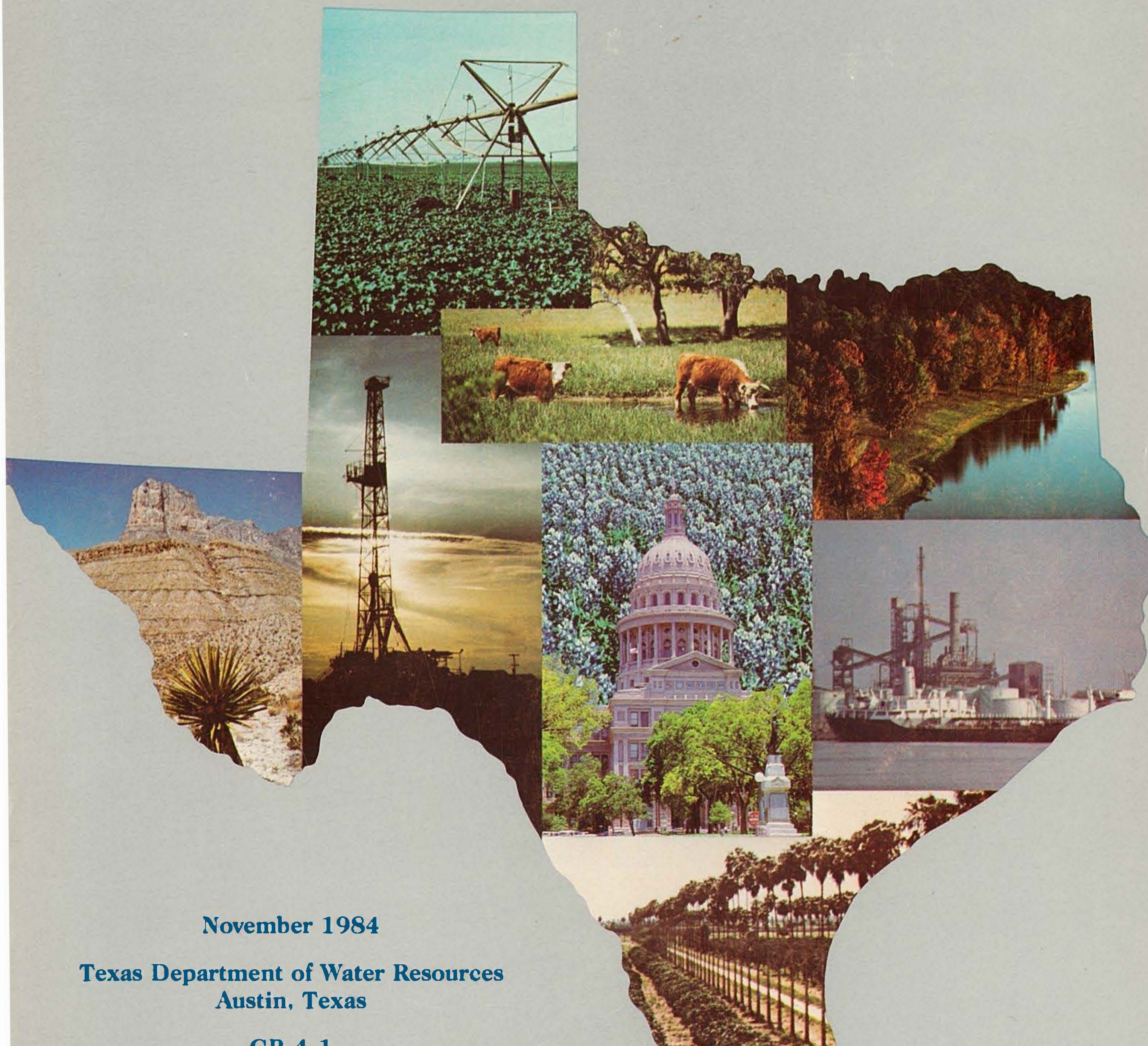
Water For Texas

Technical Appendix

Volume 2



November 1984

Texas Department of Water Resources
Austin, Texas

GP-4-1

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Section 16.051 of the Texas Water Code directs the Executive Director of the Department of Water Resources to prepare and maintain a comprehensive State water plan for the orderly development and management of the State's water resources in order that sufficient water will be available at a reasonable cost to further the economic development of the entire State. In addition, the Department is directed to amend and modify the plan in response to experience and changed conditions.

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PREFACE

This report is a companion document to *Volume 1—WATER FOR TEXAS: A Comprehensive Plan for the Future.* This Volume contains specific technical detail about the topics and planning concepts presented in Volume 1. Current water development and use, future water needs, and potentially developable water supplies to meet projected needs are presented and described for each of the 23 major river and coastal basins in the State.

The information contained herein is based upon Texas water, demographic, economic, and technical data of the recent past. Projections of the future are based on these data and take into account estimates of future trends in economic conditions and in technology that affects water use. It is important to note that the planning information and the plans contained herein must of necessity be couched in existing water law and existing institutional arrangements affecting water resources and water use. In particular, water resources planning to meet future needs must safeguard and protect water rights that are now recognized. Planning for the future must be based upon and depart from the point of existing conditions. The materials contained herein are based upon these principles.

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PART I

INTRODUCTION AND BACKGROUND

Between 1930 and 1980, the population of Texas increased from 5.8 million to 14.2 million people, and it is projected to be between 19.6 million and 21.2 million in 2000, and between 28.2 million and 34.3 million in 2030. As the population has increased, so has the demand for water. The quantity of water used in Texas has increased from about two million acre-feet (one acre- foot is 325,851 gallons) in 1930, to about 17.9 million acre-feet in 1980. As population has increased, the economy of the State has grown, and in order to meet the future employment, economic, and social needs of the people of Texas, the economy must be continually expanded at a satisfactory rate. In order to meet acceptable levels of economic and social welfare, the people, the industries, and the environment must have sufficient supplies of suitable quality water. This can only be achieved through careful planning and timely implementation, operation, and maintenance of water quality protection, water conservation, water supply development, and flood protection facilities.

Although Texas has fifteen major river basins and eight coastal basins, which together have 3,700 streams and tributaries and more than 80,000 miles of streambed, and seven major aquifers and sixteen minor aquifers, water supplies vary widely from year to year and from place to place within the State. Average annual precipitation is 56 inches on the eastern border and less than eight inches at El Paso. Average annual recharge to aquifers is 5.3 million acre-feet. Average annual surface-water runoff is about 49 million acre-feet, but runoff ranges from about 1,100 acre-feet per square mile in the easternmost parts of the State to nearly zero in far West Texas. From 1940 through 1950—a period of high rainfall—average annual runoff was 57 million acre-feet. During the State's longest and most severe drought of record—1950 through 1956—average annual runoff was only 23 million acre-feet, leaving many parts of the State short of water.

In order to meet water needs as the Texas economy has grown, local and regional governments and federal and State agencies have developed well fields, lakes and reservoirs, and sewage collection and treatment systems. According to water use statistics obtained from annual water use surveys of the municipalities of Texas, about 50 percent of municipal water is obtained from ground-water sources. Ground water is used for municipal purposes in all areas of Texas and in practically every county. However, in many areas, the long-term use of well fields is lowering the water tables to an extent that major water supply problems are occurring, or are projected to occur, in the foreseeable future.

More than 50 percent of Texas is underlain by seven major aquifers and sixteen minor aquifers. The seven major aquifers, plus the sixteen minor aquifers, have a total average annual natural recharge of about 5.3 million acre-feet and a total recoverable reserve of about 430 million acre-feet, of which about 89 percent or 385 million acre-feet is in the High Plains (Ogallala) Aquifer in West Texas. Of the 17.9 million acre-feet of water that Texans used in 1980, about 10.85 million acre-feet was from ground-water sources. Of the 10.85 million acre-feet of ground water used, 11.9 percent or 1.29 million acre-feet was for municipal uses, 2.3 percent or 249 thousand acre-feet was for manufacturing purposes, 0.5 percent or 53 thousand acre-feet are for steam-electric power generation, 1.7 percent or 183 thousand acre-feet are for mining, 1.1 percent or 120 thousand acre-feet was for livestock watering, and 82.5 percent or 8.95 million acre-feet was for irrigation.

The dependable water supply from major reservoirs—the uniform yield that can be withdrawn annually through extended drought periods from major reservoirs—is about 11 million acre-feet annually. About 7.0 million acre-feet (64 percent) of this dependable surface-water supply is now being used. A little over 21.7 percent goes for municipal uses, 18.2 percent for manufacturing purposes, 3.9 percent for steam-electric power generation, 0.8 percent for mining, 1.8 percent is for livestock watering, and 53.5 percent for irrigation. A large portion of the remaining 4.0 million acre-feet of dependable surface-water supply is committed or planned to meet growing municipal and industrial needs of major metropolitan areas of the State over the next 30 years. This supply, however, will not meet all of the municipal and industrial needs of many Central, South, North Central, and West Texas cities where practically no dependable surface-water supplies exist. Projections also show that many cities in eastern portions of the State will need additional surface-water supplies in the immediate future. It is important to note that growth in use of surface water has been about six percent per year during the last six years, and the time required to plan and construct a typical reservoir is more than 15 years.

The maintenance and recovery of the quality of Texas' limited water supplies is absolutely essential, especially so in areas of the State that are water-short. Recognition of this fact occurred years ago and led to the passage of water quality legislation, instream water quality monitoring, and water quality standards. These standards define the quality of water necessary in each stream to provide for the beneficial uses that stream should yield. Of the more than 16,000 stream miles subject to quality standards, over 90 percent currently meet the 1983 fishable and swimmable goals of federal clean water legislation. About two percent will not be compliant due to natural conditions, leaving about eight percent of the 16,000 miles of streams needing further work to eliminate sources of pollution. It is necessary to continuously operate sewage collection and treatment systems in order to protect the quality of water in all the streams and aquifers of the State.

Increasing demands for limited quantities of water require that long-range plans be developed to meet the many water resources needs of the future. The present quantity of ground- and surface-water supplies cannot meet the projected future needs of municipalities, industry, agriculture, fisheries, and the environment. The quality of present supplies must be protected from pollution and contamination, while the quality of supplies in some parts of the State must be improved if these supplies are to be useful. Thus, it is essential that water resources plans be continually revised and amended in order to meet changing economic, social, physical, legal, institutional, and environmental conditions.

Texas water planning must be flexible with respect to local conditions of climate, hydrology, topography, and local area needs, taking into account State water law, existing rights to ground water and surface water, and local area leadership's goals and objectives with respect to growth and development. Climatic factors, including precipitation levels and seasonal distribution, temperatures, evaporation rates, solar energy levels, winds, and length of growing seasons are data relevant to each area for which water planning is to be done. Likewise, hydrology and topography affecting both the demands and supplies of water of an area are data essential to water planning.

