality in groundwater basins from adverse salt balance or intrusion of poor quality waters from the ocean or from connate sources. Agricultural drainage, with the level of development anticipated at least until 1990, is not expected to affect the quality of the Sacramento River unreasonably, considering the additional streamflow that will be available from flow regulation and importations from the North Coastal subregion to satisfy needs for water supply in the Central Valley and elsewhere.

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TABLE 6–17–4.—*Projected water requirements, California Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	90	90	90	90
Municipal (public-supplied)	4,010	5,090	8,280	12,690
Industrial (self-supplied)[1]	1,250	1,660	2,590	3,960
Steam-electric power:				
Fresh water	70	90	300	300
Saline water	5,600	18,300	77,400	194,900
Agriculture:				
Irrigation	26,200	30,950	31,700	32,600
Livestock	80	110	150	220
Total	37,300	56,290	120,510	244,760
Consumptive use				
Rural domestic	60	60	60	60
Municipal	1,320	4,620	7,350	11,300
Industrial	110	380	620	960
Steam-electric power:				
Fresh water	70	80	100	180
Saline water	44	185	740	1,730
Agriculture:				
Irrigation	19,290	23,800	23,700	23,800
Livestock	50	80	90	160
Total[2]	20,944	29,205	32,660	38,190

[1] About 60% are from saline sources.
[2] Includes irrecoverable losses such as discharge to the ocean and percolation to saline ground water, except municipal and industrial uses in 1965.

TABLE 6–17–5.—*Estimated water requirements by subregions, California Region*[1]

(Million gallons per day)

Subregion	1960		1980		2000		2020	
	Withdrawal	Consumption	Withdrawal	Consumption	Withdrawal	Consumption	Withdrawal	Consumption
1	4,280	3,930	4,610	4,050	4,670	4,110	4,960	4,320
2	18,620	12,290	24,860	18,530	26,930	19,380	30,770	21,560
3	2,380	1,900	3,670	3,120	4,800	4,080	5,700	5,180
4	660	570	910	730	1,240	1,010	1,700	1,550
5	800	750	1,420	1,340	1,860	1,780	2,280	2,140
6	370	310	1,500	1,170	1,900	1,460	2,000	1,530
Total	27,110	19,750	36,970	28,940	41,400	31,820	47,410	36,280

[1] Excludes steam-electric power and saline industrial uses.

As more land is used for agricultural purposes and timber resources are harvested, exposing the land to erosion, watershed treatment needs will undoubtedly increase.

EMERGING WATER PROBLEMS

Comparison of projected net water requirements (such as those given in tables 6–17–4 and 5) and available water supplies (determined

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chiefly from simulated operation studies of existing and authorized water development facilities) reveals various emerging water problems. A small unsatisfied water requirement is developing in the northeastern part of San Francisco Bay subregion. This will amount to about 35 mgd (39,000 af/yr) and could be serviced from the proposed West Sacramento Canal of the Central Valley Project. A portion of the 2020 water demands of the southern San Francisco Bay subregion and the northern Central Coastal subregion—about 250 mgd (280,000 af/yr)—could be satisfied from the authorized San Felipe Division of the Central Valley Project. The Central Coastal subregion alone, however, will require an additional 450 mgd (504,000 af/yr) by 2020.

By 2020, the Central Valley subregion will need about 3.5 bgd (3.9 maf/yr), mainly south of Fresno. The proposed transfers from the Eel and Klamath Rivers and the East Side Canal of the Central Valley Project could supply most of this.

In the South Coastal subregion, the additional need will amount to about 1.5 bgd (1.7 maf/yr) by 2020. This estimate is premised upon the continued import of about 0.5 bgd (0.55 maf/yr) from the Lower Colorado Region.

With the exception of some local supplies and the planned California State Water Project imports to Coachella Valley, imports from the Lower Colorado Region of 3.4 bgd (3.85 maf/yr) are the major source of water in the Colorado Desert. The principal irrigated areas (in addition to Coachella Valley) are Imperial, Palo Verde, and Yuma Valleys. The quantity of water available, as well as its cost relative to the farmers' abilities to pay, will limit future irrigation development. There is sufficient irrigable land for a far higher level of development than exists.

Total deliveries to the California Region from the Lower Colorado Region are projected to be 3.9 bgd (4.40 maf/yr). This quantity is based upon the priorities provided for in the Colorado River Basin Project Act (PL 90-537).

The additional water supply needs might be met from one or more alternative sources, depending upon relative costs and other considerations. It appears that until 2000 these needs could best be met by importing water from the Sacramento River basin and the North Coastal subregion. The probable upper limit of water supply that could be developed in the latter area is about 9 bgd (10 maf/yr). However, 60% of this would be from the Lower Klamath River where fishery and other problems would be extensive; about 0.9 (1 maf/yr) would be from the Lower Eel River where costs would be high. After 2000, therefore, costs and other aspects of import from the North Coastal subregion would have to be compared with those of other alternatives, including desalination and a Western States water plan.

The growing need for recreation opportunities will require the maximum feasible integration of recreation resources of streams, lakes, and reservoirs and other recreation resources. The role that preservation and enhancement of fish and wildlife can play in meeting this recreation demand will be important.

Population growth and increasing per capita use of electric power is expected to cause more than a tenfold increase in power demands in the Region by 2020. This will expand the potential market for hydroelectric power at lower capacity factors, continuing recent trends. The most economically feasible hydroelectric power generating facilities will probably be installed in connection with large multipurpose reservoirs, water supply systems, or independent pumped-storage projects.

To protect urban developments of the future, existing standards of flood control levee systems will undoubtedly have to be improved and additional flood control storage constructed. In particular, major flood-prone sections of the North Coastal area need immediate protection against recurrence of disastrous flood damage. Alternative means of providing protection, including flood plain management, must be examined to insure that the means employed are economically sound and of maximum effectiveness.

Facilities such as the San Joaquin Valley drain will be necessary to prevent salt accumulation on productive agricultural lands. On-farm tile drains and other drainage systems in connection with the master drainage networks will also be necessary. A satisfactory plan for safe disposal of San Joaquin Valley flows remains to be developed to the satisfaction of all agencies concerned. Degradation of Colorado River water will create problems by increasing irrigation requirements for leaching and by increasing water-softening costs to municipal and industrial users.

Cursory appraisals over the past years have shown the need for several hundred small watershed projects. Major purposes of these projects would include flood prevention, irrigation, municipal and industrial water development,

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agricultural drainage, recreation development, and fish and wildlife enhancement. In many cases, the watershed lands have deteriorated and are in critical need of land treatment measures for their preservation and for reduction of their contribution of sediment.

In the water quality field, the principal emerging problems involve wastes that are nontreatable under present technology and must be conveyed to the ocean for disposal. If sufficient water is not available for dilution of these wastes in natural channels, either artificial channels or development of the necessary technology for treatment will be required.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Of the emerging needs for supplemental water supplies, a number are now materializing. Projects required to meet 1980 needs, which can now be identified, include the West Sacramento Canal and the San Felipe Division of the Central Valley Project, and Marysville and New Melones Reservoirs.

Conveying large quantities of water across the Sacramento-San Joaquin Delta for the State Water Project and the Central Valley Project will aggravate problems of water quality control and fish and wildlife preservation. This situation will be ameliorated by the Peripheral Canal, which will require early authorization and construction so that it can be operable by the mid-1970's.

Kellogg Reservoir in Contra Costa County will be needed to augment supplies now obtainable from the Contra Costa Canal of the Central Valley Project. The East Side Canal will be needed to meet demands in the San Joaquin Valley.

If future requirements are to be satisfied, it is imperative that local conservation developments, including wastewater reclamation, continue. Local development of groundwater, surface water, or both, in the North Coastal, San Francisco Bay, Central Coastal, Central Valley, and northern Lahontan subregions must continue.

Expanding needs of the North Coastal area demand early construction of additional flood control measures to permit realization of the area's economic potential. It is envisioned that multiple-purpose reservoirs will be needed on the Mad, Eel, and Russian Rivers.

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CHAPTER 18

Alaska Region

SUMMARY

The water resources of the Alaska Region are impressively abundant. The average annual natural runoff is estimated to be 580 bgd, with an additional 130 bgd entering the Region from Canada, and the groundwaters are extensive. Generally well-distributed throughout the Region, the water supplies are adequate to meet any overall foreseeable needs. However, in cold areas such as the Northwest and Southwest subregions and parts of the Interior subregion, there is seasonal deficiency, and regulation and distribution of available supplies are extremely difficult problems.

Projections of population growth and economic development in the Region indicate that water demands will increase rapidly, particularly for municipal and industrial uses. Near-future economic growth involves industries that extract and process mineral, forest, and fishery resources—all of which involve large uses of water. In general, however, the available supplies greatly exceed the projected demands, and, except in local areas of intensive development, the Region will have a water surplus for many years to come.

The largest increase in water use will be for hydroelectric power generation. The Region has the largest reserve of undeveloped waterpower in the Nation. Development needs for watershed protection, flood control, and navigation will remain local in nature in the near future. However, increased use of the forest and mineral resources will certainly require increased attention to needs for watershed management and river control.

In their natural state, water and related land resources have outstanding values. They are an important part of the Region's scenic attraction and recreation potential. They support large populations of migratory waterfowl and other game species and prime commercial and sport fisheries. Any water resource development plan must give full consideration to preservation and enhancement of natural values, for the natural state may constitute optimum use in many cases.

DESCRIPTION OF THE REGION

Geography and Climate

The Alaska Region consists entirely of the State of Alaska, the largest of the 50 States, and the westernmost extension of the North American Continent. Its 586,400 square miles of area include over 15,300 squares miles of water—more than 3 million lakes and thousands of miles of rivers; even so, there is still room left for two principal and numerous minor mountain ranges. Its coastline—33,000 miles in length—is 50% longer than that of the conterminous United States. For study purposes, the Region was divided into five subregions based upon physical factors. The subregions and major geographical features are shown in figure 6–18–1.

The geographical features have a significant bearing on the Region's varied climate. A zone of maritime influence extending throughout southern Alaska along the Gulf Coast experiences a mild, wet climate. Annual precipitation amounts at sea level are generally above 60 inches and at some stations as high as 200 inches. The rugged mountains in the Southeast subregion and along the coast of the Gulf of Alaska in the South Central subregion experience even higher precipitation amounts. These areas contain the principal glaciers of the State.

Away from the zone of maritime influence, the climate changes rapidly—with decreasing amounts of precipitation and greater extremes of temperature. Average annual precipitation in the Interior subregion is about 12 inches and along the Arctic Slope usually 6 inches or less; however, the mountainous areas have considerably more.

Mean annual temperatures range from the lower 40's in the coastal areas under the maritime influence to 10° along the Arctic Slope.

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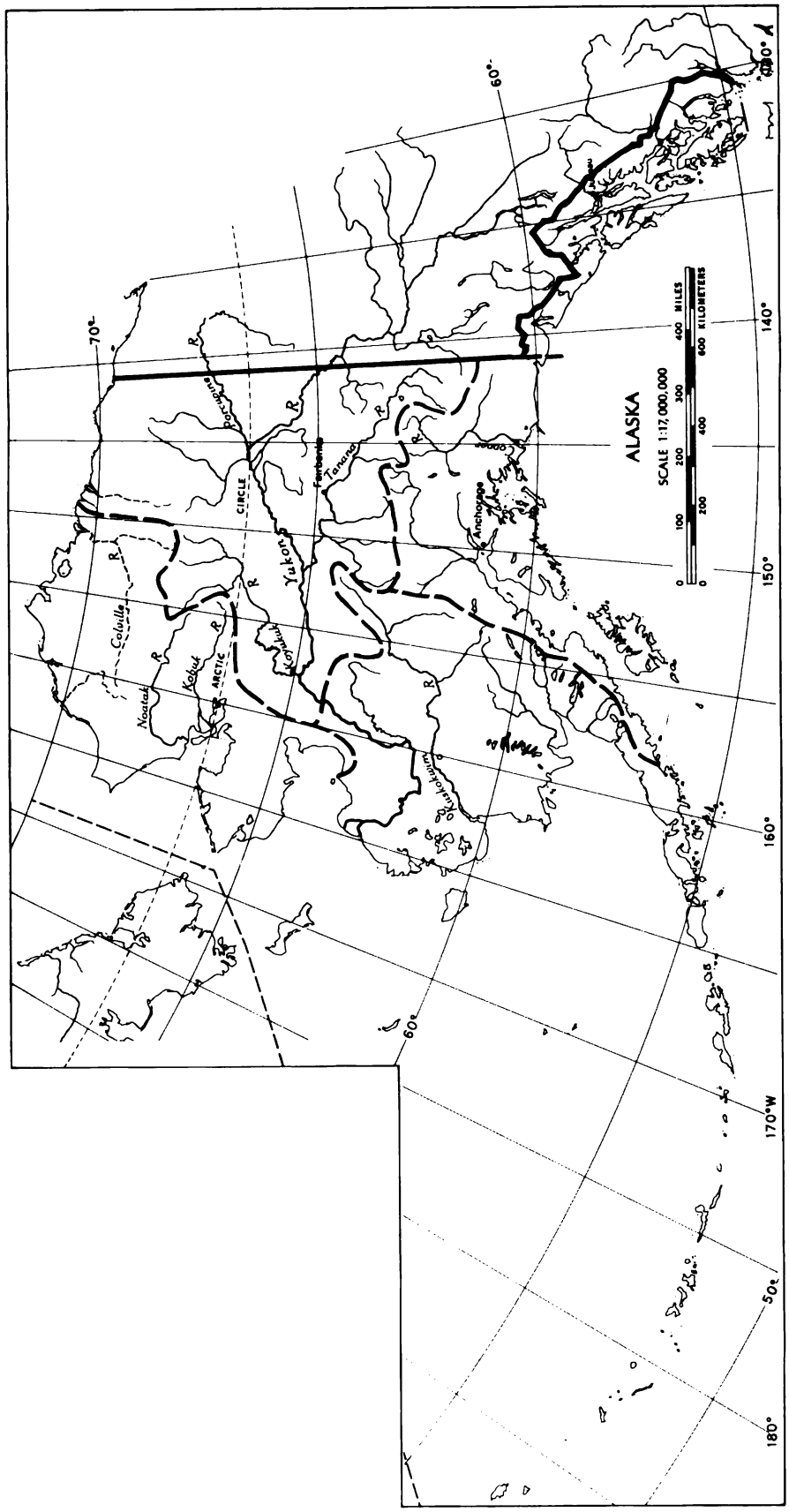

FIGURE 6–18–1.—*Map of the Alaska Region.*

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The greatest temperature contrasts between seasons are found in the Interior subregion, where summer produces average maximum temperatures in the upper 70's and extremes in the 90's; average winter minimums are -20° to -30°, with extremes in the minus 50's and occasionally even lower.

Strong surface winds affect shipping and fishing activities about eight months of the year from the Aleutian Islands eastward to the Gulf of Alaska. Winds are generally light in the Interior subregion, but they become a problem again along the Arctic Slope where, coupled with subzero temperatures, they create a hazard to people who are exposed for even short periods of time.

The continuous permafrost that exists over roughly the northern third of the Region and the discontinuous permafrost that extends over parts of the Southwest and South Central subregions present difficult water supply problems.

History

Vitus Bering, sailing under the Russian flag, discovered Alaska in 1741. The first permanent settlements were founded in the late 18th century by Russian trappers seeking furs. In 1867, Alaska was sold to the United States for $7,200,000.

Development of the area was very slow until the discovery of gold in Juneau in 1880. Increased prospecting led to gold strikes in several other areas, generating the first population boom and rapid development of the gold, salmon, and timber industries followed. However, during the 1930's, depressed markets, in combination with other factors, brought about a decline of these industries.

During World War II, Alaska became recognized as strategically important to national defense. The military construction period that followed brought new life to the territory in the form of people, roads, and service-oriented businesses. Alaska was growing, and statehood was granted in 1958.

Demography

The population grew from about 33,000 in 1897 to 129,000 in 1950, 226,000 in 1960, and 267,000 in 1965. The expansion in the 1950's was largely a result of military activity (the population figures include military personnel and their dependents). The growth since that time represents industrial and business expansion and the establishment of State government functions. The annual growth rate for the period 1960 to 1965 was 3.2%, or about twice the national average.

The Region's birth rate is the highest in the Nation. The population is young, with approximately 77% under 39 years of age, and the education level is high, with 9.5% of those over 24 years of age having four or more years of college.

The population is also largely urban, and, except for Fairbanks, the cities are all located in the coastal South Central and Southeast subregions. The three largest urban areas are Anchorage, 102,300; Fairbanks, 46,500; and Juneau, 12,400. The Region is considerably more inhabited in summer than in winter because of the seasonal influx of tourists and workers.

Economy

Historically, the Region's economy almost exclusively relied upon the development of natural resources until the military construction period started in the 1940's.

The regional personal income has shown significant growth in recent years, increasing from $0.5 billion at the time of statehood in 1958 to $0.9 billion in 1966. The economy currently relies heavily on government functions. In 1964, government wages—Federal, State, and local—accounted for 56% of personal income; commodity industries, for 14%; and distribution industries, for 30%. However, the oil and gas, forest products, and fishery industries are becoming important. Tourism has also become a major industry, and increased activities in mineral exploration may lead to significant new developments. Data concerning the principal commodity industries and the recent increase in tourism are presented in table 6–18–1.