The resource base, existing economy, and potentials for development within an area are both explicit and implicit data which must be taken into account in water resources planning. In effect, these factors are the foundations for water use in the present and establish the trends for future water supply and water quality protection needs. Particular attention must be given to the water resources needed in order to realize the potential development and use of other natural resources and capital within an area, as this development might assist in meeting local, State, national, and even international needs for employment, income, and trade. In addition, the goals and objectives of each local area must also be taken into account, since local cultural, business, and quality of life desires directly affect the need for water supplies and water quality protection.

Among the important factors affecting the use of water in Texas and long-range planning for future supplies of water is that of water rights. Ground water is recognized as private property, subject to the right of capture by landowners. Surface water is public property, the use of which is administered by the State through a system of water rights. Riparian domestic and livestock uses of surface water are exempt from the need for authorization from the Texas Department of Water Resources, and are considered as superior rights. The water rights granted or otherwise recognized by the Department have a priority status under the principal of first-in-time, first-in right, with the condition that these water rights may be subject to cancellation for nonuse.

In addition to recognizing existing water rights, water planning must also take into account the overlapping jurisdiction of federal, State, regional, and local governments, each having water resources responsibilities. Of these, the Texas Department of Water Resources is the principal State agency having water resources administration and planning responsibilities. The Texas Department of Health regulates the quality of water for public supplies and the Texas Railroad Commission regulates disposal of wastes associated with petroleum production. The Department of Water Resources working with local governments, other State agencies, federal agencies, and the private sector, and using the latest available information, ideas, and recommendations from the public, is responsible for maintaining a comprehensive statewide water plan to meet the water resources needs of Texas. In addition, the Department is responsible for the administration and enforcement of water rights permits, the administration and regulation of wastewater disposal permits, water quality protection, and the collection and analysis of various hydrologic, meteorologic, and economic data. The Department also provides some financial assistance to political subdivisions in the form of loans for water and wastewater projects and the purchase of storage capacity in local surface-water supply projects.

Federal legislation governs several water resources functions. These include flood protection, dam safety, stream quality standards and the quality of wastewater effluent that can be discharged by water users, dredge and fill in navigable waters and wetlands, navigation, hydroelectric generation, endangered species, fish and wildlife habitat protection, and cultural and environmental factors affected by water resources projects and programs. Federal agencies also assist with planning studies and in the construction and operation of major facilities such as multipurpose water projects, as well as participate in the regulation and enforcement of water quality protection, for which Congress has authorized participation and appropriated funds.

Local governments, regional water authorities, utility districts, and the private sponsor construct, operate, and maintain water supply, water quality protection, and flood protection projects and facilities. Although such functions are at the discretion of local and regional governments, all such water resources projects and services must be managed and administered in accordance with relevant and applicable State and federal laws. In these efforts, local and regional authorities are responsible for securing the necessary water rights, property, and rights-of-way, and the construction and operating permits. These local and regional authorities must also arrange financing, construct and operate facilities, pay operating costs and debt service, and repay bonds and federal contracts used in project financing. Water planning and water administration take these factors into account.

TEXAS WATER PLANNING OBJECTIVE

The objective of water resources planning is to provide a comprehensive State water plan that will serve as a flexible guide to State policy for the development, management, conservation, and protection of water resources for the State. The plan will identify and equitably consider the public and private interests and institutions of the entire State, giving appropriate attention to environmental factors, while promoting economic welfare. The plan, as a flexible guide, will identify alternative strategies for implementation in order to give direction to appropriate private and public institutions in the State to enable them to:

1. supply in a cost-effective manner sufficient quantities of suitable quality water in each area of the State, as the population and the economy of Texas grow, taking into account the practically achievable effects of improved water use efficiency and water conservation;

2. continuously protect the quality of both surface and ground water in each area of the State, and where practical and feasible, improve its quality; and,

3. provide protection of human life and public and private property from flooding and flood damage, to the extent such flood protection can be determined to be economically feasible.

Water resources planning information to be presented includes descriptions of water problems, estimates of water supplies in each area of the State, projections of future water requirements for each of 11 categories of water use in each area of the State, an identification of water conservation practices and technologies that can affect the quantity of water use, as well as identification of technologies that may have potential for extending and increasing the usable supplies of water. Present and future water quality protection needs of each area are identified, along with alternative conservation and development methods and projects. Specific analyses are given for each of the 23 river and coastal basins, including a presentation of information about the ground- and surface-water resources, economic and demographic characteristics, quantities of water use, water resource development, water rights, water conservation, water quality protection needs, and water development options within each basin.

WATER RESOURCES PROBLEMS AND POTENTIAL TYPES OF SOLUTIONS

In Texas, there is a wide range of water problems, including the contamination and the threat of pollution of existing supplies, shortages of supply to meet the needs of a dynamic and growing economy, flooding, conservation and more efficient use of water supplies, freshwater for environmental purposes, declining water tables, land subsidence resulting from ground-water use, saltwater intrusion into aquifers, increasing costs to secure water and to treat wastewater, and adequate sources of financing for sewerage, water supply, and flood protection facilities. Major problems and some potential types of solutions are identified and briefly described below.

Water Quality

There are limited supplies of water in several regions of the State, and the poor quality of some existing supplies of surface- and ground-water resources limits the quantity of usable water and increases the costs of use. Both natural contamination and man-made pollution affect the quality of existing supplies, and although different uses of water have different parameters of water quality, the degree and kind of contamination and pollution can render water unusable or perhaps too costly for use.

Natural Contamination

Several ground- and surface-water resources are presently unusable because of large concentrations of natural minerals and salts. This occurs because water is a solvent, and as such, it dissolves salts, metals, and minerals from surrounding rock and soil. Chemical materials are present to some degree in most sources of both ground and surface water. In greater concentrations, the water's usefulness is impaired.

Concentrations of salts and minerals affect several river basins in Texas, including upper reaches of the Red, Brazos, Colorado, Canadian, Pecos, and Rio Grande, and preclude the development and use of some water resources in these basins. Chloride control projects have been planned in some basins to prevent surface water with high salinity concentations from contaminating better quality water. In some areas, ground-water supplies also are adversely affected because of high concentrations of salts and minerals.

In addition to salinity, sediment also affects the quality of surface water. Soil erosion from storm and flood waters reduces the fertility of range and cropland as well as adds sediment to streams and rivers. This sediment clogs channels, reduces the storage capacity of reservoirs, and adversely affects some wildlife habitats. Controlling erosion and sedimentation through greater use of soil conservation and stabilizing measures would benefit both agriculture and water resources programs.

Pollution

Water pollution is the alteration of the quality of water to the detriment of plant or animal life or the public. Both the quantity and complexity of pollution are increasing with increasing concentrations of population and increasing levels of economic activities. While rivers, streams, and lakes are convenient for the disposal of many types of wastes, these are also the sources of water supplies in many areas and are habitats for fish and some wildlife species. Therefore, water resources must be protected from pollution. The quantity of municipal wastewater and drainage from storm sewers has increased with population and industrial growth, necessitating the installation and operation of a larger number of sewerage collection and treatment systems in order to produce effluent of suitable quality for discharge into State streams.

Some pollutants can be controlled at the point of discharge, while more dispersed sources of pollution require other measures. To meet federal and State clean water requirements, municipal and domestic wastes must have the equivalent of secondary treatment, and the use of septic tanks, except under suitable conditions, is discouraged. While industrial wastes that are discharged should receive "best practical treatment economically achievable," new technologies are needed to provide for recycling some industrial wastes and neutralizing other industrial wastes prior to any land disposal of the wastes. In addition, runoff can be managed with structural measures such as detention ponds, or nonstructural measures that include street sweeping and catch-basin maintenance. Significant progress has been made toward treating wastewater to acceptable standards for discharge into streams, but additional planning and construction of such facilities is needed and will be included in subsequent parts of this report.

Water Supply

A shortage of adequate water supplies to meet the foreseeable future municipal, industrial, and agricultural needs could occur in many regions of the State. In many areas where demand is growing, the long-range renewable supplies are quite limited. In addition, long-term dependence upon ground water, the historical water supply for much of the State, has caused ground-water resources to decline significantly. Consequently, there will be greater demand for surface-water supplies, which, in some cases, are insufficient to meet current needs during periods of drought.

In order to solve future water supply problems, it will be necessary to increase the available supplies and to increase water use efficiency through water conservation, thereby reducing demand. Techniques to increase supplies include development of new sources, recycling and reuse of some existing supplies, and increased efficiency in water use and distribution. Techniques to reduce the quantity of water required for a given population and a given economic purpose include the implementation of water conservation programs to reduce waste and to increase efficiency of use of existing supplies. Where ground-water supplies are declining, increased conservation, encouragement of recharge using flood waters, and reduced rates of pumping and use could extend the useful life of some aquifers.

In addition to increased conservation and management of water use by individuals, businesses, industries, farmers, and ranchers, meeting projected future water needs requires that supplies be increased through the development of additional reservoirs. The potential for such development is limited, and costs will be high in the future in relation to costs of similar projects in the past. As a part of planning for the future, individual reservoir projects to meet projected future needs are identified, along with an estimate of the time such projects will be needed and the costs at that time. In view of the fact that the number of suitable reservoir sites is limited, and the potential uses of such sites for other purposes may impinge upon their future availability for water supply purposes, local water supplying authorities and the State should give serious consideration to protecting such sites for water supply purposes. Since these sites are privately owned, it will be necessary to arrange for compensation of the landowners and to develop long-term management plans for the lands involved.

Flooding

Flooding is a serious problem in Texas, resulting in millions of dollars in damages annually to urban and rural areas, industry, transportation, and public utilities. Even with flood protection programs, damages from flooding will continue to increase along floodplains and in coastal areas, if these areas are selected for residential and business locations. Most people, however, do not perceive or consider the risk of flooding, and flood-prone areas continue to be developed to accommodate population and economic growth.

Since some flooding cannot be averted, the management of flood-prone areas is required to protect lives and to reduce the damages from flooding. Both structural and nonstructural flood protection measures can be used. Structural measures such as the flood-proofing of buildings and the construction of reservoirs, drainage channels, and levees provide flood protection. Nonstructural measures such as regulation of the use of flood-prone areas, regulation of land use upstream of flood-prone areas, evacuation and recovery plans, flood forecasting, and flood warnings provide means for protecting lives and property. Flood insurance provides means for compensating flood damages. Since federal funding for structural flood control projects is being reduced, State and local governments must assume more flood protection responsibilities, including flood protection planning and financing. Flood protection that is associated with water supply development is included in water planning described herein. However, more detailed local area flood protection planning is required.

Coastal Areas

Floods often occur in coastal areas as a result of inundation from heavy inland rains, hurricanes, high tides, and insufficient natural drainage. In these areas, both structural and nonstructural means can protect lives and property and reduce the damages from flooding. Structural measures applicable to flood protection in coastal areas include the construction of levees and floodways and flood-proofing existing structures. Nonstructural measures such as regulating the development of flood-prone areas, flood forecasting, advance warning, and evacuation systems should also be used to deal with flooding in coastal areas. Detailed planning for flood protection in coastal areas by local and regional governments is needed.

Inland Areas

In Texas, the character and intensity of floods differ widely on account of the varied physiography and climate within and among river basins. Because topography aggravates the severity and impact of flood waters, different flood protection measures are appropriate for different regions of the State.

Broad, flat, slow-moving floods generally occur in the upper coastal areas and eastern part of the State where rainfall is highest. Valleys are wide with gradual slopes, and timber and dense vegetation bordering rivers and streams brake the flow of runoff. This type of flood inundates these areas for prolonged periods of time and can be very damaging. Given the topography of these areas, structural measures such as flood storage in reservoirs, levees, and channelization can be used for flood protection. Nonstructural measures, including limited use of floodplains, flood insurance, and flood forecasting and warnings are also appropriate flood protection measures.

Flash floods occur in central and western regions of the State where slopes are steep, ground cover is sparse, and soils are generally thin and relatively unabsorbent. While intense, flash floods cause shorter periods of inundation. Although generally brief, these floods can be devastating. Under these conditions, both structural and nonstructural flood control measures can be used.

Water Conservation and Improving Water Use Efficiency

Through planning and management of municipal, industrial, agricultural, and other water uses, it may be possible to reduce waste and improve water use efficiency, thereby allowing existing water supplies to serve more people, meet growing industrial needs, and maintain existing levels of irrigated acreages in agriculture than would be possible otherwise. Through increased water conservation on the water demand side, the objective is to substitute management, labor, and capital for water and thereby reduce the rate of future growth in the demand for scarce water and expensive wastewater treatment facilities. In this respect, water conservation requires the adoption and use of methods and practices to prevent waste. Water conservation can be increased through the use of equipment, technologies, and management to reduce per capita water use by people, the quantities of water used per unit of product produced by industry, and the quantities of water used per acre irrigated by agriculture. However, the extent that water conservation can be used to reduce water use now and in the future, through improving water use efficiency, will be constrained by the costs of water-saving equipment and the incentive to purchase and use such equipment in the short run. In making projections of future municipal, industrial, and agricultural water requirements, conservation potentials have been taken into account. Water conservation plans are described in a later section of this report.

Municipal and Commercial Water Conservation

Currently, annual water use for municipal and domestic purposes accounts for 2.8 million acre-feet or 15.8 percent of the total water use in Texas. Long-term average daily per capita water use has increased four gallons per decade since the mid-1960's. At present rates and with expected population growth, municipal and domestic water requirements are projected to increase at least 25 percent by the year 2000 and to double by 2030. These are projected to range between 3.5 million and 5.1 million acre-feet annually in the year 2000, and between 5.1 million and 8.2 million acre-feet in 2030.

There are, however, water conserving methods available to reduce per capita water use, some at little cost. Principal methods include public information and education to encourage people to repair leaky plumbing and to more carefully manage household appliances and bathroom fixtures in order to reduce water use. Municipal plumbing codes can encourage the use of water-saving appliances, while city ordinances can encourage the use of native landscaping, permit the use of "gray water" (shower, bath, and laundry discharge) for lawn watering, and allow lot sizes and drainage grades to be selected so as to reduce the quantities of water needed for lawns and landscaping purposes.

Industrial Water Conservation

Water conservation measures are being applied in manufacturing and energy sectors to reduce energy and water costs, including costs of treating wastewater. While further reductions are possible, many require changes in the technology of production processes, which may be quite costly. If large, these added costs may reduce the competitive advantage of some industries in Texas. Additional water conservation by industry involves identifying appropriate incentives to reduce water use without unduly increasing costs.

Among the water conservation measures for industry are reduction of leaks, recycling and reuse, metering, measuring, and controlling the quantity of water used in industry. In cases where water conservation involves the purchase and use of costly equipment, governments could use tax incentives to encourage the installation of such equipment.

Agricultural Water Conservation

Future levels of irrigated agriculture in Texas are threatened by limited quantities of water supplies. Irrigation of about eight million of Texas' 30 million cropland acres uses more than 70 percent of the water used in the State, of which 75 percent is from ground-water resources having little recharge. It is important to note that irrigation is responsible for more than 40 percent or about $1.7 billion of the annual value of crops sold from Texas farms and ranches in 1980, and that data show that without improvement in irrigation efficiency, some aquifers which now supply irrigation water will be depleted to a severe degree within the next 20 years. With a high degree of water conservation, the water supplies of these aquifers could be made to support nearly 80 percent of present irrigated acreages during a foreseeable 30 to 40 year period of time, thus extending the useful life of these aquifers by 10 to 20 years.

Several water conservation techniques and practices can be used to reduce the quantities of water that need to be diverted from streams and reservoirs and the quantities that need to be pumped from wells per acre irrigated. Those conservation practices that can reduce the quantities of water diverted from surface-water sources per acre irrigated, without adversely affecting crop yields include: improvements to surface-water conveyance systems, including concrete lining of canals and the use of pipe for conveyance; scheduling and measuring quantities of water diverted; automating weirs and headgates; and pricing of water per acre-foot as opposed to charging per acre irrigated.

In the case of irrigation from ground-water sources, the use of pipe and lined canals to convey water from the wells to all parts of the fields to be irrigated can reduce the quantity of water that must be pumped per acre irrigated. In general, regardless of whether the source of irrigation water is aquifers or surface systems, several other conservation measures can reduce water use. These include: monitoring soil moisture and irrigating only when moisture conditions require it; using the knowledge of crop moisture needs in relation to growth and maturation stages and applying irrigation water only when plants need it; use of growth regulating chemicals, use of evaporation suppressants on the soil surface, and use of evapotranspiration suppressants on the plants; use of sprinklers, drip, and trickle methods to apply irrigation water; use of soil preparation and cultivation methods that retain precipitation and irrigation waters; use of crop residue as mulch; control of weeds and phreatophytes; careful monitoring and management of irrigation and cultivation systems; and, where possible, selection of less water-intensive crops and strains of crops that require less water. However, some agricultural water conservation methods mentioned here are not cost-effective at current agricultural prices and interest rates, and some methods are not well understood. Thus, technical assistance to irrigation farmers, and tax and economic incentives to adopt and use water conservation equipment, would make contributions to solving some agricultural water supply problems in the short run.

Environmental Factors

As the competition for limited water supplies increases among existing and potential users, a serious dilemma may arise involving establishment of acceptable trade-offs between the water needs of Texas' natural environmental resources and the State's social and economic needs for water. Among the environmental issues are concerns about freshwater inflows to Texas bays and estuaries, instream flow needs of the State's fish and wildlife, and protection of land resources or mitigation for loss of fish and wildlife habitat. Also at issue is how to apportion the State's surface waters among competing users as well as to determine who is responsible for paying costs associated with the provision of water for environmental uses.

Bays and Estuaries

The Texas bays, estuaries, and shallow Gulf environments of the State territorial waters (offshore boundary at nine nautical miles) are economically and ecologically important public resources. These resources provide inputs to the State economy through seafood products, tourism and recreational activities, marine commerce, and oil and gas production. In addition, these waters contain essential habitats for coastal fish and wildlife. The problems of these coastal areas are complex, involving public lands, public waters, and public wildlife.

In the 2.6 million acre estuarine area in Texas, more than 100 million pounds of seafoods is harvested annually, having an estimated annual impact on the State economy of more than $1.25 billion (1981 dollars). The fishery resources of these areas are estuarine-dependent, while the estuaries are specifically dependent on freshwater inflows for nutrients, sediments, and a viable salinity gradient for inhabiting organisms. State policy is to maintain the coastal environments and the health of their living marine resources; thus water planning work includes the collection and analyses of information about the relationships among freshwater inflows and the living organisms of the bays and estuaries. Water planning and use takes this information into account.

Instream Flows

Instream flows are necessary to retain Texas stream values for maintenance of waste assimilative capacity, general water quality, livestock water, and fish and wildlife environments. Fisheries are particularly sensitive to flow depletion that affects spawning or nursery habitats for the young. Other instream flow needs include hydroelectric, navigation, and recreation. However, the rate of streamflow needed cannot be easily generalized for such divergent uses. Moreover, significant trade-offs must occur to obtain maximum benefits from water development projects, since Texas streams must continue to provide for multiple use. Development of surface-water projects for the storage of flood flows which are released and used downstream at later dates, as well as the use, treatment, and return of wastewater effluent, some of which is from ground-water sources, provides a source of instream flows for many segments of Texas streams that would be dry during many seasons without such development.

Fish and Wildlife Habitats

Water resources development and use, and particularly the development of reservoirs, involves the inundation of large acreages of land and the associated streambeds. This, of course, is a conversion of land use from agriculture, ranching, forestry, and other purposes to reservoir sites and a change from terrestrial and stream habitat to a freshwater-lake environment. Although the lands involved are purchased at market price, thus compensating the sellers for the lands that are converted into reservoir sites, the total quantity of wildlife terrestrial and stream habitats is reduced as reservoirs are built. Lake habitat, shoreline, and waterfront types of habitat are increased. The latter group is usually considered to be a benefit in project evaluation, while the loss of terrestrial and stream habitats is considered by many to be costs for which some form of mitigation is desired. Such mitigation may be in the form of purchasing additional land to be managed specifically for wildlife habitat, the development of lakeside parks and recreation areas for public uses, the use of fish hatcheries and fisheries management programs to enhance instream fisheries downstream of lakes as well as the lake fisheries, minimum releases for downstream fish, wildlife, recreation, water quality, and other purposes, and perhaps other compensating measures. Most of these forms of mitigation are costly and if added to water supply projects, result in an increase in the cost of water to water customers.

Land Subsidence

Some aquifers in coastal areas of Texas are composed of alternating strata of sand, gravel, and clay. As water is withdrawn, pressures decrease, and the clay strata are compressed. As this phenomenon occurs, the overlying strata sink, resulting in a lowering of the elevations of land surfaces, changing of surface gradients, and the activation of faults. These changes affect drainage patterns, which aggravate flooding problems in coastal areas and increase the risk of hurricane tidal surges and flooding of coastal areas. Increased fault activity damages structures such as homes and commercial buildings, highways, airport runways, pipelines, and railroad tracks, in addition to allowing the entry of poorer quality water into ground-water resources. Subsidence is a problem in coastal areas of Texas where the water table has been lowered as freshwater has been withdrawn.

To avoid further subsidence, ground-water withdrawals must be limited to the extent that only the quantity of recharge entering the dewatered upper layers of aquifers is pumped. Further lowering of the water tables will likely result in further subsidence. Quantities of water needed above those that can be obtained from these ground-water sources must be obtained from surface sources. Planning and development of surface-water projects to meet future needs are in progress, and will be identified and described in later parts of this document.