THE WATER RESOURCE

The average annual natural runoff in the Alaska Region amounts to an estimated 580 bgd. An additional 130 bgd originates in British Columbia and the Yukon Territory and flows into the Region. The term "natural runoff" is especially appropriate as applied to the Alaska Region, in that water resources developments to date have had no significant impact on these resources.

Any discussion of the Region's water resources logically starts with the Yukon River. The Yukon, by drainage area and runoff, ranks

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TABLE 6–18–1.—*Growth in commodity industries and tourism, Alaska Region*

Industry	Value of commodity production in millions of dollars						
	1960	1961	1962	1963	1964	1965	1966
Fisheries	96.5	128.7	126.5	104.7	125.0	166.5	185.0
Forest products	47.3	44.7	49.7	50.1	58.0	57.5	67.8
Minerals	20.6	17.8	18.8	35.2	35.5	[1] 47.6	34.7
Oil and gas	1.3	17.0	28.4	32.7	35.5	35.6	50.2
Agriculture	5.4	5.5	5.8	5.5	5.6	5.2	5.5
Furs	4.8	4.2	4.3	4.4	4.4	5.8	[2] 7.0
Total	175.9	217.9	233.7	232.6	264.0	318.2	350.2
	Estimated number of tourists visiting in Alaska during April-Septetmber						
Number of tourists	62,600	63,500	68,900	85,800	85,900	95,500	

[1] Reflects post-earthquake construction.
[2] Largely an increase in unit prices.

among the five largest river systems of the North American continent. It drains a total area of 330,000 square miles, one-third of which is in Canada. The Alaska portion of the Yukon drainage area constitutes roughly 40% of the Region's land area.

The 12 largest rivers and the 3 largest tributaries of the Yukon River are listed in table 6–18–2, together with drainage areas and estimated average runoff, as well as the 7 largest lakes. The Yukon, Stikine, Alsek, and Taku may be classed as major international rivers. The 12 rivers (including the Yukon) drain roughly two-thirds of the Region. The remainder is drained by thousands of river and stream systems discharging independently into the ocean.

A rather wide range of runoff characteristics is exhibited. Low-lying areas within the influence of the Gulf of Alaska have high unit runoff with relatively little seasonal variation. Runoff from the mountainous areas adjacent to the Gulf is unusually high—annual unit runoff usually exceeds 100 inches, and in some areas exceeds 300 inches. At the other extreme, low runoff rates and progressively shorter summer runoff seasons are characteristic of the northern areas; from 80% to 95% of the annual runoff occurs during the 5-month period, May-September.

The mountains near the Gulf of Alaska contain the Region's largest glaciers; Malaspina, the largest of them all, is approximately the size of Rhode Island. Streams fed by the glaciers exhibit sustained high summer flows and relatively little variation in flow from year to year. The Alaska Range also has numerous glaciers, and these dominate the runoff characteristics of the Copper and Susitna River systems and of many Yukon and Kuskokwim tributaries draining the north slopes of the mountains. The glacier-fed streams carry large amounts of sediment.

Permafrost (permanently frozen ground) has a widespread effect on water supplies in the Interior and Northwest subregions. By restricting subsurface drainage, permafrost creates extensive wetland areas and restricts groundwater recharge. As a result, many streams of the Interior subregion and most streams and rivers of the Northwest subregion have little or no winter flow.

Severe annual flooding, complicated by ice jams, is characteristic throughout the Region. Large areas are inundated each year by overbank flow, causing evacuation of the villages along the rivers. Ice scour contributes to heavy debris and sediment loads during the spring breakup.

Water quality is good throughout the Region, except in two specific situations: (1) the sediment content of glacier-fed streams is high; (2) groundwaters and surface waters that derive from extensive muskeg and swamp areas are usually high in organic and iron content because the drainage of such areas is often restricted by impermeable subsurface materials, including permafrost.

At present, knowledge of groundwater resources is limited to the more settled areas. The principal localities of groundwater use are Anchorage (including Palmer), the Kenai Peninsula, and Fairbanks. Comprehensive

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TABLE 6–18–2.—*Major rivers and lakes, Alaska Region*

River	Subregion	Drainage area	Average annual natural runoff
		sq. mi.	*bgd*
Yukon	Interior	[1] 330,000	139.5
(Koyukuk)	(Interior)	(32,600)	(20.7)
(Tanana)	(Interior)	(44,500)	(22.0)
(Porcupine)	(Interior)	(46,200)	(12.3)
Kuskokwim	Southwest	43,600	40.1
Copper	Southcentral	[2] 24,400	34.0
Colville	Northwest	24,000	7.8
Stikine	Southeast	[3] 19,700	40.1
Susitna	Southcentral	19,400	27.8
Hushagak	Southwest	14,100	12.9
Noatak	Northwest	12,600	6.5
Kobuk	Northwest	12,000	8.4
Alsek	Southeast	[3] 9,500	12.9
Kvichak	Southwest	7,700	14.2
Taku	Southeast	[3] 6,700	7.1

Lake	Subregion	Surface area
		sq. mi.
Iliamna	Southwest	1,000
Becharof	Southwest	458
Teshekpuk	Northwest	315
Naknek	Southwest	242
Tustumena	Southcentral	117
Clark	Southwest	110
Dall	Southwest	100

[1] Includes 110,000 square miles in Canada.
[2] Includes 1,270 square miles in Canada.
[3] Most of drainage area is in Canada.

studies of the availability of groundwater in certain limited areas have been carried out in the past few years, but no reports have been made on the overall regional availability. Large quantities of groundwater are known to be available throughout most of the Yukon River flood plain, but little use is currently being made of this potential supply because settlements and industrial activity are almost nonexistent. In the portion of the Region that is underlain by permafrost, groundwater is extremely difficult to obtain. In some instances, it is present below permafrost, but in the northern areas its high salinity is a problem. Supplies of groundwater are also limited in the Southeastern subregion and on Kodiak Island where steep mountains, rapid runoff, and a lack of surficial deposits to store and retain the water preclude its extensive use.

As noted earlier, groundwater throughout the Region is generally of good quality; most of it has a dissolved mineral content of less than 200 ppm. However, many areas have problems of high iron content. In the Fairbanks and Kenai Peninsula areas, for example, treatment is needed to remove iron from the groundwater prior to municipal use.

PRESENT WATER RESOURCES DEVELOPMENT—1965

A summary of existing water withdrawal and consumption is presented in table 6–18–3. The developed uses are small and are concentrated in the more populous areas. However, per capita use from public systems is high, reflecting (1) the present unlimited supplies available to some of the smaller communities, and (2) water used by a number of industries, especially canneries.

Major categories of use for self-supplied industry are the processing of timber and seafood; pulp mills at Sitka and Ketchikan are the largest individual users. Water use for seafood process-

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TABLE 6–18–3.—*Present water use, 1965, Alaska Region*

(Million gallons per day)

	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric [4]	Agriculture		Total
					Irrigation	Livestock	
Water withdrawn							
Total	8	32	102	20	—	—	162
From groundwater	(6)	(12)	(7)	—	—	—	(25)
Water consumed							
Total	1	7	4	0	0	0	12

[1] Water used for domestic purposes not served by public systems.
[2] Serves a population of 85,000 through public (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Industrial uses supplied by industries themselves. Also includes military establishments.
[4] Public utility uses by steam-electric powerplants (predominantly for cooling).

ing is concentrated during harvest seasons: in the Southwest subregion, for example, three-fourths of the annual water use for this industry occurs during the 30 days of the salmon season.

Hydroelectric power represents the largest developed water use in the Region—amounting to 748 mgd in 1965. Other instream uses, such as navigation and recreation, involve a large part of the resource, but on a regional basis the intensity of use is very low.

Alaska has 7.4 million acres of lakes that are productive fish habitat, and over 365,000 miles of streams providing additional migration, spawning, rearing, and growth habitat. Salmon production constitutes the most important instream use of the Region's waters. All five species of Pacific salmon are anadromous and are widely distributed from the southeastern border to streams flowing into the Chukchi Sea north of the Arctic Circle. In 1966, over 64 million salmon were caught in commercial fisheries. The value of the harvest to the fishermen was over $48 million and the catch produced about 4 million cases of canned salmon, worth about $119 million. This production varies greatly in different rivers and is not closely related to the amount of runoff. In addition, salmon have rather narrow tolerance limits in their spawning habitat and such matters as bed disturbance, oxygen deficiency, temperature, silt load, water velocity, food supply, and other water quality factors may cause extremely high mortality. This large resource has developed in a natural environment and, since salmon reproduction is in delicate balance with this environment, man-made changes must be very carefully based on adequate knowledge if damage to the resource is to be avoided.

The rivers, lakes, and flood plains of the region also support prime sport fisheries and provide habitat for important waterfowl and other game populations. Recreation use of water, including sportfishing, tends to be localized because of limited access and the small population.

The existing river and watershed control works are strictly local—consisting of floodways, minor dredging, and stabilization measures in cities and towns. Fairbanks, which was completely inundated in August 1967, remains subject to serious flood problems. Flooding also causes periodic evacuation of several villages, principally along the Yukon River and its tributaries and the Kuskokwim River. Otherwise, potential flood damage to existing developments is slight.

ADEQUACY OF PRESENT DEVELOPMENT

There are very few areas within the Region where the quantity of water is inadequate for present needs. However, the provision of adequate supplies of good quality water presents a number of seasonal problems, particularly in the colder areas and in localities of rapid industrial growth.

Overall, pollution is not a serious problem, mostly because the population density of the greater part of the Region is still low. However, in such areas as the Kenai Peninsula, where

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industrial expansion has been rapid, careful control is required to prevent damage to the valuable natural environment resources. Very few of the cities and major military installations have adequate treatment plants. A recent inventory of pollution problems indicated a cost of about $82.3 million to cure those that now exist. This cost would include treatment of domestic wastes (civilian and military) and industrial wastes from pulp mills, petroleum activities, fish processing, and mining.

Although water and sanitation difficulties in small communities are classed as local problems, collectively they are a regional problem that will become major in scope, and should be treated as such. In many areas, sources of supply are limited in the winter by permafrost and extreme cold. Where water does occur in the unfrozen state, it is often high in iron and organic content and requires extensive treatment. To date, costly chemical or mechanical treatment has been the only satisfactory method of sewage disposal. The State and Federal agencies operating in these fields are making notable progress, but substandard sanitary conditions remain the normal case for Alaska's villages. It should be noted, however, that known remote-area science and technology used elsewhere in the world has yet to be employed, other than experimentally, in the Region.

Seasonal water shortages appear in many areas, affecting the existing municipal systems and some industrial supplies. The surface water shortages are the result of low-flow periods in both summer and winter. Usually, the deficiencies can be corrected by providing storage. And, in both the Anchorage and Fairbanks areas, increased use of groundwater has eased winter shortages.

Rapid settlement has resulted in sizable surburban communities without community water supply and sewage systems. In the Anchorage, Fairbanks, and Juneau areas, this factor has created health hazards.

A rather unusual quality problem has arisen in the Kodiak area. Sea water is the preferred processing medium for the crab industry; however, seafood processing wastes in Kodiak Harbor have forced plants to use fresh water with salt added.

The interrelated problems of flooding, ice damage, channel instability, and inadequate drainage make large areas along the major rivers unsuitable for development. Yet these are conditions that can be alleviated by watershed and river control works. Because of the low intensity of regional development, the demand for such control functions is, and will be for some time, slow to develop. Land-use zoning is presently the only available corrective measure for most of these problems.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

The Alaska Region's water resources presently involve very few institutional and management problems, mainly because (1) the resources are still relatively underdeveloped and (2) the entire Region is within one State. The State has recently provided a water appropriation code and is now moving toward revision of its water quality standards in compliance with the Water Quality Act of 1965. Three problems relating to the water code and quality standards need attention now:

1. The section of the Alaska Water Pollution Control Act which provides that "the results of activities connected with gravel washing plants and placer mining operations are not pollution" is at variance with provisions of the Federal Water Pollution Control Act.

2. Existing staffs and expenditure levels will not provide adequate enforcement of the State and Federal Water Pollution Control Acts. Because of the present relatively low degree of pollution in the Region, strong support for a preventive program is urged, since it is far less costly to prevent pollution than to clean up polluted waters. Such a preventive program is especially urgent in light of the Region's current economic expansion and population growth.

3. By 1962, Federal agencies had reserved 77.5 million acres of the public domain for such special uses as parks, wildlife refuges, forests, Indian reservations, and defense installations. The Federal Government and the State of Alaska will need to cooperate closely to avoid possible conflicts in the application of the Alaska Water Use Act to these federally reserved lands.

Interagency cooperation on water resource matters is generally quite effective. However, a real problem exists because each agency must deal with local problems that are spread over a very large geographic area. The result has been coordinated procedures that are often informal or irregular.

The Region has a unique public lands situation. The Statehood Act provided that the State of Alaska could select over 100 million

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acres of land from the unreserved public domain as a land and revenue base. The selection is, of course, largely dependent upon inherent values of the land. The State and Federal agencies with land management responsibilities are expediting classification programs to define land-use potentials to aid the selection. In the near future, the land selection program will require decisions on the following: (1) the potential development of water resources, (2) the review of lands presently reserved for potential water resource projects, (3) the preservation of the natural values of water and related land resources, and (4) the establishment of flood plain management programs.

Land selection has a high priority among the State's current programs. Because of the many implications for water and related land resources, a premium is placed on timely development of long-range water resource plans.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

In the future, the Alaska Region will experience increasing development of its natural resources and a trend away from an economy heavily dominated by government and military functions. The various State and Federal resource agencies are actively pursuing programs to stimulate this development. Emphasis is being placed on resource exploration and inventory, production and marketing research, and expansion of transportation and other service facilities. The Region is experiencing a tourist boom accompanied by rapidly increasing demands for recreation facilities and attendant services.

Key industries have exhibited strong growth in recent years and projections indicate continued expansion in the future. Growth in the fishery industry reflects diversification of the industry into new species and products. The forest products industry in southeast Alaska is moving strongly toward full utilization of optimum yield of the Region's forests. Current production represents only about half the allowable cut that can be harvested under present economic conditions. Timber in interior Alaska is receiving little attention because of economic constraints. Only about 3% of the estimated 300 million board foot cut available is now being harvested. Oil and gas production have advanced dramatically since 1960. Drawing from experience in similar areas of Canada and Russia, the probability is strong that mineral exploration will lead to significant new finds and developments in the near future. As a rule, industries based on extracting and processing these resources use moderate-to-large quantities of fresh water with rather strict quality requirements.

Expansion of other industries in the Region appears less certain at this time. An inflationary combination of (1) increasing commodity, realty, and transportation costs, (2) scarce labor forces, and (3) marketing and climatic factors severely limits the agriculture and manufacturing industries. Future population growth together with improvement of transport, storage, and market facilities, should create a more favorable atmosphere for these industries.

Several recent population projections are compared in table 6–18–4. Some are derived from past growth trends of various population segments, while others incorporate assumptions of accelerated development in one or more of the Region's industries.

Projected water demands based upon anticipated growth are shown in table 6–18–5. The increase in use from public supplies reflects a larger portion of the population served from public systems and an increase in industries deriving water supplies from public systems. Municipal and industrial water demands will increase most rapidly in areas adjoining Cook Inlet in the South Central subregion. Rural use and water use for irrigation are expected to remain minor.

Hydroelectric power will likely remain the largest single developed water use. In 1965, an estimated 748 mgd were used; by 1980, the use can be as high as 8.9 bgd, and by 2000, 89 bgd. Development of hydroelectric projects could proceed slowly or rapidly depending upon the market for power and the cost of power from alternative sources. With few exceptions, these water power developments would be nonconsumptive instream uses.

Other instream uses will gain in importance. The major rivers offer transportation access to many parts of the State where air travel is now the only other means of access. The demands for water-based recreation will grow rapidly, and the fish and wildlife resources will continue to increase in value.

Improved management techniques have already resulted in production increases for certain anadromous species of fish. Additional refinements in management techniques, coupled with fresh water habitat improvement, should

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TABLE 6–18–4.—*Comparison of population projections, Alaska Region*

(Thousands)

Source and date	Historic		Projected				
	1960	1965	1970	1975	1980	2000	2020
Bureau of the Census	226	267					
Projections based largely on past growth rates							
Bureau of the Census, IIB, 1966			277	313	353		
Office of Business Economics, 1967					323	456	630
Projections incorporating assumptions of changed economic growth							
Battelle Institute, 1961					394		
Alaska Department of Labor, 1963			295				
University of Alaska, 1963			312		445		
Interior Dept. Field Report on Rampart, 1965:							
Low			294	356	452	820	1,298
High			306	391	497	996	1,510
FPC Advisory Committee on Economics and Load Projections, 1965				410	[1]453		

[1] Interpolated value.

TABLE 6–18–5.—*Projected water requirements, Alaska Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	8	11	12	13
Municipal (public-supplied)	32	120	230	375
Industrial (self-supplied)	102	200	400	800
Steam-electric power:				
Fresh water	20	200	250	300
Saline water	0	0	0	2,700
Irrigation	—	4	9	18
Total	162	535	901	4,206
Consumptive use				
Rural domestic	1	2	2	2
Municipal	7	24	46	75
Industrial	4	20	40	80
Steam-electric power:				
Fresh water	0	1	2	2
Saline water	0	0	0	13
Irrigation	—	3	6	12
Total	12	50	96	184

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result in continuing gains if care is taken to assure that these advantages are not offset by deterioration of fresh water quality, and loss or destruction of fresh water habitat. However, there is little basis for estimating at this time what changes in water requirements might result.