Salt-Water Intrusion into Aquifers

Salt-water intrusion and the threat of salt-water intrusion into aquifers are present in both coastal regions and in some inland areas that now depend on ground water. Salt-water intrusion occurs from the migration of saline water from adjacent strata into areas from which large quantities of nonsaline ground water have been withdrawn without having been adequately recharged. Similar to the problem of subsidence, salt-water intrusion threatens the usefulness of aquifers. In addition to contaminating freshwater supplies, available recharge capacity is lost. Because the recovery of an aquifer from contamination is relatively slow, salt-water intrusion may become a long-term condition that precludes further use of such aquifers.

Like subsidence, measures to avert salt-water contamination include the reduction in demand for ground water through the implementation of conservation with reduced ground-water withdrawals and the development of alternative water supplies. Aquifer management techniques, including artificial recharge, may be used to assist in controlling salt movements in aquifers. In addition, in-well blending of water from saline and freshwater strata may also be used in some areas and thereby increase the total supply available. Of course, such mixtures must meet safe drinking water standards for public supply, must be carefully controlled to meet industrial water quality needs, and in the case of agriculture, must not be too concentrated to meet crop needs nor to increase soil salinity levels above those tolerated by crops.

LEGAL AND INSTITUTIONAL FACTORS AFFECTING WATER

Planning for the development and use of water and the protection of its quality must be done in accordance with provisions of State water law, interstate compacts, international treaties, federal law, established water institutions, public opinion, public preferences, public desires, and information on physical and economic conditions. Among the fundamental considerations are the distinctly different status of ownership of ground and surface water and the local, State, and federal agencies having specific authority and jurisdiction for water resources management.

Ground water is private property subject to the right of capture by owners beneath whose property ground water is found. Thus, decisions about the time and quantity of use of ground water reside with a large number of individuals whose actions are difficult to predict. Although ground water is private property, under State law, some underground water conservation districts having some regulatory powers have been formed to reduce waste, to conserve, and to manage this very important water resource. Additional such districts are needed and can be formed through referenda within areas to be affected.

In Texas, surface water flowing in public watercourses is public property, the use of which is subject to administration by the State. Texas water law has recognized claims to surface water rights granted under Spanish, Mexican, English, Republic of Texas, and United States laws, in addition to the State's Appropriation Doctrine. These claims are currently under review by the Texas Water Commission in accordance with the Water Rights Adjudication Act of 1967. Investigations of rights and claims of all 23 river and coastal basins are to be completed by 1983. Upon completion of the adjudication process, Texas surface water rights and claims will have been standardized under State law, giving priority recognition to riparian rights holders and to permits and claims having the longest history of use. The principal of first-in-time, first-in-right establishes the seniority of each recognized water use permit. However, in order to continue holding such permits, the holder must put them to beneficial use. Water rights information must also be taken into account in all water planning, so as to safeguard recognized surface-water rights. Furthermore, in planning which involves the transfer of surface water among river basins, provision must be made to meet basin of origin water needs in the foreseeable 50-year period. Only those quantities of surface water that are surplus to the basin of origin's foreseeable 50-year future needs can be considered for transfer, except on an interim basis.

Surface water of five interstate streams involving Texas is divided among the states through which they flow by compacts with neighboring states. Additionally, the United States has two treaties with Mexico to govern the international waters of the Rio Grande. The terms and conditions of these permits and treaties must also be taken into account in all water administration and water planning work.

Water resources in Texas are managed by hundreds of local agencies with the assistance of several State and federal agencies. Legislation specifies the conditions, rules, and guidelines for planning in addition to providing technical resources or programs for the collection and maintenance of water resources data and information. Those that define the principal legal and institutional parameters for planning are briefly described below.

State Agencies and Statutes

There are ten state agencies and five river compact commissions that administer water law and water policy in Texas. Of these, the Texas Department of Water Resources has the major responsibility for managing water resources. As the legislative arm of the Department, the Texas Water Development Board establishes general policies and rules to implement the Department's statutory responsibilities, makes loans for water supply development, and makes loans and grants for water quality protection. Acting as the judicial branch, the Texas Water Commission adjudicates water rights and approves plans to appropriate State surface water, construct levees, and dispose of treated wastewater and industrial solid wastes. The Department's Executive Director and staff monitor water quality and water rights and provide enforcement activities when warranted. The Executive Director supervises the management of the Water Development and Water Loan Assistance Funds, prepares and maintains a comprehensive State water plan, and reviews and audits water districts. The Department develops procedures, plans, and processes for water quality protection consistent with the Texas Water Code and the Federal Clean Water Act, and has applied to the Environmental Protection Agency for authority to administer the National Pollutant Discharge Elimination System permits for wastewater disposal. The Department acts as the coordinating agency for the National Flood Insurance Program and administers the dam safety program, which involves scheduled inspections to insure that no dam or reservoir in Texas will become a public hazard.

The Texas Department of Health administers legislation that regulates the disposal of municipal and mixed municipal-industrial solid wastes. The Health Department establishes drinking water standards for public water supplies, reviews plans for the construction of drinking water projects and sewer projects, has primacy in administering the provisions of the federal Safe Drinking Water Act, and maintains surveillance over the operation of all public drinking water supplies. The Department of Health and the Department of Water Resources jointly administer the Texas hazardous waste management program, for which federal funding and oversight authority have been delegated by the Environmental Protection Agency.

The Railroad Commission of Texas regulates water pollution resulting from the exploration, development, and production of petroleum, natural gas, surface mining, and geothermal resources, along with its responsibility for and jurisdiction over transportation enterprises operating within Texas.

Other State agencies having water resources responsibilities include the General Land Office, in the leasing of mineral resources in riverbeds and tidelands; the Parks and Wildlife Department has responsibility for management of lakes, streams, and marine resources to protect wildlife and to provide public recreation; and the Texas Department of Agriculture certifies and regulates pesticides and herbicides, and monitors for pesticide residues. The State Soil and Water Conservation Board and local soil and water conservation districts develop soil and water conservation plans and plan and install irrigation water conveyance facilities for individual farms. The Water Well Drillers Board licenses water well drillers, and the Board of Irrigators licenses commercial installation of lawn irrigation equipment.

Several public and private educational institutions in Texas perform water resources and related research studies made by Agricultural and Engineering Experiment Stations that have led to improved efficiencies in irrigation techniques and improved methods for water use in the home, industry, and the environment. The transfer of new technologies to various sectors of the State economy involved in food and fiber production is the responsibility of the Agricultural Extension Service.

Regional and Local Agencies

Political subdivisions at the regional and local levels of government construct, operate, and maintain the water quality protection, water resource conservation, and water supply programs of Texas. Currently, there are 1,092 public municipal systems, 800 rural water supply corporations, and 750 investor-owned public water supply systems now operating in Texas. In addition to municipalities that construct and operate water supply and wastewater treatment facilities, there are special purpose subdivisions that include 28 river authorities and regional water supply districts that handle water supply and distribution, flood control, and water quality protection. There are 950 water supply, irrigation, and municipal utility districts, 45 flooding and drainage organizations, 56 drainage districts, nine ground water conservation districts, and one subsidence district presently engaged in water conservation and in supplying or regulating water for irrigation, domestic and commercial uses, navigation, and recreation. The Harris-Galveston Coastal Subsidence District is engaged in regulation to reduce subsidence resulting from pumping ground water. These local entities plus the thousands of businesses, farmers, ranchers, and citizens must implement and operate the plans described herein.

Federal Agencies and Statutes

There are several federal agencies and departments with authority and responsibility in water resource management that affect Texas water resources programs. The U.S. Army Corps of Engineers has responsibility for flood protection, regulation of the use of the Nation's navigable waters, dam safety, floodplain mapping, and the planning and construction of multipurpose water resource projects. Within the U.S. Department of the Interior, the U.S. Geological Survey (USGS) operates programs that are the foundation for national water data and water studies, and the Bureau of Reclamation (BUREC) conducts basin-wide water resource planning studies and constructs surface water supply reservoirs and conveyance works; and, the U.S. Fish and Wildlife Service has responsibility for the protection of fish and wildlife resources through a number of programs for conservation, development, and management.

The U.S. Soil Conservation Service (SCS), of the U.S. Department of Agriculture, implements soil conservation programs cooperatively with State and local agencies and constructs floodwater retarding structures in small watersheds. In some cases these structures are also used for water supply purposes. The Environmental Protection Agency (EPA) regulates and funds federal water quality programs concerned with water quality planning as well as standards for water quality, solid waste management, underground injection of wastes, construction grants for municipal sewerage systems, and the federal safe drinking water act.

Within the U.S. Department of Commerce, the National Oceanic and Atmospheric Administration (NOAA), through the National Weather Service (NWS), provides meteorological activities, hydrologic forecasts and services, and oceanographic and climatological services. The International Boundary and Water Commission oversees the treaty-mandated division of surface waters of the Rio Grande, and the Colorado River of the western states between the United States and Mexico. The National Marine Fisheries Service (NMFS) provides federal review, technical data, and services for the conservation, development, and management of coastal and marine fisheries. The Economic Development Administration (EDA), through the development of areas having high unemployment or low family incomes, provides funding for water supply distribution projects and wastewater collection systems.

There are other federal agencies that are directly involved in water resource development that impact Texas water programs, notably the U.S. Department of Housing and Urban Development, which administers loans, grants, and other assistance for programs concerned with flood protection, and the Federal Energy Regulatory Commission, which regulates hydroelectric power production from federal water projects. The Farmers Home Administration makes grants and loans to rural water supply corporations. The Federal Emergency Management Agency has responsibility for the National Flood Insurance Program and federal disaster relief response and recovery.

Federal legislation enacted in recent years affects three broad facets of State water resources programs. With respect to water conservation and development, the Water Resources Planning Act of 1965 encourages the cooperation among federal agencies for the conservation, development, and use of the Nation's water. The planning and development of water resources must consider the presence of endangered species and the protection of their habitats as mandated by the Endangered Species Act of 1973. The Water Resources Development Act of 1974 authorizes the U.S. Army Corps of Engineers to assist states in the development, utilization, and conservation of water. The Coastal Zone Management Act makes available grants to coastal states for the development of procedures to manage land and water resources in coastal zones. The Fish and Wildlife Coordination Act requires the equal consideration for fish and wildlife conservation in any federal project that modifies streams or other bodies of water.

With respect to water quality, the Federal Water Pollution Control Act of 1972, as amended, provides for the restoration and maintenance of the chemical, physical, and biological integrity of the Nation's waters through permitting public participation in permitting and planning programs for discharge of pollutants and through grants for wastewater treatment works and other water pollution control mechanisms. The National Environmental Policy Act of 1969 provides for environmental assessment and coordination review of all major federal actions, including water resource projects, that may significantly affect the environment. The Safe Drinking Water Act of 1974 establishes uniform national safety and quality standards for drinking water. A third facet of water programs—the prevention and control of floodwaters—was addressed by the

Flood Control Acts of 1936 and 1938. In addition, the Watershed Protection and Flood Prevention Act of 1956 made available federal financial assistance to local political subdivisions for implementing watershed protection and flood-prevention measures. The 1968 National Flood Insurance Program established nonstructural alternatives and local floodplain management to deal with flood hazards and made available federally subsidized flood insurance.

Surface-Water Law in Texas

Sources of water generally are categorized as surface or underground. Surface water may be classified either as diffused surface water or as water within a defined watercourse. Diffused surface waters are those which occur in a natural state in places on the earth's surface other than in a watercourse, lake, or pond. In Hoefs v. Short, 114 Tex. 501, 273 S.W. 785 (1925), the Texas Supreme Court defined a watercourse as having the following legal elements:

(1) a well-defined permanent natural channel—although in places the bed and banks may be absent.

(2) a permanency of source of water—an intermittent stream can qualify despite having a channel that is dry for long periods of time if the flow of water recurs with some degree of regularity. Otherwise, it is but a ravine which is a drainage area of diffused surface water.

Rain that falls on a watershed of a stream in sufficient volume to produce concentrated runoff to make artificial irrigation valuable is a permanent source of water supply.

The point of formation of a watercourse is often difficult to establish. Waters present in a watercourse may be subclassified as (a)ordinary or normal flow, (b)underflow, and (c)storm and floodwater.

(a) The ordinary or normal flow of a watercourse has been judicially defined as a flow below the line "which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal and usual conditions, uninfluenced by recent rainfall or surface runoff" [Motl v. Boyd, 116 Tex. 82, 286, S.W. 458 (1926)].

(b) The underflow consists of water in the sand, soil, and gravel immediately below the bed of an open stream, which supports the surface stream in its natural state or feeds it directly, together with the water in the lateral extensions of the subterranean water-bearing material on each side of the surface channel.

(c) The storm and floodwater is that portion of the flow in a watercourse derived from the diffused surface water from recent precipitation that has reached the watercourse.

Diffused surface waters are considered to be private waters and are subject to capture and use by the owners of the surface estate prior to its entry into a watercourse. No State regulation of use is exercised with respect to diffused surface water until it reaches a watercourse.

Two basic doctrines of surface water are recognized in Texas, the Prior Appropriation Doctrine and the Riparian Doctrine. The corresponding water rights perfected thereunder are commonly referred to, respectively, as appropriative rights and riparian rights. Simplistically, the riparian right arises by operation of common law concepts as an incident to the ownership of land abutting a stream or watercourse, requiring no act other than the acquisition of title to the land (but see the Water Rights Adjudication Act of 1967, discussed later). The appropriative right, on the other hand, is regulated by statute. It is not related to the land ownership and is today acquired by compliance with statutory requirements implemented by the rules and regulations of the Texas Department of Water Resources.

The Riparian Doctrine

Although not defined in Texas statutes, riparian rights are mentioned in legislative acts. Some of these statutory references appear contradictory.

In 1840, the Republic of Texas adopted the Common Law of England as the rule of decision insofar as it was not inconsistent with the Constitution and acts then in force. The judicial application and recognition of the riparian right concept in Texas began in 1856 with what appears to he the first reported Texas court decision involving any phase of water law (Haas v. Choussard, 17 Tex. 588). In this case, the court quoted with approval the classic common law riparian doctrine that, except for his natural wants, a riparian user could not diminish the quantity of water in a stream that would otherwise flow past downstream riparian owners.

A subsequent series of court decisions created considerable contradiction and confusion. Initially, the courts held that irrigation was a natural use and that downstream riparian owners could not complain if upstream riparian owners consumed the entire water supply for irrigation.

This was followed by contradictory decisions that irrigation was not a natural use of water, but was an artificial use. Still later, the courts held that if a particular stream was sufficiently large to permit irrigation without unreasonable impairment of the rights of downstream riparian owners, the use of water for irrigation would be lawful. Unlike the absolute right to use water for domestic and livestock purposes, the right to irrigate by riparian doctrine is a correlative right. In 1926, the entire subject of riparian and appropriative rights was considered by the Supreme Court of Texas in the case of Motl. v. Boyd, 116 Tex. 82, 286 S.W. 458 (1926). The court concluded that since the Mexican Colonization Law of 1823 (1 Gammel, p. 28), all of the several governments which had been sovereign in the State had recognized the right of the riparian owner to use water, not only for his domestic and household use, but for irrigation as well.

However, in 1962 the State Supreme Court, in Valmont Plantations v. The State of Texas, 163 Tex. 381, 355 S.W.2d 502, held that Spanish and Mexican grants do not have appurtenant riparian rights in the absence of specific grants of irrigation water.

The Prior Appropriation Doctrine

Historical Origin

The Prior Appropriation Doctrine evolved in the arid western states of the United States, from whence Texas water statutes were largely borrowed. Nevada, Colorado, and particularly Nebraska, contributed substantially to the text of early Texas water statutes.

Unlike the other western states which entered the union as territories, with the United States government assuming ownership of the public domain, Texas joined the union with full ownership of her land and water. Water rights to both surface and ground water in the other western states are subject to the Desert Land Act of 1853 and the Reservation Doctrine by which federal jurisdiction is asserted over uses of water which is often in conflict with state regulatory systems. However, in the early development of the West, rights to use of water from streams were not acquired by any orderly or systematic administrative procedure.

The early failure of the federal and state governments to assert control over streams as a public resource left water to be treated as though it belonged to no one, and could be appropriated in a manner similar to that of a gold claim. In the absence of public control, men took water from streams and used it; that is, they appropriated it—using the word appropriate in its ordinary sense—to take for one's own use. When water laws were enacted, this appropriation practice was legalized, and the basis of such laws became known as the Doctrine of Appropriation. This concept is contrary on the one hand to the common law doctrine of riparian right (which strictly construed demands that water must not be taken from the stream unless it can be returned undiminished in volume), and on the other hand, to a public policy of permanent governmental control under a system whereby all water is disposed of by license, which had been adopted in some European countries, the British Colonies, and a few of the arid states.

Originally the Prior Appropriation Doctrine was simply that any one needing water had the right to take it. Changed conditions in the West, resulting from population growth, and the consequent increase in demand for water, produced many limitations and modifications. Early definitions of appropriations contained in court decisions do not agree. The following is a synopsis of early equitable concepts and/or doctrines which, in combination, form the basis of the Prior Appropriation Doctrine:

Doctrine of Priority

Justice demanded that when there was not enough for all, those who first used water from a stream should have the superior right to continue that use, and the Doctrine of Priority resulted. The doctrine originated with the belief of the first settlers that their claims were superior to those of latecomers, and they insisted that the owner of the last ditch or facility built should be the first to suffer when a stream failed to supply the needs of all. The first builders of water facilities could not anticipate how many were to follow. Unless protected by some such principle, the greater their success, the sooner they would be injured by the attempts of others to benefit by their experience. The general principle that among appropriators the first-in-time is the first-in-right is now a recognized rule in the water laws of the arid regions of the United States and was so recognized by end of the last century.

Doctrine of Relation

Since many ditches were built about the same time, it became necessary to prescribe rules in determining when a right should attach. If the right should date from the time of actual use of the water, a premium would be placed upon poor construction. It might happen that during the construction of a large canal, smaller canals or those more easily built might be begun and completed and appropriate all water, leaving the large canal a total loss to its builders. To avoid this, the Doctrine of Relation evolved, that is, the right does not date from the time the water is used but relates back to the time of the beginning of the work.

Modification as to Due Diligence

To prevent abuse, the Doctrine of Relation was modified by the provision that the work of construction must be carried on continuously and with "due diligence." Under the Doctrine of Relation, a water right is initiated when the work of construction begins, and dates from that time, but is not perfected until the water has been actually diverted and beneficially used. The question of "What is due diligence?" is a question of fact to be determined in each particular case, and when such diligence is not exercised, the right dates from the time of use.

Beneficial Use Limit as to Quantity

As scarcity of water led to the adoption of the Doctrine of Priority, the two led to the necessity of defining the quantity of water to which an appropriator should be entitled. While the early appropriators were entitled to protection in their use of water, the latecomers had equal claim to protection from an enlargement of those uses. The first appropriator had the first right, but he did not have the right to take all the water he might want at any future time. His rights must, in justice to others, be defined as to quantity as well as to time. By Section 11.002 and 11.025 ofthe Texas Water Code, "beneficial use" has been made the measure of a right as to quantity. What constitutes "beneficial use," and the determination of the quantity of water so used, is left to the courts in most states.

Notice

With the adoption of the Doctrine of Priority, the need to provide notice of the extent of rights already acquired became apparent. Such notice was needed both for the protection of the rights already in existence, and as a warning to intending investors, of the extent to which the stream had already been absorbed.

Initially, most western states, except Colorado and Texas, required the actual physical posting of a written notice at the intended point of diversion. While this procedure was undoubtedly an adaptation of the system of "posting" a gold or mineral claim with a physical monument containing a written description of the claim, there is little similarity between a stationary gold claim and the fluid movement of water on its way to the sea.

The diversion of water without any centralized official record of the time or place of use produced much confusion and hardship when it became necessary to determine the priorities and amounts of appropriations. In early years, the absence of official records meant that facts which governed rights in the stream had to be established by testimony. Often, this determination was required many years after the irrigation appropriation had begun and continued for several generations. Eyewitnesses to the early development frequently were unavailable. The memory of those actually present was often faulty. Wide discrepancies regarding the dates of beginning the work, the size of the ditches, and the amounts of water used were the rule rather than the exception.

To achieve greater permanence, and to afford something approaching actual notice, most state statutes eventually required public registration of the claim in the office of the county clerk. Inadequate supervision coupled with poor understanding of the law by appropriators resulted in a "system" whereby all one need to do to claim his own stream or river was present a proper fee to the registry official with a document setting forth his claim.

For many streams, appropriations have been initiated which aggregate to many times the available yield. Sometimes cities claimed entire rivers without regard to earlier established concepts requiring "beneficial use." (On occasion, e.g., pueblo rights, these claims have been upheld.) Disregard, carelessness, and misunderstanding of the law and its requirements evolved into habit; habit into community accepted custom; and custom in some instances became generally, but erroneously, accepted as law. Throughout the arid western states, it is today common for holders of these early filings to flaunt them as superior vested rights—absolute and secure against the state—when there exists no relation between "beneficial use" and the appropriation claimed, and the requirement of "due diligence" has been completely disregarded.

Development of Appropriative Rights in Texas

Prior to the 1870's, Texas water legislation was limited to an 1852 Act giving each County Commissioners Court administrative control over water distribution systems within the county and to a limited number of special laws granting franchises to canal companies and to individuals authorizing the construction of specific dams and canals to utilize specified quantities of water for stated beneficial purposes.