EMERGING WATER PROBLEMS

A comparison of available supplies and projected requirements indicates that the Region will still enjoy a sizable water surplus in the foreseeable future. Withdrawal uses will increase rather rapidly, but the total of these uses should be only a small fraction of the available supply by 2020. There will be a large number of local problems in finding suitable supplies, and costs of developing even modest water supplies will remain high throughout the Region and especially in the colder areas. Instream use for hydroelectric power will likely remain the largest developed water use in the Region. In addition, there will be geographically localized and economically significant increased use of groundwater aquifers for agriculture and selective industries.

The predicted growth in the Region's resource-based industries involves many local problems. Collectively, the problems are of regional importance. Harvest of the forest and some mining activities involve major requirements for watershed management. The growing major industries—fisheries, oil and gas, forest products—all involve considerable water use and problems of waste disposal. These developments require careful attention to selection of industrial processes and waste disposal methods, and they place an increasing burden on the agencies enforcing water quality standards. Improved flood and low-flow forecasting would assist in reducing flood damages and aid the operations of water supply works, and others in need of forecasts of streamflow information.

The greatest problem facing water resources planners in Alaska is the lack of adequate data on the water, land, and other resources affected by water resources developments. This lack makes the determination of criteria, costs, and single-purpose benefits difficult even for small water resources projects. The difficulty is compounded when alternatives are weighed, impacts of larger potential developments are evaluated, and meaningful long-range plans are formulated.

Continued growth and expansion of the Region's population and economic base will undoubtedly create a need for various control works on streams. This need must be weighed against the impact of the projects on fish and wildlife and other resources, the possibilities for mitigation and enhancement, and the use of alternate sites and development schemes. Alternate power sources and flood plain zoning are examples of ways whereby long-range planning could avoid possible conflicts with existing instream uses.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

The Region's existing water resource developments are small, local, and usually single-purpose. On a regional basis, they represent a very small alteration of the natural conditions. Thus, the future needs are largely those actions that will insure wise and orderly development starting from the natural state.

There are now no comprehensive long-range water plans for the Alaska Region or for its major river basins. Development of a type 1 framework study is a key goal in light of the land selection program and the Region's economic expansion. With State-Federal participation, this water and related land resources planning can be organized and coordinated under provisions of the Water Resources Planning Act and integrated with other economic planning in Alaska.

The need for coordinated planning with Canada on the international rivers must be recognized. Development of an international planning entity for water and related resources is considered essential.

Much inventory-type information on resources has been assembled in recent years, and this will be important to river basin planning. Much additional work along the lines of basin resource evaluation and attendant research is needed for evaluating water resource developments. This is particularly true in regard to water and related land use for recreation and fish and wildlife. The portions of these resources that represent optimum use in their natural state should be defined and reserved. For the remainder, sufficient knowledge of the resources must be gained to permit realistic appraisals of economic values, project effects, opportunities for enhancement through development, and possibilities for mitigation of losses.

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In many cases, there is a glaring deficiency in basic data for even a general resource inventory. Hydrologic information—streamflow, sediment, water quality, groundwater occurrence—is simply nonexistent for large areas of the Region. Except for salmon, little is known of the fresh water fisheries, and similar information deficiencies are found in the other resource fields. Given adequate funding and manpower, correction of these basic information problems can be achieved in a relatively short period of years.

Cook Inlet in the South Central subregion is the Region's industrial and population center, and it is also the most rapidly growing area. The concentration of people and industries, coupled with the physical features, poses potentially serious water supply and pollution problems, which demand special attention through expedited research and engineering studies.

Further research and development in ways of providing water supplies and sewage treatment in the colder areas is imperative—first, from the standpoint of providing suitable health standards, and, second, to permit future developments.

Future planning must consider possibilities of large water exports such as those proposed by the North American Water and Power Alliance. Studies should be initiated to determine what effects such water exports would have on the ecologic, biologic, hydrologic, and economic environment of the Alaska Region.

The State is providing a good legal framework for water management; however, emerging industries will place increasing demands on its management agencies. The State must anticipate these demands by providing adequate management and enforcement staffs.

An overall problem in the Alaska Region—small population and an extremely limited tax base—severely limits the State's funding capability for planning and resource development activities. The projected development will undoubtedly ease this situation in the future. Considering this, the national importance of the resources involved, and the extent of public lands, it is reasonable to expect that Federal participation in the Region's resource development programs will remain at a high level in the foreseeable future.

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CHAPTER 19

Hawaii Region

SUMMARY

The Hawaii Region is unique in its history, geography, demography, geology, and climate. This uniqueness has shaped the Region's development and will continue to do so. Gross water resources appear to be ample for all present and future needs, assuming adequate research and planning and proper management and conservation.

Major population growth is expected to be concentrated on Oahu Island, principally in the dry leeward areas contiguous to the present urban and suburban developments. To provide for future water requirements, it will be essential to prevent overdraft and quality deterioration of Oahu's basal aquifer, to minimize leakage, and to assure adequate recharge. Other emerging problems relate to the development of adequate water supplies for expansion of existing resort areas and the establishment of new resort areas outside of high-density Waikiki, and to the development of irrigation water supplies for new croplands required to maintain present and anticipated production levels, considering some displacement by urban and resort developments.

Because stringent financial considerations limit the capacity of the respective neighbor island water boards to finance improvements designed for long-term island-wide needs, the State will continue to participate directly in such developments. The presently inadequate county systems serving existing needs in the resort areas will be upgraded as an ancillary benefit to the communities that could not otherwise justify the large capital expenditures required.

Watershed protection, flood prevention, and flood control measures, important generally, are particularly significant in resort areas located near streambeds and natural drainage channels. Pollution control of coastal waters is important to Hawaii's tourist industry, as well as to oceanographic research.

DESCRIPTION OF THE REGION

Although the Region includes 122 islands under the present jurisdiction of the State of Hawaii, only the 7 inhabited islands shown in figure 6–19–1 are significant for purposes of this Assessment.

The islands were first settled by Polynesians, who arrived in three migrations, circa A.D. 200, 450, and 1100. Other immigrants arrived in the 12th and 13th centuries. As the social structure developed, the islands were partitioned into various land divisions, which today form the basis for county boundaries, judicial districts, taxation units, and other minor political subdivisions.

Between 1782 and 1810, Kamehameha-I—called "Nui," meaning "the Great"—who was born on the Island of Hawaii, united the main islands into one kingdom through conquest of three other warring kings. The friendly visit he had paid in 1778 to Captain Cook's ships influenced his later decision, following his organization of the government, to admit foreign traders. The last of his direct line died in 1872. The progress made by his dynasty had been impressive, but the next two monarch's misrule led to deposition of the second—Queen Liliuokalani—in 1893 and a provisional government, followed by a republic in 1894. Annexation to the United States had been requested by the provisional government in 1893, but was not granted until 1898. In April 1900, the Islands were established as a U.S. Territory; in August 1959, Hawaii became the 50th State of the Union.

The land area of the 7 inhabited islands of the Region is 6,401 square miles; the population (including military) was 744,500 in 1965. Area and population distribution among the islands are shown in table 6–19–1.

County governments in the State function much the same as municipal governments in other States. There are no incorporated towns

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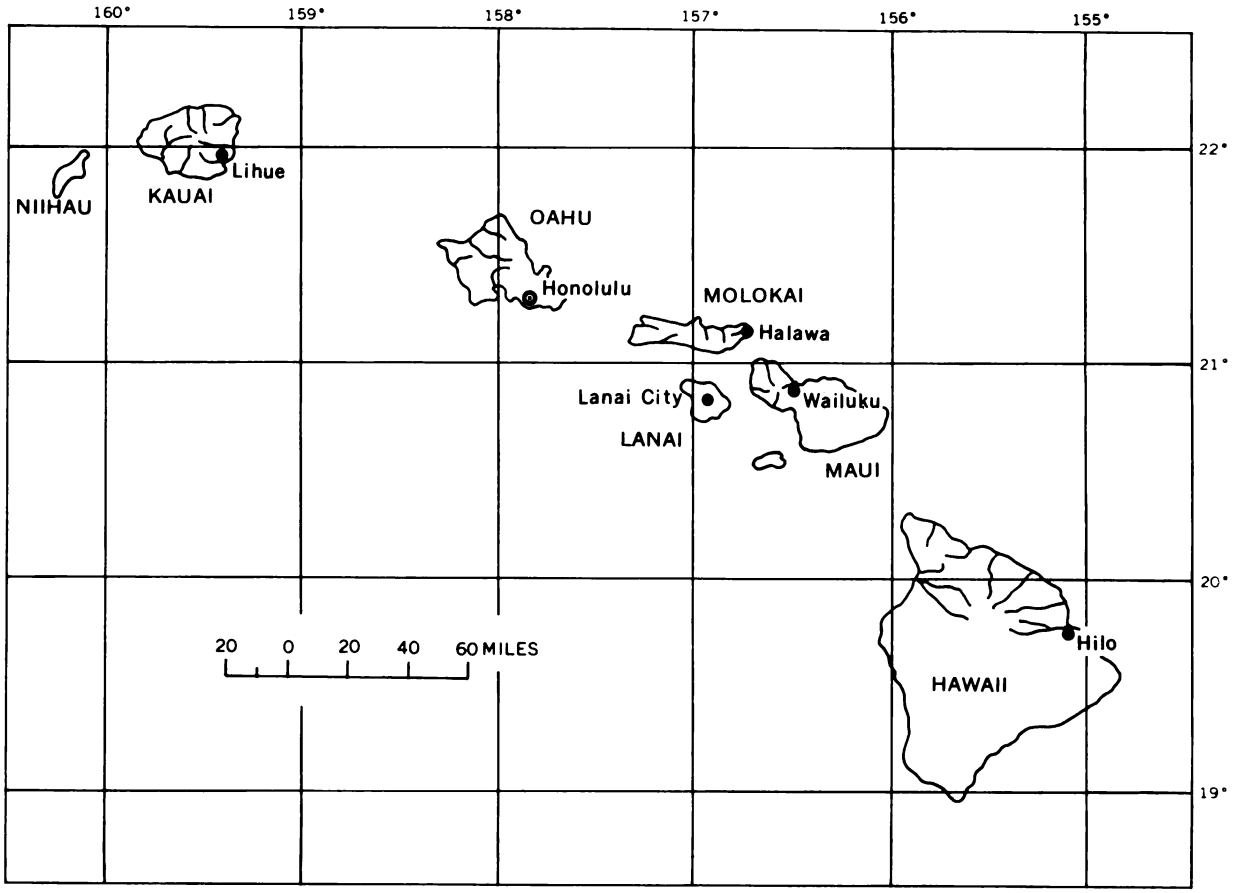

FIGURE 6–19–1.—*Map of the Hawaii Region*

TABLE 6–19–1.—*Area and population of inhabited islands, Hawaii Region*

Island	Area	Population
	sq. mi.	
Niihau	73.0	280
Kauai	553.3	26,181
Oahu	607.7	613,027
Molokai	261.1	5,694
Lanai	139.5	2,975
Maui	728.8	37,058
Hawaii	4,038.0	59,290
Total	6,401.4	744,505

or cities except for the hybrid City and County of Honolulu chartered in 1959. The median age of the Region's polyglot population is in the middle 20's. Males outnumber females, and the average household is estimated to be 4.2 persons. In 1965, the labor force averaged 266,500 and employment about 256,000; per capita income averaged about $2,900.

Private land ownership in the Hawaii Region was first established by King Kamehameha III in 1848, when those lands not reserved to the crown were divided among government, nobles, and commoners. Several tracts reserved to the crown or granted to nobles form the basis of large landholding estates today. Plantation companies also acquired large tracts of land in the latter half of the 19th century. As a result, most of the private land is in the hands of a relatively few large landowners.

Subsistence farming and fishing formed the basis of the Region's economy until the advent of missionaries, whalers, merchants, and planters. The sugar industry was founded in 1835 and dominated the economy during the last third of the 19th century and the first third of the 20th; in the latter period the pineapple industry also achieved prominence. During World War II the Federal Government became

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the largest source of income to the Region, and it remains so today. Started about 1920, the tourist industry has made rapid progress since World War II. Diversified agriculture and diversified manufacturing (other than sugar and pineapple) are also significant. Education and research are playing an increasingly important role in the economy.

Mean annual precipitation ranges from less than 18 inches to more than 250 on each of the major islands except Lanai, and the total annual rainfall of the Region is about 73 inches—about 22 bgd. Precipitation gradients are steep, with differences of 100 inches or more within 3 miles not at all uncommon. Annual variations are also great, often exceeding 300%, and intensities are high, exceeding 3 inches per hour or 12 inches per day at least once a year somewhere in the Region.

Most of the annual rainfall is deposited by the northeasterly trade winds as they ascend and traverse the mountain barriers of the islands. These orographic rains are heaviest in upland windward areas. Maximum precipitation occurs at elevations of 2,000 to 3,000 feet on the windward slopes of the large mountain masses of the Islands of Hawaii and east Maui; along the crestline of the smaller and lower mountains of the other islands; and on Oahu, just to leeward. The driest zones are usually in the western and southern lowlands leeward of the mountain ranges, receiving little trade wind rainfall and depending chiefly on winter storms for their moisture.

Although trade wind showers occur throughout the year, they are more frequent in summer than winter. Between October and April, rains associated with cold fronts or with the cyclonic storms that are locally called Kona storms are most prevalent. Leeward lowlands experience their heaviest precipitation from such storms in the winter, except for the Kona coast of the Island of Hawaii, where onshore drift of sea breezes results in maximum precipitation in the summer.

Temperatures above 90° are uncommon, except in the dry sunny lowlands during the summer. Temperatures less than 55° are unusual at elevations below 2,000 feet, where the mean daily range is 10° to 18°. Like rainfall, evapotranspiration differs markedly over short distances, consuming all or most of the rainfall in dry areas and only a relatively small percentage in wet areas. In many localities, frequent showers and the moderately high humidity (the average is 65% to 80%, except in the driest areas) tend to diminish evapotranspiration, which in places exceeds 80 inches per year.

THE WATER RESOURCE

Each of the islands of the Hawaii Region has been built by successive lava flows from one or more volcanic vents, group of central vents, or series of vents along fissures. Land surfaces are incised by hundreds of small streams radiating seaward from mountain peaks and ridges.

Typically, perennial streams occur on steep northeast trade wind slopes and discharge directly to the sea through relatively short channels. On the longer, more gentle leeward slopes, few streams flow perennially to the sea, but many have continuous flows at the elevations where rainfall is greatest. All streams are subject to phenomenal flood volumes in comparison to basin size, then, a few hours after the rain has stopped, receding to base flow because of the short channels and porous soils.

Natural runoff for the Region (shown in table 6–19–2) amounts to about 60% of the annual precipitation, which averages about 73 inches. The estimate of this average annual natural runoff includes surface and groundwater discharge, since most of the latter issues at springs near the shore. Approximately 28% of the discharge is surface water runoff in streams; 72% is groundwater, including tidal springs.

TABLE 6–19–2.—*Annual natural runoff, Hawaii Region*

Subregion	Drainage Area	Average precipitation	Average runoff	
	sq. mi.	*in/yr*	*in/yr*	*bgd*
Kauai	553	99	54.5	1.44
Oahu	608	58	33.4	.97
Molokai	261	42	33.1	.41
Lanai	140	21	11.4	.08
Maui	729	75	54.4	1.89
Hawaii	4,038	75	44.1	8.48
Total	6,329	72.9	44.0	13.3

Approximately 45% of the fresh water used in Hawaii is diverted streamflow occurring abundantly to windward. This diversion and use is geared primarily to base flows.

A high percentage of the rainfall infiltrates into the ground. The largest and most wide-

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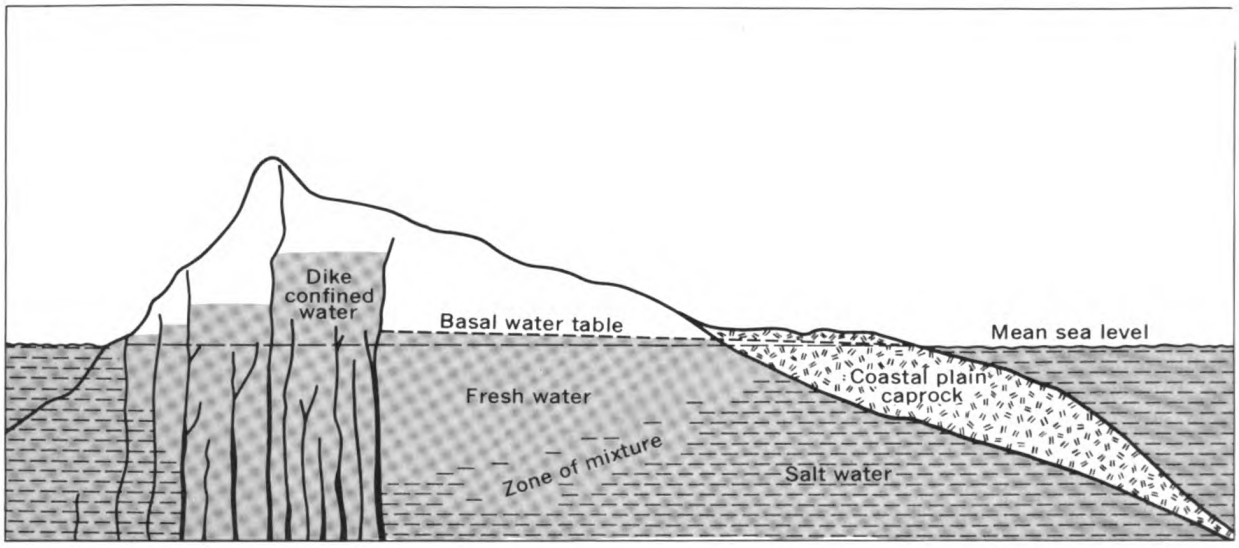

FIGURE 6–19–2.—*Diagrammatic geologic-hydrologic cross section through Oahu.*

spread groundwater supplies occur as basal water floating on sea water within subsurface rocks, termed the Ghyben-Herzberg lens. This is shown schematically in figure 6–19–2. The fresh water in these lenses varies in thickness from a few feet to many hundreds of feet, generally depending upon the presence of coastal cap rock; where it is absent, the lens is thin and subject to salt water intrusion. At high levels, groundwater is impounded by lava dikes and perched on impermeable beds of lava ash and soil, discharging underground and at springs.