Acts were passed in 1875 and 1876 to encourage development which authorized the donation of public lands to canal companies for canal construction. These acts were later construed to mean that the act of incorporating a canal company authorized the company to acquire a right to use water, but did not actually confer the perfected right.

The first effort to establish the Doctrine of Prior Appropriation with the State was made in the Irrigation Act of 1889. This statute was rewritten and reenacted in 1895.

The 1889 Act declared that the unappropriated waters of every stream "within the arid portions" of the State in which, by reason of the insufficient rainfall irrigation is necessary for agricultural purposes, may be diverted from its natural channel for irrigation, domestic, and other beneficial uses, provided, that water shall not be diverted so as to deprive landowners along the stream of domestic use. The 1895 Act extended the area affected to "those portions of the State of Texas in which by reason of the insufficient rainfall or by reason of the irregularity of rainfall, irrigation is beneficial for agricultural purposes." A system of registration was established which required the filing of a sworn statement describing the proposed appropriation of water with a county clerk in the county where the point of diversion was to be located. As between appropriators, the first in time was to have a prior claim to a given water supply.

In 1913, the Texas Legislature rewrote the laws relating to the use of water. The new act extended the classical system of prior appropriation to the entire State. The most important feature of the new act was the establishment of a Board of Water Engineers with original jurisdiction over all applications to appropriate water. That agency has functioned since 1913, having been renamed the Texas Water Commission in January 1962, the Texas Water Rights Commission September 1965, and the Texas Department of Water Resources effective September 1, 1977.

Certified Filings

The 1913 Irrigation Act required everyone who had constructed or partially constructed a system for the diversion and use of water, and who had actually diverted and used water prior to January 1, 1913, to file a sworn statement describing the system with the county clerk of the county where the point of diversion was located, if they had not previously done so in accordance with the acts of 1889 and 1895 and to file such with the Board of Water Engineers. The act also required anyone who had actually taken or diverted water for beneficial use prior to January 1, 1913, to file a certified copy of the previous statement describing the system and the amount and purpose for which water was diverted and used with the Board of Water Engineers. An initial time limit of one year for compliance with the provision was later extended to 1916. In 1964, in State Board of Water Engineers v. Slaughter, 382 S.W.2d 111 (TEX.CIV.APP.-San Antonio 1964, writ ref'd-.n.r.e.), the requirement of filing a sworn statement with the Board of Water Engineers was held to be directory only. The act provided that those who filed with the Board "shall, as against the State, have the right to take and divert such water to the amount or volume thus being actually used and applied."

Together, the two statements and map filed with the Board came to be known as "certified filings" and are now so defined by statutes. Many of these filings declared an intent to irrigate several hundred thousand acres of land. Many of these large filings were never developed in accordance with the sworn statement describing the irrigation system, nor have the vast acreages been irrigated. Some of these undeveloped certified filings have been canceled in whole or in part by subsequent action of the Texas Water Commission. The extent to which other undeveloped certified filings will be recognized as vested rights to water use remains one of the several unresolved questions affecting optimum development of the water resources within the State. It is a matter of conjecture as to how many of these early rights could be maintained in litigation today since many declared appropriations (1) were never attached by virtue of lack of due diligence, or (2) were never limited as to quantity measured by "beneficial use," or (3) have been abandoned.

Appropriative Permits

The Irrigation Act of 1913 was revised and reenacted in 1917. A principal feature of the Act of 1917 authorized the Texas Board of Water Engineers to adjudicate water rights. This provision of the act was held unconstitutional in 1921. The Act of 1917, without the adjudicative provision, was reenacted in the 1925 revision of the Texas Civil Statutes and, with numerous amendments, remains the statutory basis for appropriative rights concepts in the State today.

Present-day statutes retain the cornerstone of the Doctrine of Prior Appropriation in that "as between appropriators, the first in time is the first in right." To this cornerstone, the statutes add the following concept of actual beneficial use as a limit to the measure and extent of a perfected water right: "A right to use State water under a permit or a certified filing is limited not only to the amount specifically appropriated but also to the amount which is being or can be beneficially used for the purposes specified in the appropriation, and all water not so used is considered not appropriated" §11.025, Texas Water Code. Beneficial use is defined as "the amount of water which is economically necessary for a purpose authorized by this chapter, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose" (Section 11.002(3), Texas Water Code).

In 1931, the Wagstaff Act was enacted which provided that "any appropriation made after May 17, 1931, for any purpose other than domestic and municipal use, is subject to the right of any city or town to make appropriations of water for domestic or municipal use without paying for the water." The Rio Grande was specifically excluded (Section 11.028, Texas Water Code).

In Texas today, anyone who desires to appropriate water must make an application in writing to the Texas Department of Water Resources. The Texas Water Commission of the Department, as a regulatory agency with broad discretionary powers, is charged with the administration of rights to the surface-water resources of the State. The Commission consists of three members appointed by the Governor for six-year staggered terms with the consent of the Senate. The Chairman is designated by the Governor.

The Rules of the Texas Department of Water Resources prescribe the procedures for applying for a water permit. The Department and the Commission will consider an application for approval if the application is in proper form and complies with statutory provisions. It may be granted only if unappropriated water is available, if the application contemplates a beneficial use of water, does not impair existing water rights or vested riparian rights, and is not detrimental to the public welfare.

After approval of an application, the Commission issues a permit giving the applicant the right to take and use water only to the extent stated. Permits may be regular, seasonal or temporary, or emergency in nature. A regular permit may be permanent in nature or issued for a term, and does not limit the appropriator to the taking of water during a particular season or between certain dates. A seasonal permit is also normally issued in perpetuality, but the taking of water is limited to certain months or days during the year. A temporary permit is granted for a period of time not exceeding three years and does not vest in the holder any permanent right to the use of water.

The Texas Water Commission may also grant permits for the impoundment and storage of water with the use of the impounded water to be determined at a later date by the Commission.

Once the right to the use of water has been perfected by the (1) issuance of a permit from the Texas Water Commission and (2) the subsequent beneficial use of the water by the permittee, the water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation until the permit is cancelled. Formal cancellation of unused permits, certified filings, or certificates of adjudication is possible by administrative action initiated by the Executive Director and subsequent Commission hearings.

Section 11.142 (formerly Article 7500a) allows a landowner to construct a dam and reservoir on his own property, that is, on a nonnavigable stream, and to impound not to exceed 200 acre-feet of water for domestic and livestock purposes only, without securing a permit. A simplified, short form application for permit to appropriate water for other than domestic and livestock purposes is available for the owner of such an exempt reservoir which was originally built for domestic and livestock purposes.

Water Rights Adjudication

In 1956, the Attorney General of Texas filed suit in the 93rd District Court of Hidalgo County seeking a judicial adjudication of the water rights to the American share of the waters of the Rio Grande on that segment of the river lying immediately below the International Falcon Dam and extending to the mouth of the Rio Grande.

After a lengthy trial, on August 1, 1966, District Judge J.H. Starley rendered an order, but attempted to retain continuing jurisdiction. In 1969, a landmark decision, the State of Texas v. Hidalgo County Water Control District No. 18, 443 S.W.2d 728, the Corpus Christi Court of Civil Appeals entered a judgment modifying and affirming the trial court judgment. Writ of error was refused by the Texas Supreme Court.

In an earlier decision, of Valmont Plantations v. State, in 1962, the Supreme Court of Texas affirmed the decision of the Court of Civil Appeals and adopted it as its opinion. This was an appeal out of the same lawsuit. It held that the original Spanish and Mexican grants did not carry with them rights of irrigation unless the rights were specific in the grants.

While the Hidalgo County Water Control and Improvement District No. 18 decision, commonly known as the Lower Valley Case, is a momentous ruling, the segment adjudicated is unique in two respects: (1) the Rio Grande is an international stream upon which Falcon and Amistad Reservoirs were constructed under a treaty without an allocation of the American share of the storage therein, and (2) the lower valley has a long history of development for irrigation.

In 1967, the Texas Legislature enacted the Water Rights Adjudication Act which is codified as Section

11.301 et seq. of the Texas Water Code. The declared purpose of the act was to require a recordation with the Texas Water Rights Commission of claims of water rights which were presently unrecorded, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. Pursuant to the act, all persons wishing to be recognized water rights at the end of the administrative adjudication who were claiming water other than under permits or certified filings were required to file a claim with the Commission by September 1, 1969. Such a claim is to be recognized only if valid under existing law and only to the extent of the maximum actual application of water to beneficial use without waste during any calendar year from 1963 to 1967, inclusive. Riparians were allowed to file an additional claim on or before July 1, 1971, to establish a right based on use from 1968 to 1970, inclusive.

Pursuant to the authority and responsibility of this act, The Texas Water Rights Commission (now the Texas Water Commission of the Texas Department of Water Resources) initiated a series of administrative adjudications of water rights other than domestic and livestock uses on a river segment by river segment basis as shown by the accompanying table and map. After an initial investigation by a Department engineer, and required notices, claimants are afforded an administrative hearing conducted by the Commission to show the nature and extent of their claim. After the Commission renders a preliminary determination, which includes an evaluation of each claim presented in the segment, affected claimants in the adjudication are afforded an opportunity to file contests. At the contest hearings, claimants and protestants are again given an opportunity to present additional evidence and oral argument. The Commission then enters a final determination. After ruling on motions for rehearing from the final determination, the Commission is required to file a certified copy of the final determination, together with all evidence presented to or considered by it, in a district court of any county in which the stream segment is located. After a final hearing, the Court enters a decree affirming or modifying the order of the Commission. Section 11.326 of the Texas Water Code provides that the Executive Director may appoint a watermaster for the purpose of administrating adjudicated water rights in those areas of the State where adjudication has become finalized.

On February 29, 1984, the adjudication process was about 91 percent complete, with plans for completion of all investigations by September 1, 1984, with the exception of the Rio Grande segment above Fort Quitman. Work in this area is not underway because of litigation.

The question of constitutionality of the Water Rights Adjudication Act has been resolved. On November 24, 1982, in re: The Adjudication of Water Rights in the Llano River Watershed of the Colorado River Basin, the Supreme Court of Texas rendered the decision that the act is constitutional.

Ground-Water Law in Texas

As a prelude to any discussion of the ground-water law of Texas, it is desirable to understand the term "ground water" as defined by statute and case law. A more accurate term would probably be percolating water.

Percolating waters are defined as those waters below the surface of the ground not flowing through the earth in known and defined channels, but are waters percolating, oozing, or filtrating through the earth. Percolating waters are distinguished from: (1) "subterranean streams flowing in well-defined beds and having ascertainable channels" and (2) "the ordinary underflow of every river and natural stream of the state."