Chemically and bacteriologically, most of the basal water used is of high quality. Its chloride content depends not only on local geologic factors but also on the amount of withdrawal from the basal aquifer. In periods of heavy rainfall, surface water supplies are often turbid.

PRESENT WATER RESOURCES DEVELOPMENT—1965

Water withdrawal and consumption in Hawaii in 1965 is summarized in table 6–19–3. Irrigation has been the dominant water use in the Region from earliest times. Hawaiians built ditches (called auwai) for the paddy cultivation of taro, their staple crop. Since the latter part of the 19th century, several sugar plantations in leeward areas have irrigated with streamflow diverted from windward watersheds and conveyed by elaborate and extensive networks of tunnels and ditches.

The consumptive use of water for sugar cane varies from 6 to 9 feet per year. The irrigation of diversified crops consumes from 2.5 feet to 4 feet per year, and occasionally as much as 5 feet. Consumptive use for pineapple averages from 1 foot to 1.5 feet per year. Irrigation requirements for these two crops vary from locality to locality and from season to season. The heaviest requirements occur in the leeward areas during summer months. Much of the planted acreage is not irrigated; for example, of 233,000 acres planted to sugar cane in 1965, only 54% was irrigated. Saline water containing 1,300 to 2,000 ppm of chloride has been successfully used for crop and golf course irrigation and cattle production.

Industrial use of water is primarily for milling sugar, processing pineapples and other food products, and manufacturing. About 364 mgd is used for hydroelectric power generation at 20 small-capacity plants, most of which are operated by sugar plantations for their own use. Steam-electric powerplant requirements for cooling water are met from saline sources.

Navigable harbor channels in the Region total 58.4 miles, navigable fresh-water channels, 45.3 miles. Instream water uses other than boating are only nominal. Some streams are stocked by the State with game fish, and ditches and reservoirs on some plantations are stocked with fish to inhibit aquatic plant growth. Waterfowl are relatively uncommon.

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TABLE 6–19–3.—*Present water use, 1965, Hawaii Region*

(Million gallons per day)

	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
Total	7	115	112	300	1,060	3	1,597
From:							
Groundwater	(1)	(106)	(64)	—	(534)	(1)	(706)
Saline	—	—	(16)	(300)	—	—	(316)
			Water consumed				
Total	7	39	4	3	477	3	533

[1] Water used for domestic purposes not served by public water supply systems.
[2] Serves a population of 612,000 through public water supply (both public and private) systems. Includes domestic, public, commercial, and industrial uses.
[3] Water supplied by the industry itself; also includes military establishments.
[4] Water supplied for cooling and operation of public utility steam-electric powerplants.
[5] Conveyance losses not included in consumption.

Treatment for watershed protection and flood prevention in 1965 included five projects, involving 278,300 acres. Improvements to flood control channels totaled 38 miles.

ADEQUACY OF PRESENT DEVELOPMENT

Hawaii's mean annual precipitation of about 73 inches provides an adequate gross water supply for all present and anticipated future needs. However, the utilization of this ample water resource is dependent upon economic and engineering feasibility, because of wide geographic variations in precipitation; great losses of water by immediate runoff into the ocean; steep, narrow, permeable streambeds; depths to basal water supplies; and mountain masses separating the wet windward areas from the dry leeward areas.

Groundwater supplies are not appreciably affected by withdrawals during late winter and early spring, when rainfall is comparatively heavy and demand for water comparatively light. They are generally reduced during the dry season, although seldom to a critical level. Surface water supplies are sometimes locally inadequate during the dry season, requiring rationing and supplementation.

For many years, private interests have economically developed water sources for sugar cane irrigation. However, in the case of some watersheds, further development for cane irrigation is economically infeasible. Considering the high unit value of water for domestic use, compared with sugar cane irrigation use, it would be more feasible to develop such watersheds intensively for other water uses, as the demand for these uses materializes. Also, although the intention of the State's Land Use Act of 1961 is to minimize conversions of lands now devoted to sugar cane production to urban and resort uses, such conversions will require the development of water supplies elsewhere if the production level of the sugar industry is to be maintained.

The State has recently been active in water resources planning and development, but most of the existing public and private water systems were developed by local agencies and water users without particular regard to competitive needs. Fortunately, serious use-control problems have not yet materialized.

To maintain present or improved levels of adequacy, it is essential to ascertain the quality of the groundwaters and the safe withdrawal rate for each basal aquifer. The probability of overdraft and resultant salt water intrusion is directly related to increased land development for residential, industrial, and resort use.

Because existing surface water systems are geared to base flows, storage capacity is an immediate need. Filtration and chlorination of water for human consumption are prevalent needs for surface water quality control.

Inventories by local conservation committees

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indicate that 43 watersheds have inadequate rural water developments, 21 have insufficiently developed public water supplies, and 25 have water quality control needs.

A recent assessment of conservation needs in the Region indicated the increasing use of land for nonagricultural purposes, and emphasized the importance of careful conservation of vital soil, water, and other natural resources. A total of 10,700 acres in agricultural areas require project action to alleviate drainage problems, and 5,600 acres in urban areas require action to lessen flood waters and sediment damage. Recreational and fish and wildlife development needs exist in many of the watersheds.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

Water rights in the State of Hawaii are not governed by a body of statutory law. The prevalent system of surface water rights is unique, being derived from ancient customs and practices established to fill the specific needs of the native society, free of influence either by civil law or common law. The basic principles of this law of custom have been defined by court decisions over the past century.

Surface water rights can be sold or acquired separately from the land to which they are appurtenant. Although these rights appurtenant to private land are privately owned, except where expressly acquired by government, there appears to be no need for legislation to strengthen or modify the established law relating to them. On the other hand, the principles that govern groundwater rights, as viewed from the few relevant court cases, are somewhat vague. Legislation is needed for their clear definition.

Except for auwai and related water rights established in the early days for paddy crops, all of the private irrigation systems in the Region are subsidiaries of sugar plantation companies. Futhermore, most of the surface water used for domestic, industrial, and hydroelectric purposes is derived from watersheds owned or leased by these subsidiaries. Government control extends only to public health standards and to the terms under which 8,161 acres of public watersheds are licensed to the plantation water companies.

The State's Director of Health is responsible for determining present and prospective best-water uses and adopting and enforcing standards of water quality. The present laws and related regulations appear to require some changes to conform to Federal requirements and to facilitate adequate implementation, surveillance, and enforcement of water quality standards. Additional legislation, as well as amendments to present regulations, is required to accomplish the necessary changes.

Public water systems in each county are operated by semiautonomous water boards. Because of the limited fiscal capacity of each neighbor island's water board, as contrasted with Oahu's, many of the major improvements to public water systems on those islands are funded by the State through grants-in-aid for capital improvements. The situation is the same regarding local participation in financing the construction of Federal flood control projects.

The Division of Water and Land Development, Department of Land and Natural Resources, is the State's agency for water resources data collection, planning, and development, including flood control and flood water conservation. It also plans, constructs, and operates public irrigation systems. It has recently completed a comprehensive water development plan for the Island of Molokai, where the Molokai Irrigation Project, which was constructed with Federal assistance, provides the foundation for the Island's economic growth. A similar comprehensive plan will be produced for each major island.

Intergovernmental relationships in flood control are defined in general terms in the first of three volumes describing the State's flood control program. The second volume is a comprehensive general guide to project planning approved by the Legislature. The third volume, still in preparation, is expected to delineate with some specificity the respective flood control functions of government agencies at all levels, as an aid to the more effective implementation and coordination of flood control programs.

Implementation of comprehensive water development and flood control plans, with the full cooperation of public agencies, private watershed owners, and water users, will continue to be a problem until the relatively new concept of comprehensive planning and coordinated multiple-use development at optimum levels has been widely understood and accepted.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

During the 1955-65 decade, the Region experienced unprecedented economic growth, as well as significant educational, cultural, and

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political advances which have substantially enhanced the economic climate and growth potential. The most significant political event of the decade contributing to economic progress was the achievement of statehood in 1959. Probably the most significant economic factor in the recent growth of the Region has been the increased availability of (including reduced tariffs) and facilities for jet air transport of freight and passengers.

During the decade, personal income for the Region rose from $972 million to $2.0 billion; retail sales from $637 million to $1.2 billion; bank deposits from $395 million to $1.0 billion; the annual dollar volume of construction from $97 million to $281 million; and the annual volume of the tourist industry from $55 million to $265 million. The agricultural industries, although experiencing less spectacular growth, also increased in annual dollar volume: sugar from $146 million to $176 million; pineapple (facing more intensive foreign competition) from $115 million to $127 million; and diversified agriculture from $36 million to $47 million.

A major factor in the Region's economic growth potential is the continuing expansion of the tourist industry, with a projected increase in the number of visitors from 0.6 million in 1965 to 1.0 million in 1970. Anticipated expansion in the Region's economy is shown in table 6–19–4. (The data for the table were developed by the State of Hawaii's Department of Planning and Economic Development.)

Projected water requirements for the respective islands are based on the assumption that present economic and population distinctions between Oahu and the other islands will generally continue through 2020 (table 6–19–5). For projection purposes, it is expected that the regional population will increase to 1,086,000 in 1980, 1,680,000 in 2000, and 2,610,000 in 2020.

Water used for rural domestic purposes will decrease as community systems are enlarged. On the other hand, rural uses for livestock watering will increase slightly as ranchers continue to increase their production.

Because Hawaii is a "pocket market," isolated from nearby trading areas, its future water needs for diversified manufacturing and agriculture (other than sugar and pineapple) are based primarily on local consumption by an increased number of residents and tourists.

Projected water use for sugar cane irrigation is based on an annual growth rate of about 2.9% for 1965-70 and about 1.5% thereafter. Increase in pineapple production is estimated at 0.5% annually for determining future irrigation requirements.

EMERGING WATER PROBLEMS

Future water problems will relate primarily to increased needs for domestic and commercial uses, and for supplies to new agricultural areas needed to replace existing agricultural lands which have become urbanized.

The State's Land Use Act of 1961 will prevent impracticably scattered urban developments that

TABLE 6–19–4.—*Projections of population, employment, and income, Hawaii Region*

Item	Unit	1965	1970	1975	1980	1985
Total resident population	thou.	744	866	983	1,086	1,164
Total civilian population	do.	689	802	925	1,050	1,160
Personal income	mil. dol.	2,000	2,770	3,790	5,110	6,790
Per capita personal income	dol.	2,900	3,450	4,100	4,870	5,850
Total civilian employment [1]	thou.	256	297	342	388	430
Total private [1]	do.	197	230	266	301	333
Agricultural complex	do.	33.2	29.3	26.2	23.9	22.1
Manufacturing, utilities, communications, and construction	do.	33.6	38.1	40.3	43.8	46.3
Wholesale trade and transportation	do.	25.9	29.5	33.5	36.4	38.9
Retail trade	do.	55.4	69.5	84.0	96.2	107.0
Services	do.	48.6	63.6	82.2	100.2	118.2
Total public	do.	58.9	67.2	76.3	86.8	97.8
Non-defense	do.	39.9	49.1	59.1	70.6	79.7
Civilian defense	do.	19.0	18.1	17.2	16.2	18.1

[1] May not check due to rounding.

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TABLE 6–19–5.—*Projected water requirements, Hawaii Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020
Withdrawals				
Rural domestic	7	5	4	3
Municipal (public-supplied)	115	195	320	520
Industrial (self-supplied)	112	134	159	188
Steam-electric power (saline)	300	900	2,300	5,300
Agriculture:				
Irrigation	1,060	1,420	1,910	2,570
Livestock	3	4	5	6
Total	1,597	2,658	4,698	8,587
Consumptive use				
Rural domestic	7	5	4	3
Municipal (public-supplied)	39	65	106	173
Industrial (self-supplied)	4	5	5	6
Steam-electric power (saline)	3	9	20	30
Agriculture:				
Irrigation	477	640	860	1,150
Livestock	3	4	5	6
Total	533	728	1,000	1,368

would encroach upon agricultural lands. Therefore, those leeward areas on Oahu that are presently idle or in low-capacity pasture and contiguous to existing residential developments would be the most likely to experience growth. Since such areas are dry and will generally have to be served primarily from existing groundwater sources, a potential water problem is the overdraft of the aquifer centered at Pearl Harbor, which has dropped about 20 feet in the past 30 years. The fiscal capacity and operational efficiency of the Honolulu Board of Water Supply provide reasonable assurance that emerging public water problems on Oahu will generally be solved.

The water requirements of neighbor islands have been affected by two significant trends that will, to some extent, influence future problems. First, the plantations have been replacing substandard camps with low-cost housing in or near existing urban areas. Thus, the demands upon the private domestic systems have been or are being shifted to public systems. The second and more significant trend is the development of large resorts in new areas. Added to the direct commercial water needs of the tourist facilities will be the domestic water requirement for employees housed in nearby communities. Further, large resort developments usually act as a catalyst for smaller tourist facilities in the general vicinity, as well as the more intensive development of vacation and/or retirement homes on or near the shore.

Many of the public water systems on the neighbor islands, including those in resort areas, have inadequate sources and antiquated facilities. Stringent economic considerations limit the capacity of the respective boards of water supply to finance major improvements geared to future, and even to present, needs for commercial and residential development.

The resolution of problems incident to urban and resort development—the Region's most significant emerging water problems—appears to lie in continued and increased participation by State and Federal Governments in the planning and development of required supplies.

Increased pollution of coastal waters, as population and industry expand, may affect beaches and shoreline vistas and therefore the tourist industry, as well as shore fishing and oceanographic research. Implementation by the State of the Federal Water Pollution Control Act will result in standards for waste disposal which are expected to help control related pollution problems effectively. Discoloration of

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coastal waters by soil erosion, presently the most serious water pollution problem, should decline with continued and increasing emphasis on watershed treatment and flood control measures.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

Although the pace of water development has paralleled economic growth to date, the Region's present growth rate will require all water agencies to assume a larger role in future water resources development and management.

Comprehensive and coordinated water resources planning and development will continue to be a pressing need, requiring adequate staffing and funding of many agencies. The formation of a Federal-State coordinating committee, chaired by the State, would do much to alleviate present planning inadequacies and to develop a type 1 framework study for the Region.

The basic data collection program must be reevaluated. Additional basic data on rainfall, streamflow, evaporation, and other hydrologic factors are needed, particularly in the less accessible mountainous areas of heavy rainfall.

There is a need for detailed studies of water resources to provide the basis for selecting the most feasibly developed supplies for specific future requirements. Studies must be made to determine aquifer yields on all islands, to develop management practices to prevent salt water intrusion, and to reduce leakage from basal aquifers. Other studies should include delineation of flood-prone areas and investigation of meteorologic, hydrologic, and hydraulic factors relevant to the development of improved engineering design standards, flood protection facilities, and flood forecasting and warning techniques and systems.

In order to appreciably increase the diversion of streamflow, less costly water storage methods are required. For example, low-cost linings would greatly reduce the cost of reservoir construction on the permeable island lavas. Research is also needed to determine the type, cost, and effectiveness of small retarding dams in gulches, small valleys, and similar intermittent waterways to impound surface water for recharging groundwater supplies.

Although pollution has not to date been a problem of significance, continued surveillance is essential. The recent application of the multiple-use concept to watersheds in the Region calls for studies of the water-yielding process and how it may be affected by land uses other than water development.

Planning for the acquisition and management of sites suitable for water-related recreation, for the construction and operation of marinas, and for the promotion of fishing and hunting must be considered in the overall development plan of the Region. An accelerated program should be initiated to acquire and preserve the needed recreation areas and concomitant water resources before they are destroyed by urbanization, pollution, incompatible land and water uses, overcrowding, and lack of planning and regulation.

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CHAPTER 20

Puerto Rico Region

SUMMARY

The water resources of the Puerto Rico Region are adequate in quantity for all anticipated uses to 2020. However, because a number of distribution and storage problems are not yet solved, various localities frequently suffer from inadequate supplies of water for domestic and irrigation uses. Additional water development projects are needed immediately to alleviate critical shortages in these problem areas.

The population and economic growth anticipated for the Region over the next 55 years will make heavy demands on the water resources. Population is expected to increase from 1965's 2.7 million to about 6.5 million by 2020. Employment in manufacturing is expected to increase accordingly. Development of additional water, as well as management of its quality, must be planned carefully, to assure that the resources needed for the future anticipated uses will be, and remain, both adequate and available.

To accomplish the formulation, appraisal, and review of plans for the type of development and management that will make the best possible use of the Region's resources for present and future requirements, changes will be needed in the Region's organizational approach to the conservation, development, and use of its water resources.

DESCRIPTION OF THE REGION

Puerto Rico and its associated islands are part of a chain of mountainous islands that stretch from Florida on the mainland of North America to Venezuela on the mainland of South America and, in effect, separate the Caribbean Sea from the Atlantic Ocean. Located at latitude 18 degrees North, Puerto Rico is within the tropical zone.

The Region consists of the 9 islands included within the jurisdiction of the Commonwealth of Puerto Rico (fig. 6–20–1). Four of these are of significant size (square miles in parentheses): Puerto Rico (3,339.5), Vieques (50.7), Mona (21.0), and Culebra (10.4). Since the Island of Puerto Rico contains almost 99.7% of the population of the Region and is by far the most important of the group, it alone is considered hereafter in this Assessment.

The major topographical feature of Puerto Rico is the Cordillera Central, a line of mountains that runs east-west, dividing the island into a northern two-thirds and a southern one-third. The Cordillera forms the principal drainage divide, with the majority of the rivers on this island draining north or south from it. The rivers are deeply entrenched in narrow valleys between knife-edge ridges; the Cordillera is rugged, and its area is sparsely populated.

Although the geology and topography of Puerto Rico are both diverse and highly complex, certain broad generalizations are possible. Physiographically, the north and south coasts are limestone lowlands backed by foothills that merge into a large mountainous interior composed of volcanic rocks. The east and west coasts are generally lowlands composed of a series of broad, flat valleys with interrupting mountain spurs. Only about 645,700 acres, or some 30% of the total land area, contain soils which are suitable for cultivation, and for much of this acreage intensive conservation techniques are required to prevent erosion.

Early in the 1950's, the Commonwealth launched a massive industrialization program based on three major factors: (1) exemption from United States taxes, (2) exemption from Commonwealth taxes for periods ranging from 10 to 17 years, and (3) the Commonwealth's advantageous position within the tariff system of the United States. Between 1950 and 1965, the program created a total of 67,900 new jobs. New employment is shifting from agriculture and small workshops to factories, commercial centers, and other urban occupations. Other

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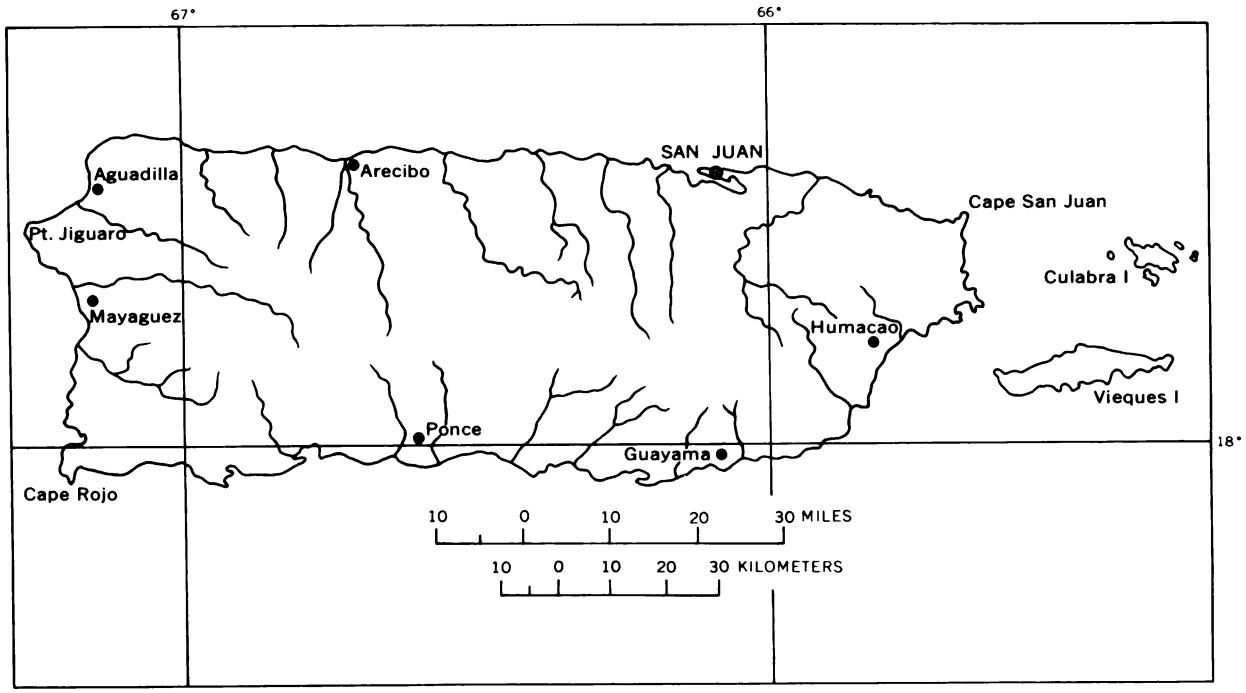

FIGURE 6–20–1.—*Map of the Puerto Rico Region.*

rapidly emerging sectors of the economy are services (mainly tourism), cattle raising, and government. Small-scale farming, home needle work, and tobacco stemming by hand are decreasing rapidly. The net result has been a rapid change in character for the Region. Formerly an agricultural society, it is becoming an urbanized industrial society, and the change entails many new needs and problems.

THE WATER RESOURCE

The average annual rainfall for the Region is about 69 inches, equivalent to about 11 bgd. It ranges from about 60 inches along the north coast to about 100 inches at the divide of the Cordillera Central, and down to about 30 inches along the western portion of the south coast. The highest rainfall occurs in a small area near the northeast corner of the Island in the Sierra de Luquillo, where an average annual rainfall of about 210 inches has been reported.

Streamflow varies widely, depending on the intensity of rainfall and the degree of rugged terrain. Peak discharges during major floods rank with the highest known peaks in the world. Low flows are variable: in the Luquillo Mountains, the low base flow ranges from 1 to 2 cfs per square mile (cfsm); in the interior uplands, 0.3 to 1 cfsm; on the south slope of the central divide, 0 to 0.4 cfsm; and in the coastal plain the streams are often dry.

The composition of the water in the streams reflects the geology, with calcium and bicarbonate as the predominant ions. Salt water has been observed almost 4 miles inland in Rio Loiza, indicating that streams may be spearheads of salt water intrusion. Some basins yield sediment at a rate of 1,000 to 6,000 tons per square mile annually; however, the great flood of September 1960 produced 6,000 tons of sediment per square mile in the Rio Humacao in less than a day. Temperature of streams ranges from 70° to 90°.

The quantity of groundwater available appears to be substantial, although it varies considerably from area to area. From the data available, the maximum groundwater potential has apparently not been realized in any of the groundwater areas (fig. 6–20–2). At some localities within a few of the areas, however, further development may not be feasible at this time. It is believed that large to moderate supplies of groundwater of good quality are available from the limestone and alluvium of northern Puerto Rico. Wells very near the coast, especially if drilled to or below sea level and to topographic lows, are subject to salt water intrusion. Small to moderate supplies of ground-

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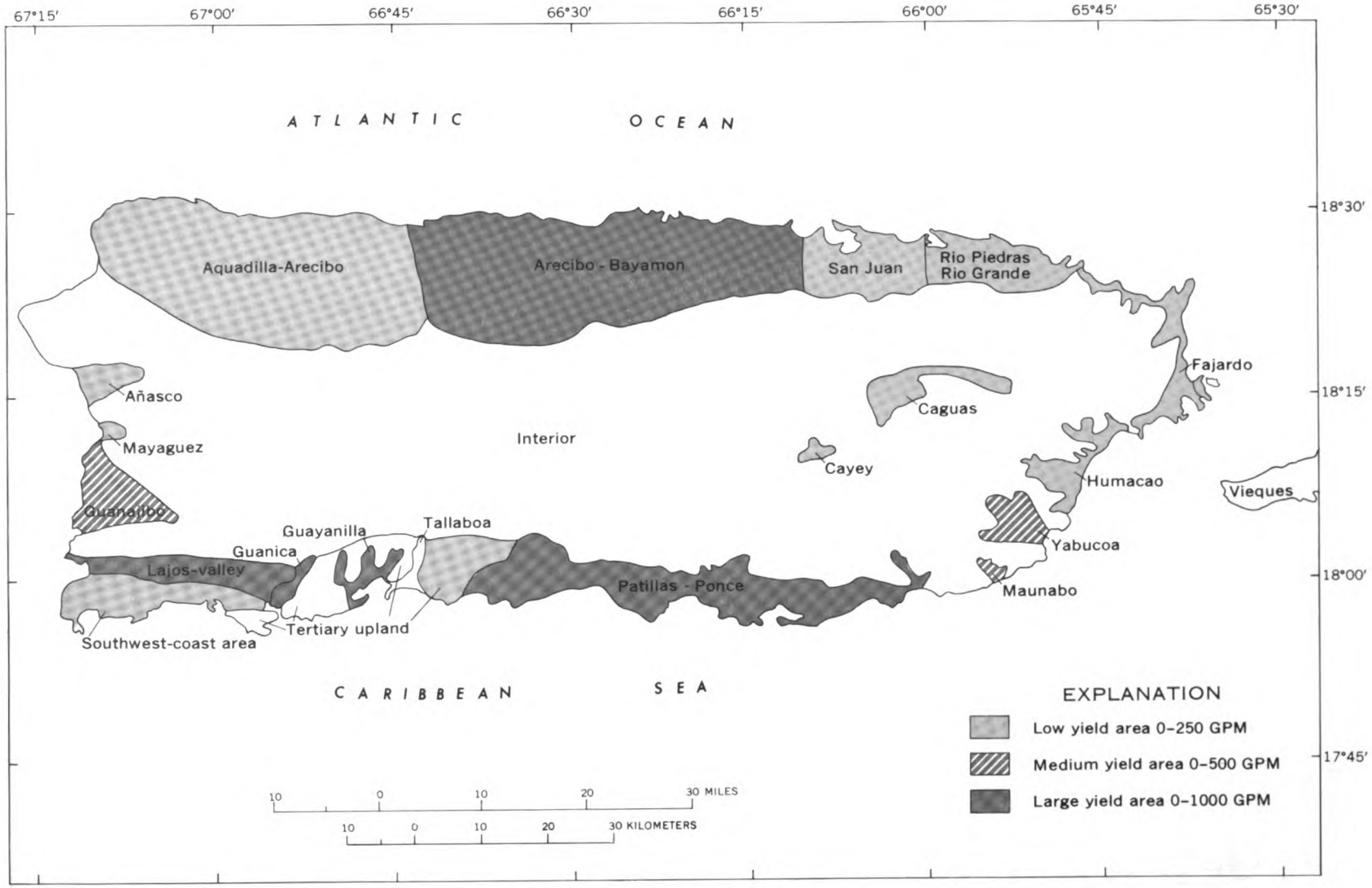

FIGURE 6–20–2.—*Areas of groundwater development, Puerto Rico Region.*

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water are also available in many places in the valleys along the west coast, and larger supplies may be obtained in a few places. In the southwest corner of the Island, only small supplies are available and may be of poor chemical quality.

Although local groundwater development has been the most extensive in valleys along the south coast, supplies are also available in many other places. Small to large supplies of good quality water may be obtained in the valleys along the east coast by proper construction of carefully located wells. Small to moderate supplies are available locally in the mountainous interior, especially in the valleys and lowlands. Dissolved solids in groundwater are commonly in the range of 65 to 250 ppm, with calcium, magnesium, and bicarbonate as the principal ions; nitrates are low.

Except in a few small areas of salt water contamination, the regional waters are satisfactory for most uses. However, in many areas, water for boilers and some industrial purposes must be treated for hardness, pH, or silica.

PRESENT WATER RESOURCES DEVELOPMENT—1965

In 1965, regional withdrawals of water amounted to 1,120 mgd, of which only 270 mgd were consumed (table 6–20–1). Irrigation accounted for the major withdrawal of fresh water and over 80% of all consumed water. Most of the water withdrawn for municipal use is lost to further use by discharge near the coast.

Sugar mills are the largest industrial users, taking water directly from lower stream reaches and returning it after use in their sugar manufacturing process. Similarly, much of the groundwater used by the mills is discharged into surface channels. Cooling water for steam-electric power is almost entirely from saline sources. Hydroelectric power uses about 513 mgd, which generally is available for other purposes; this availability is recognized, of course, in multipurpose developments.

ADEQUACY OF PRESENT DEVELOPMENT

The development of surface water for public projects in Puerto Rico is shown in figure 6–20–3. Streamflow in most of the unshaded southern portion of the Island has been allocated to private use by franchises. In addition, numerous smaller areas throughout the Island are developed for both public and private purposes.

Although figure 6–20–3 indicates that a large part of the surface water supply has been developed, much of the water is available for further use. This is especially true of hydroelectric power projects. For example, Rio

TABLE 6–20–1.—*Present water use, 1965, Puerto Rico Region*

(Million gallons per day)

Region	Rural domestic [1]	Municipal [2]	Self-supplied industrial [3]	Steam-electric power [4]	Agriculture		Total
					Irrigation [5]	Livestock	
			Water withdrawn				
Total	5	141	317	401	250	6	1,120
From:							
Groundwater	(4)	(18)	(39)	—	(95)	(1)	(157)
Saline	—	—	(135)	(400)	—	—	(535)
			Water consumed				
Total	5	21	10	3	225	6	270

[1] Water used for domestic purposes not served by public water supply systems.
[2] Serves a population of 2,374,000 through public water supply (both public and private ownership) systems. Includes domestic, public, commercial, and industrial uses.
[3] Water supplied by industry itself; also includes military establishments.
[4] Water supplied for cooling and operation of public utility steam-electric powerplants.
[5] Conveyance losses not included in consumption.

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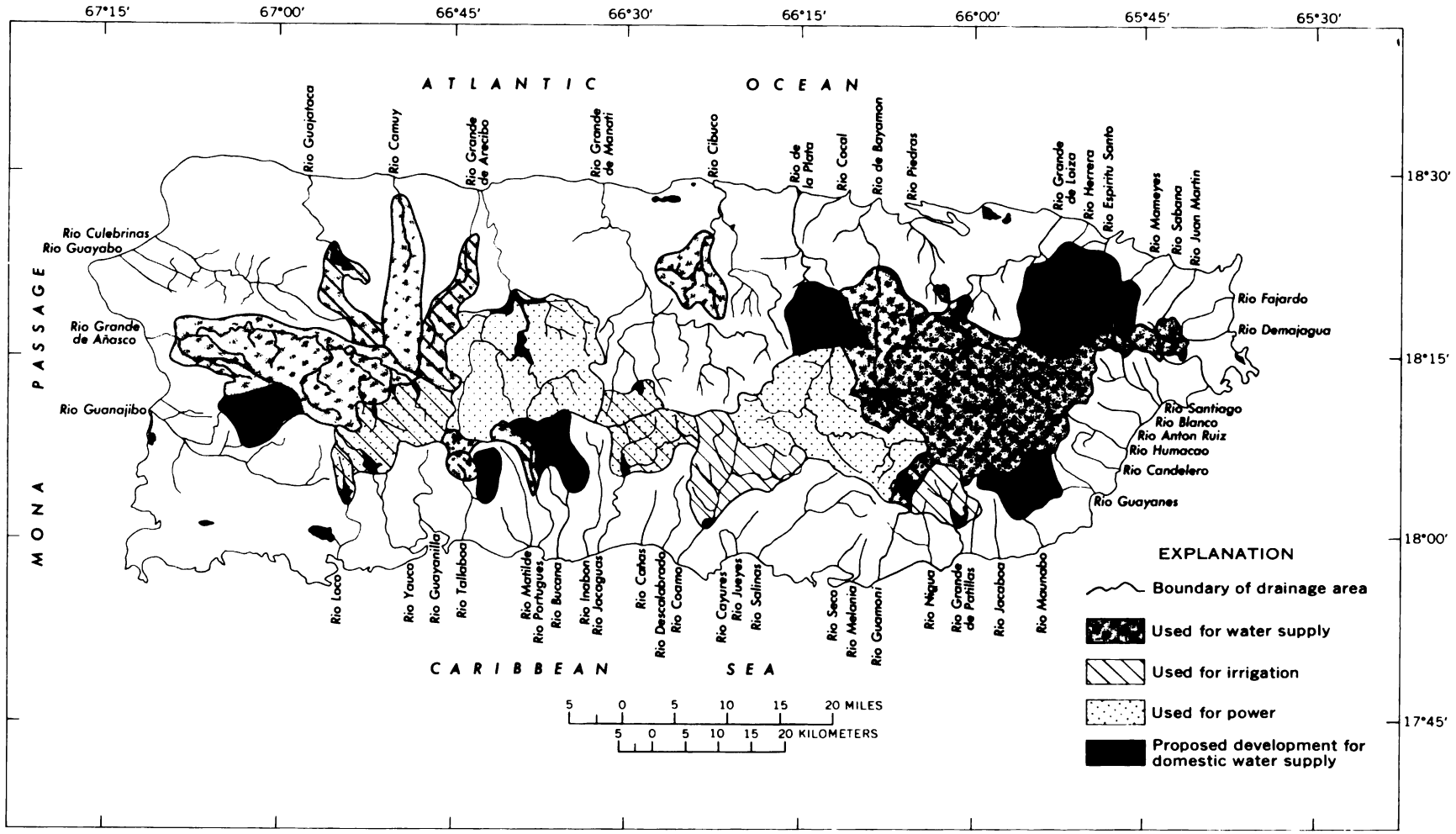

FIGURE 6–20–3.—*Areas of surface water development, Puerto Rico Region.*

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Grande de Loiza, the largest river of the Island, is used for water supply and for power by means of Lago Loiza; however, most of the water runs to the sea with relatively little other use and with almost no consumptive use. Similarly, much of the basin of Rio Grande de Arecibo has been developed for power at Dos Bocas Dam and at other upstream sites, but almost all of the water passing Lago Dos Bocas is available for further use downstream.