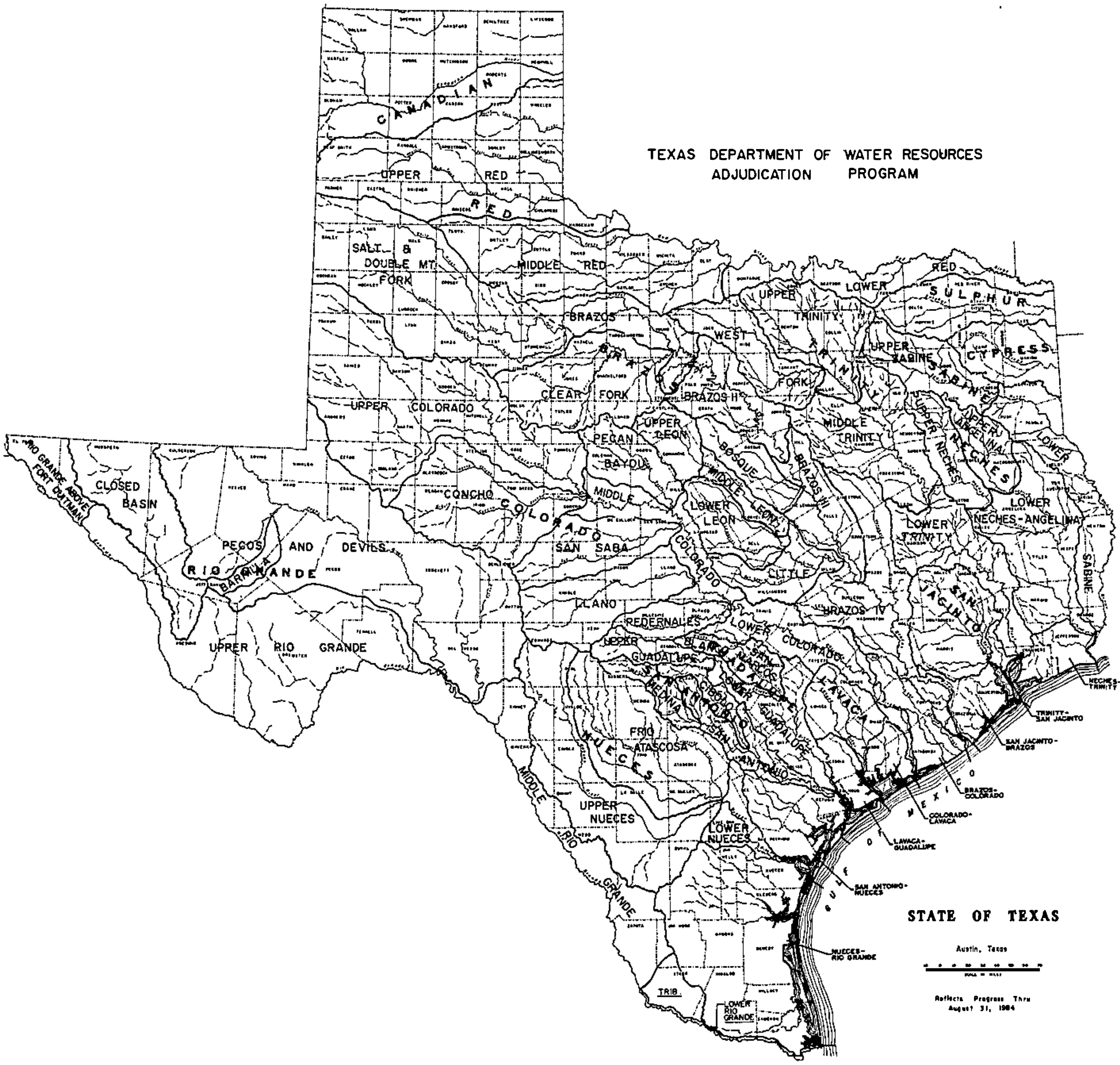
The state of the law with respect to ownership of subterranean streams flowing in well-defined channels is not settled in Texas. However, "stream underflow" (the water that flows beneath and alongside of a surface stream channel) is the property of the State (Section 11.021, Texas Water Code). Both stream underflow and subterranean streams have been expressly excluded from the definition of underground water in Section 52.001 of the Texas Water Code, which article recognizes the ownership and rights of Texas landowners to underground water.

There exists a legal presumption in Texas that all sources of ground water are percolating waters as opposed to subterranean streams. The courts in the past have been reluctant to accept testimony of engineers and hydrologists as conclusively rebutting this presumption. Consequently, the surface landowner is presumed to own underground water until it is conclusively rebutted by a showing that the source of such supply is a subterranean stream or stream underflow, a burden of proof that may be very difficult to carry.

Texas courts have followed unequivocally the "English" or "common law" rule that the landowner has a right to take for use or sale all the water he can capture from beneath his land. The judiciary early chose not to adopt the "American rule" with respect to ground water, which is based on "reasonable use" and correlative rights. Consequently, neither an injured neighbor nor the State can effectively exercise control over water-use practices involving ground water. This is in contrast with the extensive and direct involvement of the State in conserving and controlling surface-water supplies. The situation is paradoxical when one realizes the actual interrelationship of ground and surface water, and even more so when one realizes the