Of still greater importance is the fact that most of the larger rivers of Puerto Rico remain virtually unused, except for the relatively small amount of diversion to south coast areas. A great amount of water is available in the rivers along the west, north, and east coasts. Outstanding as additional water sources are Rio Guanajibo, Rio Grande de Anasco, Rio Culebrinas, Rio Grande de Manati, Rio de La Plata, and Rio Grande de Loiza. Smaller streams such as the Rio Camuy, Rio Cibuco, Rio Guayanes, and the streams of the northern slopes of the Sierra de Luquillo also have excellent possibilities. Supplies in the order of 10 to 30 mgd can be obtained from some of these rivers by pumping stations in the coastal plain if precautions are taken to prevent salt water contamination.

Except in the north coast limestone area, reservoir sites are plentiful in the Region. A survey for additional hydroelectric power developments identified sites with a combined storage capacity of 103 billion gallons. One of these, on Rio Grande de Manati, can impound 47 billion gallons, nearly 3 times the capacity of any existing reservoir. Sites for purposes other than power undoubtedly also exist.

Water usage for irrigation along the southern coast of Puerto Rico has been severely curtailed by the lack of adequate storage facilities. During the heavy rain seasons, high runoff floods the coastal plains and is lost to the sea. During the major drought of 1963-65, numerous agricultural zones were declared disaster areas due to lack of water, and salt water intruded into several groundwater aquifers.

Water needs for industry, irrigation, domestic use, and recreation are increasing rapidly, while needs for power generation are decreasing. Present facilities are not able to supply the needs of the existing irrigation districts. Major construction projects are under study to divert water to the south coast for irrigation and industry. This effort, together with additional storage facilities on the south coast, will help alleviate the problem. In addition, several upstream watershed projects are feasible, and a number of others appear to be.

Flood-warning systems, flood-plain zoning, and flood-control works are urgently needed. Unfortunately, preliminary studies of flood control projects indicate that many are not economically justified. However, without an adequate flood-plain management program, such havoc as Hurricane Donna caused in September 1960—more than 100 persons killed and property damages of $7 million—is bound to recur.

PRESENT INSTITUTIONAL AND MANAGEMENT PROBLEMS

At the time of this writing, various aspects of the responsibility for and management of the Region's water resources are distributed among various Federal and Commonwealth agencies and departments. The lack of an overall centralized body for the total management of the resources has engendered problems. A study on ways to centralize the Commonwealth's water management has recently been completed, but a decision concerning its conclusions has not yet been made.

Until recently the economy of the Region was predominantly agrarian, and most of the large demand for water was for sugar production. The use of water for the irrigation and grinding of sugar cane was geared perfectly to the existing water law, which is basically the Spanish Law of Waters of 1863 and part of the Civil Code System of Puerto Rico. It regulates the use of public waters for public and private uses through franchises authorizing withdrawals from streams. Most of these franchises have been granted by the Puerto Rico Public Services Commission, the present agency responsible for authorizing the use of surface waters, and are revocable. Some franchises, however, were granted by the former Spanish Government, and are not revocable unless an agreement can be reached with the holders. Withdrawal of groundwater is controlled by law only in regard to the franchises that are required for wells constructed less than 100 meters from a river.

Manufacturing has now supplanted agriculture as the main source of income in Puerto Rico, and the accelerating industralization is expected to continue into the future. A conflict is thus to be expected between (1) the traditional use of water by agriculture, which is backed by existing water law, (2) the growing need for water for industries (which have been

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attracted to the Island by the Commonwealth Government) and (3) the steadily increasing domestic use.

The Puerto Rico Water Resources Authority is responsible for the collection and distribution of water for irrigation and for the generation and distribution of power. Responsibility for soil conservation and watershed protection is assigned to the Commonwealth Department of Agriculture. Flood control management and protection programs are the responsibility of the Public Works Department, and the Commonwealth Planning Board is studying zoning regulations to control use of flood plains.

The Puerto Rico Aqueduct and Sewer Authority is responsible for the construction and management of facilities required to supply water for, and dispose of wastes from, municipalities and industries. However, most of the heavy industries established on the Island provide their own supply of water with the advice of the Puerto Rico Industrial Development Company (Fomento). Pollution control programs, standards, and regulations are the responsibility of the Commonwealth Health Department; at present, however, no definite water quality standards, especially regarding inland surface waters, have been established to regulate industrial and municipal wastes.

PROJECTED REGIONAL ECONOMY AND WATER REQUIREMENTS

The industrialization program will continue to be the major spearhead in the Region's economic development. Over 25% of the increase in the domestic income during the period 1965 through 2020 will come from this economic sector. It is expected that the economic growth will be accompanied by considerable increases in the demand for goods and services. Demands for housing, commercial space, industrial areas, education, highways, and parks will also increase considerably.

The Puerto Rico Planning Board has estimated that the population of the Region will reach 6.5 million in 2020, or an increase of almost 4 million from 1965 (table 6–20–2). With the population growth, employment will increase dramatically to an estimated 2.2 million in 2020, and net adjusted income is expected to increase to $29.5 million.

It is also expected that the majority of the population and employment will concentrate in the urban areas that have greater potentials for development—for example, San Juan, Ponce, Mayaguez, Caguas, Arecibo, Guayama, Humacao, and Cayey. As a result, the urban population, which was around 47% of the total population in 1965, will increase to 67% in 1980 and to about 80% in 2020.

The petrochemical industry is expected to continue to locate in Puerto Rico, especially in the south and western areas of the Island where the best ports are. This industry is a great water user and will require considerable attention in the water resources planning of the Region. Projected water requirements are shown in table 6–20–3.

EMERGING WATER PROBLEMS

The Region is in a stage of rapid economic growth that involves a continuously increasing demand for water for municipal, agricultural, and industrial uses. Therefore, it must not only insure that water supplies will meet the growing demand but also, to avoid the evils that inevit-

TABLE 6–20–2.—*Population and economic projections, Puerto Rico Region*

Item	Unit	1965	Projections		
			1980	2000	2020
Population, total	thou.	2,665	3,620	5,000	6,500
Total personal income	mil. dol.	2,308	8,300	18,500	29,500
Per capita personal income	dol.	866	2,290	3,700	4,540
Employment, total	thou.	672	1,086	1,742	2,190
Agriculture	do.	124	86	58	40
Manufacturing	do.	112	250	480	660
Commerce	do.	125	208	282	330
Government	do.	87	162	302	360
Other	do.	224	380	620	800

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TABLE 6–20–3.—*Projected water requirements, Puerto Rico Region*

(Million gallons per day)

Type of use	Used 1965	Projected requirements		
		1980	2000	2020
Withdrawals				
Rural domestic	5	7	7	7
Municipal (public-supplied)	141	250	400	750
Industrial (self-supplied):				
Fresh	182	240	350	450
Saline	135	500	1,000	1,500
Steam-electric power:				
Fresh	1	3	3	3
Saline	400	2,700	6,200	10,600
Agriculture:				
Irrigation	250	300	350	400
Livestock	6	10	15	20
Total	1,120	4,010	8,325	13,730
Consumptive use				
Rural domestic	5	5	5	5
Municipal	21	35	50	75
Industrial:				
Fresh	10	15	25	40
Saline	–	5	10	15
Steam-electric power:				
Fresh	–	–	–	–
Saline	3	20	55	100
Agriculture:				
Irrigation	225	270	315	360
Livestock	6	10	15	20
Total	270	360	475	615

ably result from competition for any natural resource, develop the supplies to serve multipurpose needs.

Puerto Rico's total available natural water supply is abundant enough to meet the greatest anticipated demands for all uses. Nevertheless, it poses a major problem for two chief reasons: (1) it is not equally distributed in time or place; (2) the demand for it is also not equally distributed because of varied terrain and spotty port facilities. In those areas where supply exceeds the demand, no problems exist at present. Where the demand exceeds, or is expected to exceed, the supply competition has already arisen among the various users of water.

As a consequence of the natural abundance, the development of surface water and groundwater has proceeded with relatively little attention to the high interdependence of the two sources. Wells were drilled on a trial-and-error basis, which generally has been a successful procedure because the limits of groundwater development seldom have been exceeded. Water is still easy to obtain, but its optimum utilization, both now and in the future, requires that the close relationship of all aspects of the supply be recognized. Much detailed information is needed, if the anticipated future demands are to be met properly. Each area of possible further development must be studied carefully to obtain the maximum amount of water consistent with the extent of the supply.

The combination of deeply weathered rocks, steep land slopes, torrential rainfall, and certain customary land-use practices has introduced large quantities of sediment into the streams and lakes of the Region. Unfortunately, owing to presently limited data, evaluation of the reduction in the effective life of reservoirs or other water resources structures from sedimentation is extremely difficult.

Flooding as a result of steep stream gradients and torrential rainfall is of major concern. Hurricane rains, such as those which accom-

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panied the passage of Hurricane Donna in 1960, are extremely devastating. Because the projected increased population will undoubtedly be largely centered in coastal areas and river valleys, increased damages can be anticipated from such floods coming out of the mountains and entering the coastal plains.

Salt water intrusion of streams or aquifers is at present not considered a major problem. Nevertheless, a number of wells that have been continuously pumped, especially during drought periods, have been reported as yielding increasingly mineralized water; several of them have been abandoned. Furthermore, when extensive industrial facilities are being constructed at port areas or when marine sloughs are being drained for agricultural use, intrusion of sea water into fresh water supplies can and will occur unless careful control is exercised.

Preliminary studies have shown that human wastes and the waste products of the sugar industry are the major sources of pollution. The problem of human wastes has been a large one for some time. The Island's population density is so high that there are practically no uninhabited areas; as a result, only the water in the uppermost reaches of a few of the streams is fit for human consumption without treatment. With the anticipated development of more industries, better water quality will be demanded. At the same time, the new industries will themselves create additional contamination problems affecting maximum use of water. Data are needed on the quality of both developed and undeveloped waters, so that effective standards and controls may be established and enforced.

Drainage of marshes for agricultural use and protection of beaches for recreation purposes are among the many other problems of water and related land resources in the Region.

Except for good precipitation records that have been compiled during the past 62 years, relatively few long-range data on occurrence, movement, and availability of water have been collected in the Region. This lack seriously restricts water resources planning and investment planning. However, the presently limited data on surface water and groundwater are being supplemented by a cooperative data collection program that is under way.

DEVELOPMENT AND MANAGEMENT NEEDS—1980

At the present time, the most important major water resource projects in the Region have been developments for hydroelectric power and irrigation. The only major project for municipal water supply was developed for the San Juan metropolitan area.

In the future, important projects will be required for industrial and irrigation purposes, particularly along the southern coast of the Island where the amount of water is limited. Municipal water supply projects are also needed to satisfy increasing demands in the metropolitan areas of San Juan, Ponce, and Mayaguez.

Near-future projects in the southern part of the Island currently being considered by the Commonwealth include the development of the Toa Vaca River—a 3.85 billion-gallon reservoir for irrigation and municipal uses—and the Rosaria-Guanajibo project, a 2.6 billion-gallon reservoir for industrial uses. Development of the Portugues River on the south coast is also proposed to provide 7.5 mgd for municipal uses in the Ponce area. Plans are nearly completed for the development of the Rio La Plata to provide an initial 20 mgd for municipal uses in the San Juan metropolitan area. In addition, studies of recreation facilities have identified the need for recreation reservoirs on the Island.

A comprehensive planning study for the development of water resources has been initiated by the Commonwealth. It will cover all aspects of water demand and supply and will serve to indicate priorities in water resources development projects. The scope of the study extends to 2020, with revisions to be made every 5 years.

It is apparent that there is a need to centralize the responsibility for establishing policies, standards, and procedures for uniform use in the formulation, appraisal, and review of plans for the development of water resources to provide the best use of water to meet all foreseeable short- and long-term needs. Specific recommendations are being considered by the Commonwealth Governor toward the creation of a new organization for the complete control and management of water resources development in the Region.

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PART 7

Appendices

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APPENDIX 2

Acknowledgments

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APPENDIX 3

Supporting Material

TABLE 7–3–1.—*Annual natural runoff*

(Billion gallons per day)

Region	Mean	50% [1]	90% [1]	95% [1]
North Atlantic[2]	163	163	123	112
South Atlantic-Gulf	197	188	131	116
Great Lakes [2 3]	63.2	61.4	46.3	42.4
Ohio[4]	125	125	80.0	67.5
Tennessee	41.5	41.5	28.2	24.4
Upper Mississippi[4]	64.6	64.6	36.4	28.5
Lower Mississippi[4]	48.4	48.4	29.7	24.6
Souris-Red-Rainy[2]	6.17	5.95	2.60	1.91
Missouri[2]	54.1	53.7	29.9	23.9
Arkansas-White-Red	95.8	93.4	44.3	33.4
Texas-Gulf	39.1	37.5	15.8	11.4
Rio Grande[5]	4.9	4.9	2.6	2.1
Upper Colorado[6]	13.45	13.45	8.82	7.50
Lower Colorado[4 5]	3.19	2.51	1.07	0.85
Great Basin[4]	5.89	5.82	3.12	2.46
Columbia-North Pacific[2]	210	210	154	138
California[5]	65.1	64.1	32.8	25.6
Conterminous United States[7]	1,201			
Alaska[2]	580	[8]	[8]	[8]
Hawaii	13.3	[8]	[8]	[8]
United States[7]	1,794			

[1] Flow exceeded in indicated percent of years. [2] Does not include runoff from Canada. [3] Does not include net precipitation on the Lakes. [4] Does not include runoff from upstream regions. [5] Does not include runoff from Mexico. [6] Virgin flow. Mean annual natural runoff estimated to be 13.7 bgd. [7] Rounded. [8] Not available.

TABLE 7–3–2.—*National water use and requirements by use*

(Million gallons per day)

Type of use	Used 1965	Projected requirements 1980	2000	2020	Used 1965	Projected requirements 1980	2000	2020
		Withdrawals				*Consumptive use*		
Rural domestic	2,351	2,474	2,852	3,334	1,636	1,792	2,102	2,481
Municipal (public-supplied)	23,745	33,596	50,724	74,256	5,244	10,581	16,478	24,643
Industrial (self-supplied)	46,405	75,026	127,365	210,767	3,764	6,126	10,011	15,619
Steam-electric power:								
Fresh	62,738	133,963	259,208	410,553	659	1,685	4,552	8,002
Saline	21,800	59,340	211,240	503,540	157	498	2,022	5,183
Agriculture:								
Irrigation	110,852	135,852	149,824	160,978	64,696	81,559	89,964	96,919
Livestock	1,726	2,375	3,397	4,660	1,626	2,177	3,077	4,238
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

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TABLE 7–3–3.—*National water use and requirements by region* [1]

(Million gallons per day)

Region	Used 1965	Projected requirements			Used 1965	Projected requirements		
		1980	2000	2020		1980	2000	2020
	Withdrawals				*Consumptive use*			
North Atlantic	37,467	54,920	113,860	236,290	2,023	2,870	4,960	8,490
South Atlantic-Gulf	20,560	53,180	87,440	130,190	2,695	3,395	5,655	8,265
Great Lakes	25,119	47,893	96,594	190,960	1,199	1,881	3,183	5,484
Ohio	28,255	41,749	65,109	90,163	1,134	1,619	2,539	3,623
Tennessee	5,767	12,252	13,877	18,106	331	572	834	1,132
Upper Mississippi	8,179	14,800	30,587	41,266	770	1,103	1,778	2,624
Lower Mississippi	5,571	12,816	27,967	39,442	1,470	3,012	4,453	6,251
Souris-Red-Rainy	391	936	2,002	2,758	77	215	494	544
Missouri	19,344	23,264	27,876	31,572	10,554	13,160	14,979	16,378
Arkansas-White-Red	9,410	17,279	25,336	31,589	5,874	8,482	10,587	12,329
Texas-Gulf	16,410	29,080	57,330	92,640	7,289	9,435	10,890	12,300
Rio Grande	7,289	8,330	9,510	11,680	4,403	4,676	4,991	5,466
Upper Colorado	4,017	5,675	6,575	6,725	1,982	2,700	3,100	3,140
Lower Colorado	6,913	8,497	8,428	8,889	3,448	4,075	4,645	5,310
Great Basin	5,115	7,055	7,550	7,800	2,253	3,299	3,562	3,776
Columbia-North Pacific	29,631	41,407	90,135	156,735	10,521	13,581	17,325	21,616
California	37,300	56,290	120,510	244,760	20,944	29,205	32,660	38,190
Alaska	162	535	901	4,206	12	50	96	184
Hawaii	1,597	2,658	4,698	8,587	533	728	1,000	1,368
Puerto Rico	1,120	4,010	8,325	13,730	270	360	475	615
Total	269,617	442,626	804,610	1,368,088	77,782	104,418	128,206	157,085

[1] WRC estimates. Some regional estimates differ.

TABLE 7–3–4.—*Present regional withdrawals, 1965*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total	From groundwater sources	From saline sources
				Fresh	Saline	Irrigation	Livestock			
North Atlantic	390	5,446	9,499	10,500	11,400	151	81	37,467	2,562	15,380
South Atlantic-Gulf	504	1,980	3,360	7,600	3,700	3,270	146	20,560	4,221	4,132
Great Lakes	274	3,622	9,069	12,000	—	75	79	25,119	963	25
Ohio	300	1,791	8,606	17,400	—	24	134	28,255	1,760	27
Tennessee	64	253	1,076	4,329	—	8	37	5,767	202	—
Upper Mississippi	203	1,103	1,664	4,800	—	95	314	8,179	1,707	18
Lower Mississippi	58	470	1,884	1,600	200	1,320	39	5,571	1,671	240
Souris-Red-Rainy	14	36	98	200	—	24	19	391	55	—
Missouri	106	969	462	1,400	—	16,039	368	19,344	4,005	—
Arkansas-White-Red	103	687	910	600	—	6,960	150	9,410	5,598	75
Texas-Gulf	40	1,055	5,465	2,100	200	7,450	100	16,410	8,390	3,300
Rio Grande	10	254	215	70	—	6,671	69	7,289	3,130	133
Upper Colorado	6	60	40	20	—	3,880	11	4,017	36	—
Lower Colorado	6	342	140	10	—	6,400	15	6,913	4,147	—
Great Basin	15	274	225	10	—	4,575	16	5,115	935	—
Columbia-North Pacific	148	1,105	1,911	8	—	26,400	59	29,631	4,289	31
California	90	4,010	1,250	70	5,600	26,200	80	37,300	13,610	6,140
Alaska	8	32	102	20	—	—	—	162	25	—
Hawaii	7	115	112	—	300	1,060	3	1,597	706	316
Puerto Rico	5	141	317	1	400	250	6	1,120	157	535
Total	2,351	23,745	46,405	62,738	21,800	110,852	1,726	269,617	58,169	30,352
From:										
Groundwater sources	2,012	8,051	7,965	610	—	38,531	1,000	58,169		
Saline sources	—	—	8,552	—	21,800	—	—	30,352		

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TABLE 7–3–5.—*Present regional consumptive use, 1965*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	186	905	555	75	83	150	69	2,023
South Atlantic-Gulf	472	363	260	42	19	1,400	139	2,695
Great Lakes	100	502	362	95	—	68	72	1,199
Ohio	200	230	410	138	—	24	132	1,134
Tennessee	61	46	174	6	—	8	36	331
Upper Mississippi	101	162	58	61	—	83	305	770
Lower Mississippi	52	175	296	16	3	890	38	1,470
Souris-Red-Rainy	14	11	7	2	—	24	19	77
Missouri	85	221	71	24	—	9,798	355	10,554
Arkansas-White-Red	94	241	322	41	—	5,030	146	5,874
Texas-Gulf	40	400	880	57	2	5,810	100	7,289
Rio Grande	7	108	46	9	—	4,165	68	4,403
Upper Colorado	3	14	8	13	—	1,934	10	1,982
Lower Colorado	5	203	50	8	—	3,170	12	3,448
Great Basin	9	94	37	2	—	2,100	11	2,253
Columbia-North Pacific	134	182	100	—	—	10,050	55	10,521
California	60	1,320	110	70	44	19,290	50	20,944
Alaska	1	7	4	—	—	—	—	12
Hawaii	7	39	4	—	3	477	3	533
Puerto Rico	5	21	10	—	3	225	6	270
Total	1,636	5,244	3,764	659	157	64,696	1,626	77,782

TABLE 7–3–6.—*Projections of regional withdrawals, 1980*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	400	7,100	14,100	10,900	22,100	230	90	54,920
South Atlantic-Gulf	380	3,300	4,900	28,500	12,000	3,900	200	53,180
Great Lakes	257	5,030	16,700	25,700	—	110	96	47,893
Ohio	350	2,330	11,600	27,300	—	40	129	41,749
Tennessee	128	358	1,600	10,100	—	18	48	12,252
Upper Mississippi	143	1,770	2,800	9,500	—	110	477	14,800
Lower Mississippi	80	647	2,500	5,900	600	3,030	59	12,816
Souris-Red-Rainy	16	49	150	500	—	200	21	936
Missouri	134	1,225	584	1,500	—	19,300	521	23,264
Arkansas-White-Red	213	1,418	1,880	4,100	40	9,400	228	17,279
Texas-Gulf	70	1,890	9,340	5,500	2,700	9,400	180	29,080
Rio Grande	10	430	910	70	—	6,840	70	8,330
Upper Colorado	10	120	200	30	—	5,300	15	5,675
Lower Colorado	7	520	210	40	—	7,700	20	8,497
Great Basin	15	450	340	30	—	6,200	20	7,055
Columbia-North Pacific	148	1,304	4,478	4,000	—	31,400	77	41,407
California	90	5,090	1,660	90	18,300	30,950	110	56,290
Alaska	11	120	200	200	—	4	—	535
Hawaii	5	195	134	—	900	1,420	4	2,658
Puerto Rico	7	250	740	3	2,700	300	10	4,010
Total	2,474	33,596	75,026	133,963	59,340	135,852	2,375	442,626

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TABLE 7–3–7.—*Projections of regional consumptive use, 1980*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	200	1,210	850	120	180	230	80	2,870
South Atlantic-Gulf	355	600	380	190	80	1,600	190	3,395
Great Lakes	85	702	728	184	—	95	87	1,881
Ohio	250	300	550	350	—	40	129	1,619
Tennessee	122	64	258	65	—	16	47	572
Upper Mississippi	94	258	98	166	—	95	392	1,103
Lower Mississippi	72	238	400	60	4	2,180	58	3,012
Souris-Red-Rainy	16	16	8	4	—	150	21	215
Missouri	108	280	90	80	—	12,100	502	13,160
Arkansas-White-Red	194	496	674	95	—	6,800	223	8,482
Texas-Gulf	65	740	1,160	180	20	7,100	170	9,435
Rio Grande	7	220	90	20	—	4,270	69	4,676
Upper Colorado	4	30	35	17	—	2,600	14	2,700
Lower Colorado	5	310	80	35	—	3,630	15	4,075
Great Basin	9	154	56	25	—	3,040	15	3,299
Columbia-North Pacific	134	219	244	13	—	12,900	71	13,581
California	60	4,620	380	80	185	23,800	80	29,205
Alaska	2	24	20	1	—	3	—	50
Hawaii	5	65	5	—	9	640	4	728
Puerto Rico	5	35	20	—	20	270	10	360
Total	1,792	10,581	6,126	1,685	498	81,559	2,177	104,418

TABLE 7–3–8.—*Projections of regional withdrawals, 2000*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	400	10,000	22,800	11,300	68,900	330	130	113,860
South Atlantic-Gulf	340	5,400	8,000	39,800	27,600	6,000	300	87,440
Great Lakes	292	6,900	33,000	56,100	—	170	132	96,594
Ohio	415	3,320	15,900	45,200	—	80	194	65,109
Tennessee	167	560	2,360	10,700	—	23	67	13,877
Upper Mississippi	132	2,760	5,300	21,500	—	200	695	30,587
Lower Mississippi	147	921	3,420	16,700	2,300	4,400	79	27,967
Souris-Red-Rainy	17	82	212	1,100	—	562	29	2,002
Missouri	162	1,481	707	3,200	—	21,600	726	27,876
Arkansas-White-Red	336	2,375	3,147	8,400	40	10,700	318	25,336
Texas-Gulf	120	3,110	15,500	22,000	7,300	9,000	300	57,330
Rio Grande	10	720	1,800	70	—	6,840	70	9,510
Upper Colorado	10	160	1,000	35	—	5,350	20	6,575
Lower Colorado	8	860	280	250	—	7,000	30	8,428
Great Basin	15	745	560	100	—	6,100	30	7,550
Columbia-North Pacific	148	2,100	8,880	22,200	19,200	37,500	107	90,135
California	90	8,280	2,590	300	77,400	31,700	150	120,510
Alaska	12	230	40	250	—	9	—	901
Hawaii	4	320	159	—	2,300	1,910	5	4,698
Puerto Rico	7	400	1,350	3	6,200	350	15	8,325
Total	2,852	50,724	127,365	259,208	211,240	149,824	3,397	804,610

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TABLE 7–3–9.—*Projections of regional consumptive use, 2000*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	200	1,750	1,500	320	750	330	110	4,960
South Atlantic-Gulf	320	1,000	620	765	215	2,450	285	5,655
Great Lakes	103	953	1,400	467	—	140	120	3,183
Ohio	290	450	770	775	—	80	194	2,539
Tennessee	158	95	381	115	—	21	64	834
Upper Mississippi	85	403	184	373	—	170	563	1,778
Lower Mississippi	133	343	550	175	7	3,170	75	4,453
Souris-Red-Rainy	17	26	10	10	—	402	29	494
Missouri	130	339	109	200	—	13,500	701	14,979
Arkansas-White-Red	325	832	1,114	205	—	7,800	311	10,587
Texas-Gulf	110	1,200	1,650	495	55	7,100	280	10,890
Rio Grande	7	400	180	65	—	4,270	69	4,991
Upper Colorado	5	35	140	20	—	2,880	20	3,100
Lower Colorado	5	515	130	210	—	3,760	25	4,645
Great Basin	9	255	92	75	—	3,110	21	3,562
Columbia-North Pacific	134	350	481	180	180	15,900	100	17,325
California	60	7,350	620	100	740	23,700	90	32,660
Alaska	2	46	40	2	—	6	—	96
Hawaii	4	106	5	—	20	860	5	1,000
Puerto Rico	5	50	35	—	55	315	15	475
Total	2,102	16,478	10,011	4,552	2,022	89,964	3,077	128,206

TABLE 7–3–10.—*Projections of regional withdrawals, 2020*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	400	14,200	37,200	14,700	169,200	420	170	236,290
South Atlantic-Gulf	310	8,300	12,200	56,000	44,800	8,200	380	130,190
Great Lakes	347	9,500	66,000	114,700	—	230	183	190,960
Ohio	490	4,900	23,200	61,200	—	115	258	90,163
Tennessee	212	872	3,100	13,800	—	29	93	18,106
Upper Mississippi	130	4,000	10,000	25,900	—	280	956	41,266
Lower Mississippi	254	1,334	4,740	19,500	7,500	6,000	114	39,442
Souris-Red-Rainy	21	124	297	1,700	—	576	40	2,758
Missouri	190	1,738	829	4,800	—	23,000	1,015	31,572
Arkansas-White-Red	515	3,438	4,553	11,100	40	11,500	443	31,589
Texas-Gulf	160	4,540	22,100	41,000	15,900	8,500	440	92,640
Rio Grande	10	1,090	3,570	100	—	6,840	70	11,680
Upper Colorado	10	240	1,500	50	—	4,900	25	6,725
Lower Colorado	9	1,400	340	600	—	6,500	40	8,889
Great Basin	15	1,005	740	200	—	5,800	40	7,800
Columbia-North Pacific	148	3,240	13,500	44,600	52,600	42,500	147	156,735
California	90	12,690	3,960	300	194,900	32,600	220	244,760
Alaska	13	375	800	300	2,700	18	—	4,206
Hawaii	3	520	188	—	5,300	2,570	6	8,587
Puerto Rico	7	750	1,950	3	10,600	400	20	13,730
Total	3,334	74,256	210,767	410,553	503,540	160,978	4,660	1,368,088

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TABLE 7–3–11.—*Projections of regional consumptive use, 2020*

(Million gallons per day)

Region	Rural domestic	Municipal	Self-supplied industrial	Steam-electric power		Agriculture		Total
				Fresh	Saline	Irrigation	Livestock	
North Atlantic	200	2,550	2,600	580	2,000	420	140	8,490
South Atlantic-Gulf	290	1,500	940	1,440	385	3,350	360	8,265
Great Lakes	125	1,304	2,800	898	—	190	167	5,484
Ohio	340	620	1,100	1,190	—	115	258	3,623
Tennessee	202	140	500	175	—	26	89	1,132
Upper Mississippi	76	580	346	607	—	240	775	2,624
Lower Mississippi	229	497	760	295	40	4,320	110	6,251
Souris-Red-Rainy	21	35	12	20	—	416	40	544
Missouri	153	397	128	320	—	14,400	980	16,378
Arkansas-White-Red	470	1,205	1,611	310	—	8,300	433	12,329
Texas-Gulf	145	1,750	2,160	590	145	7,100	410	12,300
Rio Grande	7	670	350	100	—	4,270	69	5,466
Upper Colorado	5	50	150	35	—	2,880	20	3,140
Lower Colorado	5	840	200	470	—	3,760	35	5,310
Great Basin	9	345	123	160	—	3,110	29	3,776
Columbia-North Pacific	134	537	738	630	740	18,700	137	21,616
California	60	11,300	960	180	1,730	23,800	160	38,190
Alaska	2	75	80	2	13	12	—	184
Hawaii	3	173	6	—	30	1,150	6	1,368
Puerto Rico	5	75	55	—	100	360	20	615
Total	2,481	24,643	15,619	8,002	5,183	96,919	4,238	157,085

TABLE 7–3–12.—*Projections of average water availability* [1] *(used in figure 1–21)*

(Billion gallons per day)

Region	1965	1980	2000	2020
North Atlantic	163	163	163	163
South Atlantic-Gulf	197	197	197	197
Great Lakes [2]	80.3	80.3	80.3	80.3
Ohio	125	125	125	125
Tennessee	41.5	41.5	41.5	41.5
Upper Mississippi [3]	66.7	66.7	66.7	66.7
Lower Mississippi [4]	408	401	395	390
Souris-Red-Rainy [5]	6.2	6.4	6.8	6.8
Missouri [6]	54.5	54.6	54.8	54.9
Arkansas-White-Red [6]	95.8	95.9	96.0	96.0
Texas-Gulf [7]	39.1	39.2	39.2	39.2
Rio Grande [8]	5.2	5.3	5.3	5.3
Upper Colorado [9]	13.5	13.5	13.5	13.5
Lower Colorado [10]	14.1	12.6	11.9	11.6
Great Basin [11]	6.9	7.0	7.1	7.2
Columbia-North Pacific [12]	258	258	258	258
California [13]	69.7	69.4	69.3	69.2
Alaska [12]	710	710	710	710
Hawaii	13.3	13.3	13.3	13.3

[1] Natural runoff adjusted for imports and upstream runoff where appropriate, values rounded.
[2] Includes net precipitation on U.S. portion of Great Lakes.
[3] Includes import from Great Lakes Region.
[4] Includes net upstream runoff and imports (table 6-7-5).
[5] Includes import from Missouri Region.
[6] Includes imports from Upper Colorado Region.
[7] Includes import from Arkansas-White-Red Region.
[8] Includes imports from Upper Colorado Region and Mexican Treaty deliveries.
[9] Virgin flow at Lee Ferry Compact point.
[10] Includes net upstream runoff (table 6-14-5).
[11] Includes imports from Upper Colorado Region and natural runoff from California Region.
[12] Includes natural runoff from Canada.
[13] Includes imports from Lower Colorado Region.

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TABLE 7–3–13.—*Projections of fresh-water withdrawal and consumptive use requirements*[1] *(used in figure 1–21)*

(Billion gallons per day)

Region	1965	1980	2000	2020
	Withdrawals			
North Atlantic	26.1	32.8	45.0	67.1
South Atlantic-Gulf	16.9	41.2	59.8	85.4
Great Lakes[2]	27.2	50.0	98.7	193.1
Ohio	28.3	41.7	65.1	90.2
Tennessee	5.8	12.3	13.9	18.1
Upper Mississippi	8.2	14.8	30.6	41.3
Lower Mississippi	5.4	12.2	25.7	31.9
Souris-Red-Rainy	0.4	0.9	2.0	2.6
Missouri[3]	25.1	29.3	34.3	38.0
Arkansas-White-Red[4]	9.4	17.4	25.4	31.7
Texas-Gulf	16.2	26.4	50.0	76.7
Rio Grande[5]	7.4	8.4	9.6	11.8
Upper Colorado[6]	12.1	14.5	15.8	16.2
Lower Colorado[7]	14.1	15.2	15.0	15.4
Great Basin[8]	5.4	7.4	7.9	8.1
Columbia-North Pacific[9]	29.6	41.5	71.0	104.3
California[10]	32.6	38.9	44.0	50.8
Alaska	0.2	0.5	0.9	1.5
Hawaii	1.3	1.8	2.4	3.3
	Consumptive use			
North Atlantic	1.9	2.7	4.2	6.5
South Atlantic-Gulf	2.7	3.3	5.5	7.9
Great Lakes[2]	3.3	4.0	5.3	7.6
Ohio	1.1	1.6	2.5	3.6
Tennessee	0.3	0.6	0.8	1.1
Upper Mississippi	0.8	1.1	1.8	2.6
Lower Mississippi	1.5	3.0	4.5	6.2
Souris-Red-Rainy	0.1	0.2	0.5	0.5
Missouri[3]	16.4	19.2	21.4	22.8
Arkansas-White-Red[4]	6.0	8.6	10.7	12.4
Texas-Gulf	7.3	9.4	10.9	12.4
Rio Grande[5]	4.5	4.8	5.1	5.6
Upper Colorado[6]	10.1	11.5	12.3	12.6
Lower Colorado[7]	10.6	10.8	11.2	11.8
Great Basin[8]	2.6	3.6	3.9	4.1
Columbia-North Pacific[9]	10.5	13.6	17.5	22.3
California[10]	21.8	29.9	32.9	37.4
Alaska	0.01	0.05	0.1	0.2
Hawaii	0.5	0.7	1.0	1.3

[1] Totals adjusted for saline steam-electric power, reservoir evaporation where known, exports, and downstream requirements where appropriate, values rounded.

[2] Includes export to Upper Mississippi Region.

[3] Includes reservoir evaporation and export to Souris-Red-Rainy Region.

[4] Includes export to Texas-Gulf Region.

[5] Includes Treaty deliveries to Mexico.

[6] Includes some reservoir evaporation; exports to Missouri, Arkansas-White-Red, Rio Grande ,and Great Basin Regions; and Compact deliveries to Lower Colorado Region.

[7] Includes some reservoir evaporation, exports to California Region, and Treaty deliveries to Mexico.

[8] Includes managed waterfowl habitat.

[9] Includes managed recreation areas.

[10] Includes runoff to Great Basin Region.

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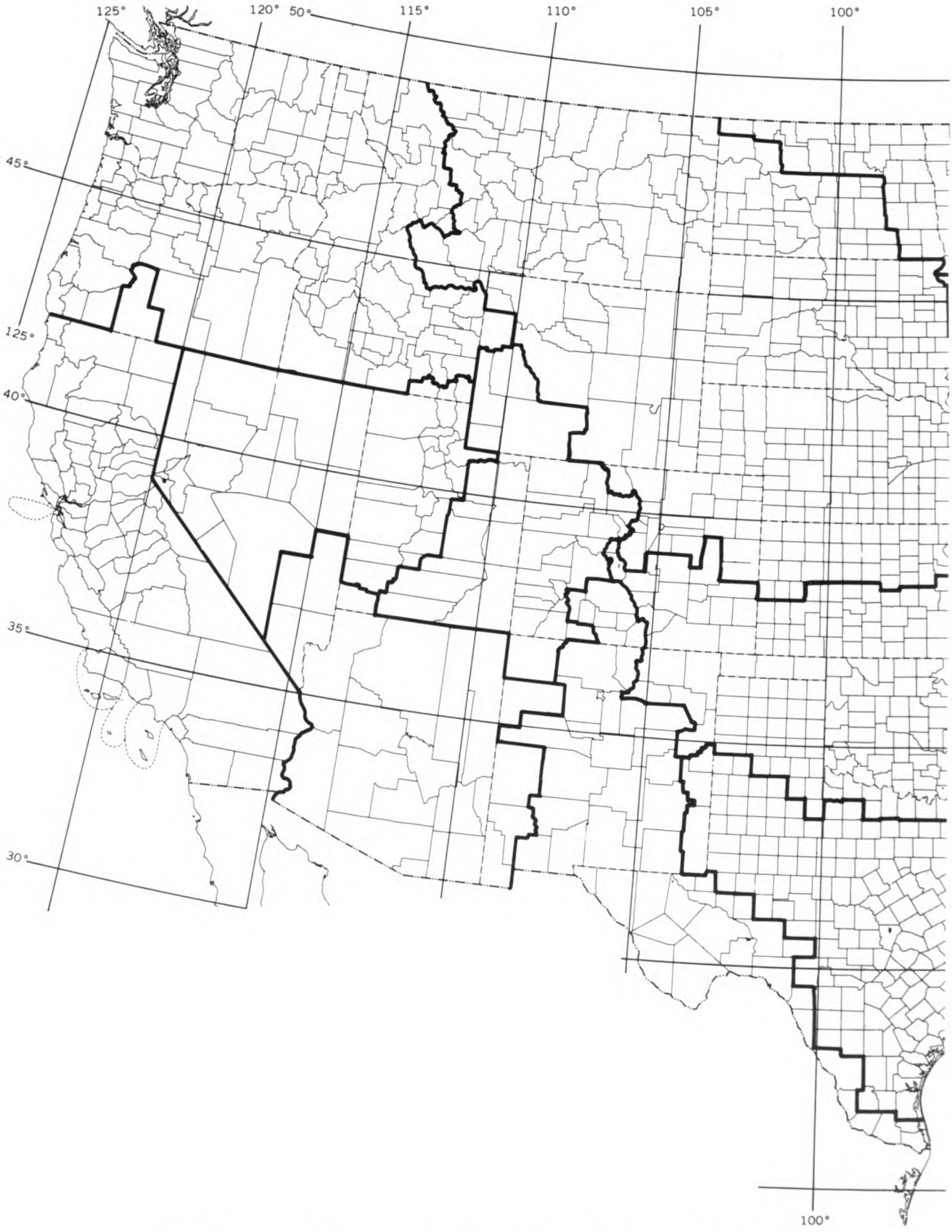

FIGURE 7–3–1.—*Key to areas used for demographic, economic, and land-use projections.*

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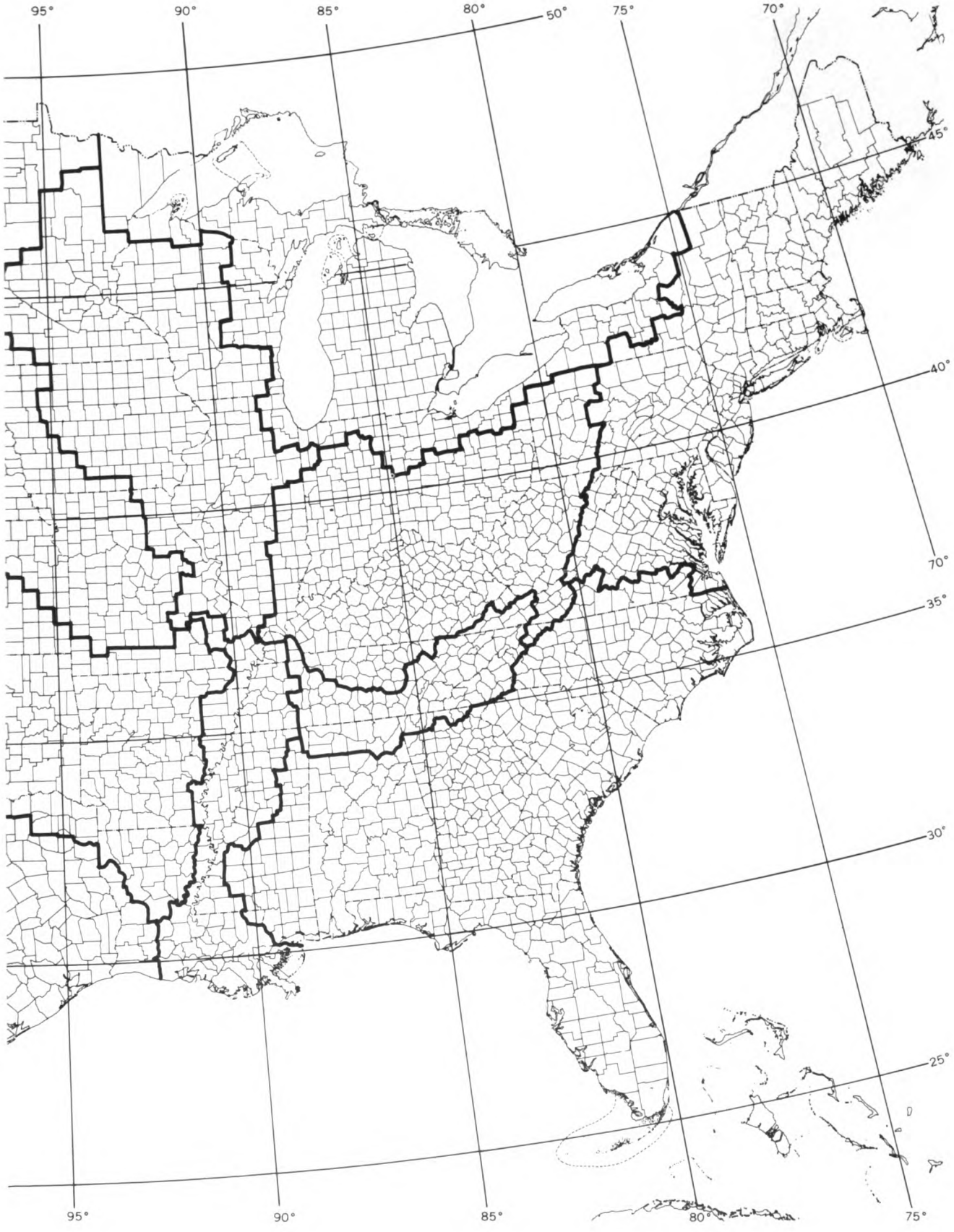

7–3–9

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FIGURE 7–3–2.—*Key to areas used for determination of natural runoff.*

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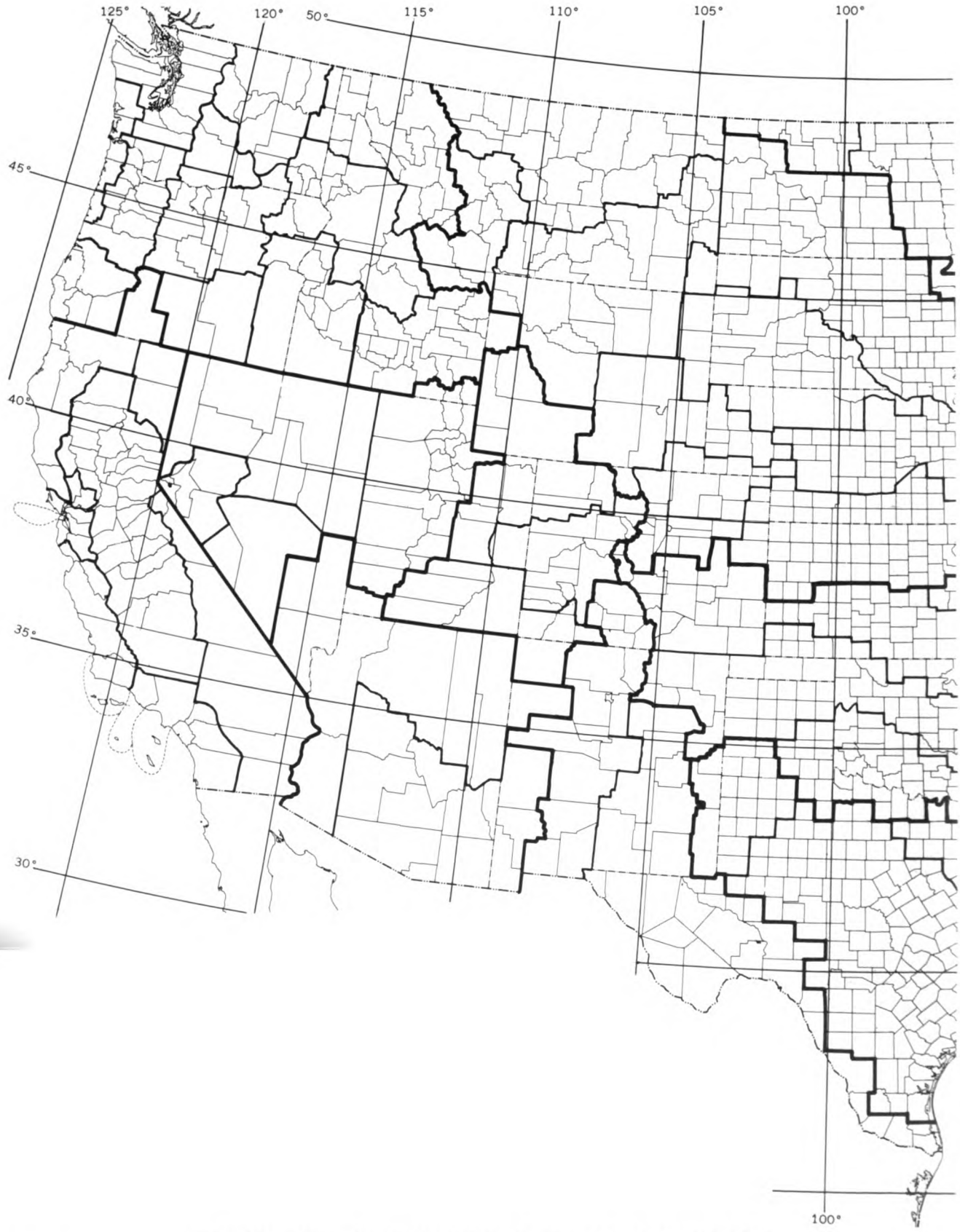

FIGURE 7–3–3.—*Key to areas used for initial aggregation of present water use data.*

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7–3–13

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COMMON ABBREVIATIONS

acre	ac
acre-foot	af
acre-feet per year	af/yr
average	avg
billion gallons per day	bgd
capita	cap
cubic feet per second	cfs
dollars	dol.
foot	ft
gallon	gal
gallons per capita per day	gcd
gallons per minute	gpm
inch	in
inches per year	in/yr
kilowatt	kw
kilowatt-hour	kwh
megawatt	mw
mile	mi
million	mil.
million acre-feet	maf
million acre-feet per year	maf/yr
million gallons per day	mgd
month	mo
number	no.
parts per million	ppm
percent	%
square mile	sq mi
thousand	thou.
year	yr

APPROXIMATE CONVERSION FACTORS

1 bgd	= 1.12 maf/yr
1 maf/yr	= 0.892 bgd
1 billion gallons	= 3.07 thou. af
1 maf	= 326 billion gallons

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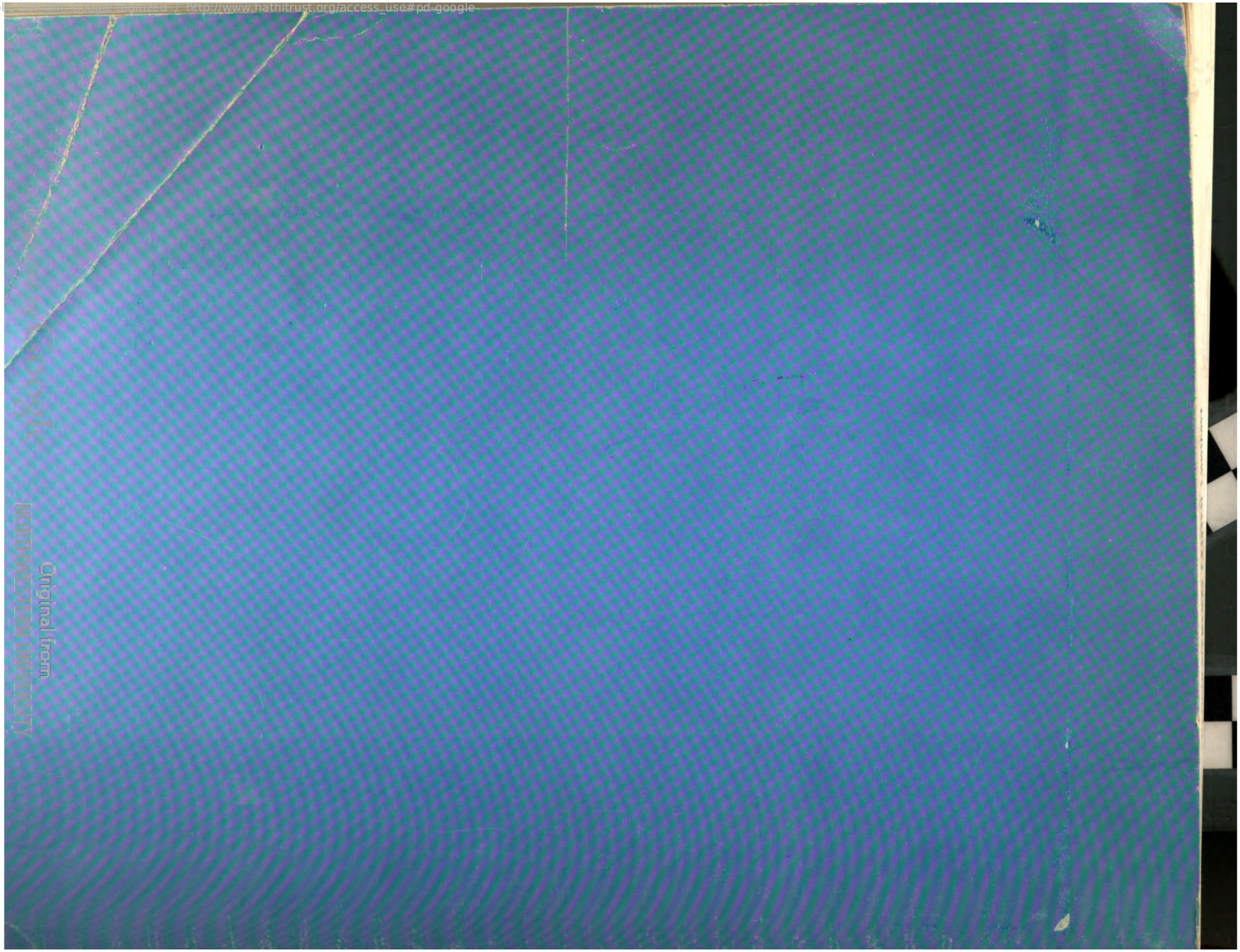

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