PERTINENT DATES IN ADJUDICATION PROGRAM

BASIN STREAM SEGMENTS OR WATERSHEDS	INVESTIGATION BEGAN	PUBLISHED REPORT	NOTICE FOR 11.307 CLAIMS	11.307 CLAIMS DUE	EVIDENTIARY HEARINGS SCHEDULED	EVIDENTIARY HEARINGS COMPLETE	PUBLISHED PRELIMINARY DETERMINATION	NOTICE FOR CONTESTS	CONTESTS DUE	CONTEST HEARINGS SCHEDULED	CONTEST HEARINGS COMPLETE	PUBLISHED FINAL DETERMINATION	NOTICE FOR MOTIONS ON REHEARINGS	DATE FOR ACTION ON MOTIONS	PUBLISHED MODIFIED FINAL DETERMINATION	FINAL DETERMINATION TO ATTORNEY GENERAL	FINAL DETERMINATION FILED DISTRICT COURT	DISTRICT COURT NO. AND CITY	FINAL JUDGEMENT ISSUED	CERTIFICATES OF ADJUDICATION ISSUED	NUMBER OF CERTIFICATES ISSUED
A. RIO GRANDE BASIN																					
1. Lower Rio Grande	Adjudicated By The 95th District Court With Modifications By Appellate Court																				879
a. Tributaries	1-28-84	3-15-84	6-15-84	10-5-84	10-19-84																
2. Middle Rio Grande	8-8-66	11-1-68	10-22-69	2-20-70	7-15-70	5-25-71	8-30-72	4-9-73	7-16-73	8-28-73	8-29-73	10-15-74	10-15-74	11-15-74	2-27-75	4-22-75	5-2-75	200-AUSTIN	11-9-82 /	8-15-83 /	179 /
3. Upper Rio Grande	10-15-68	4-1-71	8-30-71	12-20-71	3-28-72	3-1-74	5-13-74	8-1-74	9-16-74	12-19-74	8-12-75	1-19-76	2-18-76	2-19-76	—	3-9-76	5-12-76	201-AUSTIN	8-13-76	8-18-77	107
4. Pecos-Devils Rivers	7-8-69	6-1-71																			
a. Barrilla Draw	10-1-69	6-1-71	11-2-72	2-20-73	4-24-73	6-14-74	12-17-74	12-17-74	4-16-75	7-15-75	7-15-75	11-10-75	11-10-75	12-10-75	—	1-14-76	3-10-76	112-FORT STOCKTON	6-6-78	9-28-78	13
5. Rio Grande above Ft. Quitman																					
B. COLORADO RIVER BASIN																					
1. Concho River	9-1-71	9-8-72	9-11-72	1-8-73	3-6-73	8-30-74	4-14-75	4-14-75	7-28-75	9-23-75	10-29-75	3-1-76	3-1-76	4-25-76	8-16-76	10-13-76	11-1-76	51-SAN ANGELO	6-14-79	3-12-80	220
2. Upper Colorado River	11-15-71	5-1-73	4-25-73	7-27-73	9-4-73	8-9-74	10-30-74	1-13-75	4-17-75	7-15-75	8-12-75	2-2-76	2-2-76	3-3-76	—	3-17-76	4-6-76	51-SAN ANGELO	9-10-76	8-19-77	149
3. Pecan Bayou	12-19-72	2-15-74	2-19-74	5-21-74	6-24-74	10-22-74	4-14-75	4-14-75	7-28-75	9-22-75	10-29-75	3-1-76	3-1-76	4-25-76	—	5-27-76	6-10-76	27-GOLDTHWAITE	9-14-79 / 11-23-82	4-13-81 / 6-1-83	105 / 2
4. Middle Colorado River	9-15-72	5-15-75	5-19-75	9-2-75	10-7-75	11-10-76	8-20-79	9-24-79	1-7-80	3-26-80	4-8-80	3-16-81	4-29-81	6-29-81	9-14-81	11-20-81	12-10-81	33. - BURNET	3-18-82 / 10-29-82	8-31-83	182
5. San Saba River	3-10-73	4-1-75	4-8-75	7-21-75	8-25-75	4-30-76	8-31-77	8-31-77	1-12-78	3-13-78	3-29-78	3-28-79	3-28-79	5-4-79	—	6-21-79	7-9-79	33 - SAN SABA	9-19-79 / 1-7-83	4-20-81 / 2-7-83	165 / 1
6. Llano River	12-1-73	8-20-75	12-15-75	4-1-76	5-17-76	4-14-77	8-31-77	8-31-77	1-12-78	3-16-78	3-16-78	4-4-78	4-4-78	7-7-78	—	7-20-78	9-25-78	33-LLANO	9-24-79 / 11-24-82	8-15-80 / 3-8-83	177 / 1
7. Lower Colorado River	9-19-73	2-20-76	4-26-76	8-16-76	10-18-76	4-20-78	8-31-82	10-8-82	1-10-83	1-11-84	3-17-84										
8. Pedernales River	11-26-73	9-1-75	12-15-75	4-1-76	5-3-76	10-1-76	1-25-78	7-19-78	11-3-78	12-11-78	12-11-78	3-1-79	3-1-79	4-6-79	—	4-13-79	4-26-79	200-AUSTIN	7-2-79	8-15-80	78
C. SAN ANTONIO RIVER BASIN																					
1. Cibolo Creek	8-19-70	10-4-71	11-15-71	3-15-72	7-27-72	9-27-72	5-29-73	5-29-73	9-10-73	11-28-73	11-28-73	12-31-73	3-19-74	4-18-74	8-5-74	10-4-74	10-7-74	73-SAN ANTONIO	7-28-77	9-28-78	30
2. Medina River	2-19-71	6-1-73	8-29-74	12-3-74	1-6-75	3-13-75	9-9-76	9-2-76	1-31-77	5-2-77	7-14-77	12-5-77	12-5-77	2-15-78	5-23-78	9-7-78	11-20-78	37-SAN ANTONIO	11-12-80 /	8-28-81 /	54 /
3. San Antonio River	8-21-72	11-15-73	9-16-74	1-20-75	3-18-75	8-6-75	10-18-76	10-19-76	3-4-77	4-18-77	5-16-77	8-15-77	10-18-77	11-3-77	—	2-6-78	3-27-78	57-SAN ANTONIO	10-3-80	7-29-82	55
D. GUADALUPE RIVER BASIN																					
1. Upper Guadalupe River	10-18-71	12-15-72	1-15-73	5-1-73	6-25-73	1-23-74	7-30-75	7-30-75	12-16-75	4-5-76	2-17-77	3-28-77	3-28-77	6-24-77	—	7-18-77	9-9-77	57-SAN ANTONIO	11-12-79 / 11-24-82	7-17-81 / 3-8-83	134 / 14
2. Lower Guadalupe River * * *	1-22-73	12-5-75	11-21-77	3-3-78	5-1-78	1-10-79	4-15-80	5-12-80	8-11-80	10-28-80	2-20-81	10-13-82	12-3-82	2-8-83	—	4-28-83	2-16-84	287-VICTORIA	5-25-84 /		
3. Blanco-San Marcos Rivers	10-28-72	12-20-77	4-10-78	7-28-78	9-11-78	4-2-79	8-10-79	8-14-79	12-17-79	2-20-80	3-4-80	6-3-80	6-30-80	8-29-80	—	9-24-80	10-7-80	200-AUSTIN			
E. NUECES RIVER BASIN																					
1. Lower Nueces River	7-23-73	7-22-74	11-21-77	3-3-78	5-22-78	7-15-80	3-19-81	4-17-81	7-17-81	9-3-81	9-3-81	11-4-81	11-25-81	1-26-82	1-26-82	2-9-82	6-30-82	214-CORPUS CHRISTI	9-23-82	6-30-83	7
2. Upper Nueces River	12-2-74	5-22-78	6-26-78	10-6-78	11-13-78	7-20-79	2-20-80	2-26-80	7-1-80	9-17-80	9-26-80	6-18-81	7-24-81	9-9-81	—	9-18-81	10-28-81	38-UVALDE	9-18-82	1-24-84	129
3. Frio-Atascosa Rivers	11-11-74	4-26-76	3-27-78	7-14-78	8-28-78	3-22-79	3-13-80	4-11-80	7-17-80	9-16-80	10-31-80	5-20-81	6-26-81	8-19-81	—	9-2-81	1-29-82	73-SAN ANTONIO	4-12-82 /	8-11-84 /	75 /
F. BRAZOS RIVER BASIN																					
1. Brazos I	5-17-76	8-31-78	12-19-79	4-11-80	4-21-80	6-2-80	2-27-81	4-1-81	7-6-81	9-15-81	9-15-81	2-10-82	3-18-82	5-5-82	—	6-22-82	9-13-82	39-HASKELL	11-18-82		
a. Salt & Double Mt. Forks	5-17-76	8-31-78	2-13-79	5-18-79	5-21-79	8-31-79	1-6-81	2-9-81	5-13-81	7-13-81	7-13-81	2-10-82	3-18-82	5-5-82	—	6-22-82	9-13-82	39-HASKELL	11-18-82		
2. Brazos II	9-12-77	1-9-79	2-6-80	5-23-80	6-2-80	4-1-81	4-14-82	5-25-82	8-31-82	11-17-82	1-7-83	4-6-83	5-6-83	6-28-83	9-20-83	6-25-84					
3. Brazos III	8-7-78	2-1-83	2-10-83	5-16-83	5-23-83	7-10-84															
4. Brazos IV * *	6-19-78	6-15-83	7-27-83	10-28-83	11-7-83	8-8-84															
5. Clear Fork	4-5-76	6-15-78	5-4-79	8-31-79	9-10-79	4-2-80	6-10-82	7-15-82	10-18-82	3-9-83	6-3-83	4-11-84	6-1-84	8-1-84							
6. Little River	1-20-76	7-1-77	9-17-79	1-7-80	1-21-80	8-26-80	11-24-81	2-8-82	5-11-82	7-21-82	9-1-82	12-14-82	1-20-83	3-29-83	—	4-28-83	9-20-83	26-GEORGETOWN	4-30-84 /		
7. Lower Leon River	8-1-75	2-22-77	9-14-79	1-4-80	1-14-80	7-31-80	3-13-81	6-19-81	9-25-81	12-1-81	1-5-82	6-2-82	7-26-82	9-8-82	—	10-28-82	10-29-82	33-BURNET	1-7-83	4-30-84	102
8. Middle Leon River	2-2-76	11-1-77	6-22-79	10-1-79	10-29-79	5-2-80	2-17-81	3-17-81	6-18-81	8-11-81	8-11-81	11-5-81	12-7-81	1-26-82	—	2-5-82	4-1-82	52-GATESVILLE	4-20-83 /	10-31-83 /	39 /
9. Upper Leon River	12-12-74	6-1-77	3-28-79	7-16-79	7-23-79	4-1-80	12-16-81	2-5-82	5-7-82	6-29-82	6-29-82	9-15-82	10-20-82	12-8-82	—	12-8-82	6-2-83	35-GOLDTHWAITE	9-8-83		
10. Bosque River	12-13-76	2-28-78	6-7-78	11-20-78	1-15-79	8-10-79	6-10-80	7-11-80	10-10-80	1-7-81	3-26-81	6-10-81	7-16-81	9-16-81	—	10-2-81	10-19-81	19 - WACO	1-5-82 / 2-8-84	3-8-83	118
11. Brazos River Authority	12-12-74	6-15-83	8-10-84	11-12-84	11-12-84																
G. TRINITY RIVER BASIN																					
1. Upper West Fork	5-12-75	2-15-79	2-23-79	6-8-79	6-11-79	8-23-79	7-30-80	8-29-80	12-5-80	4-27-81	4-28-81	12-6-81	1-15-82	3-24-82	3-29-82	5-27-82	9-30-82	160-DALLAS	1-14-83 /		
2. Middle West Fork	5-12-75	4-5-79	6-6-79	9-20-79	9-24-79	3-6-80	10-9-80	11-7-80	2-6-81	Upper West Fork, Middle West Fork And Lower West Fork Combined Into One Segment And Titled The West Fork Trinity River											
3. Lower West Fork	5-12-75	5-25-79	6-6-79	9-20-79	9-24-79	3-6-80	10-9-80	11-7-80	2-6-81												
4. Upper Trinity River	3-3-75	4-11-77	2-28-77	6-6-77	6-20-77	5-31-78	4-11-79	4-11-79	8-24-79	10-2-79	10-23-79	6-23-80	7-21-80	9-19-80	11-17-80	5-17-81	6-18-81	160 - DALLAS	10-29-81 / 1-21-83	7-22-83	111
5. Middle Trinity River	8-28-78	4-20-82	4-29-82	7-9-82	7-26-82	3-21-84															
6. Lower Trinity River *	4-18-77	7-31-79	10-7-80	1-8-81	1-19-81	3-30-82															
H. RED RIVER BASIN																					
1. Upper Red River	5-12-80	5-11-81	5-20-81	8-21-81	8-31-81	11-10-82	3-16-83	4-18-83	7-18-83	10-4-83	11-23-83	8-1-84	9-10-84	10-18-84							
2. Middle Red River	8-25-80	2-25-82	4-5-82	8-13-82	8-30-82	4-6-83	3-15-84	4-17-84	7-18-84	9-18-84											
3. Lower Red River	11-30-81	12-27-82	1-21-83	4-11-83	4-25-83																
I. NECHES RIVER BASIN																					
1. Upper Angelina River	1-9-78	3-15-79	2-19-80	6-13-80	6-23-80	12-18-80	9-3-82	10-15-82	1-20-83	3-24-83	3-24-83	4-18-84	5-21-84	7-10-84							
2. Upper Neches River	7-18-77	3-15-79	11-26-79	3-10-80	3-24-80	9-19-80	4-16-81	5-15-81	8-14-81	10-15-81	10-15-81	2-23-82	3-30-82	5-18-82	—	5-12-82	6-28-82	241-TYLER	10-11-82 / 5-10-83		
3. Lower Neches-Angelina Rivers *	2-20-78	4-15-80	6-16-80	9-26-80	10-13-80	10-1-82															
J. SABINE RIVER BASIN																					
1. Upper Sabine River	8-21-78	2-1-82	2-10-82	5-25-82	6-14-82	2-25-83															
2. Lower Sabine River	6-8-81	6-4-82	6-15-82	9-10-82	9-20-82	6-28-83															
K. CANADIAN RIVER BASIN	6-4-79	1-31-80	5-30-80	9-5-80	9-8-80	2-3-81	7-14-82	8-20-82	11-30-82	—	—	1-10-83	2-1-83	4-12-83	—	4-28-83	2-29-84	108-AMARILLO	7-3-84		
L. SULPHUR RIVER BASIN	10-1-79	8-14-81	9-4-81	12-10-81	12-14-81	4-13-82	2-17-83	4-15-83	7-18-83	11-2-83	11-3-83										
M. CYPRESS CREEK BASIN	4-9-79	2-15-82	2-23-82	5-25-82	6-14-82	1-5-83															
N. SAN JACINTO RIVER BASIN	10-11-77	2-25-80	2-21-80	5-30-80	6-9-80	1-22-81	6-8-82	7-9-82	10-8-82	12-14-82	2-10-83	10-23-83	11-22-83	1-4-84	—	2-16-84					
O. LAVACA RIVER BASIN * * *	8-7-78	1-9-79	1-26-79	5-4-79	5-7-79	7-2-79	12-18-79	12-21-79	4-21-80	—	—	6-4-80	6-30-80	8-14-80	—	8-26-80	9-25-80	155 - LA GRANGE	1-14-81	7-3-81	28
P. COASTAL BASINS																					
1. Trinity-San Jacinto	4-18-77	4-20-79	6-18-80	9-26-80	10-6-80	12-16-80	2-16-82	3-11-82	6-11-82	7-21-82	7-21-82	10-6-82	11-8-82	12-21-82	—	12-21-82	12-20-83	253-LIBERTY	4-12-84		
2. Brazos-Colorado	3-24-80	10-1-80	10-24-80	2-13-81	2-23-81	5-14-81	4-23-82	6-8-82	9-10-82	11-18-82	11-19-82	4-12-83	5-17-83	7-5-83	—	8-24-83	4-4-84	25-COLUMBUS	6-19-84		
3. Colorado-Lavaca	8-6-79	12-17-79	2-11-80	6-13-80	6-23-80	9-4-80	9-30-82	11-19-82	2-21-83	6-1-83	7-19-83										
4. San Antonio-Nueces	4-12-81	10-20-82	10-28-82	2-14-83	2-21-83	11-1-83															
5. Nueces-Rio Grande	7-14-80	10-20-82	10-28-82	2-14-83	2-21-83	1-18-84															
6. Neches-Trinity	*	Included With The Lower Trinity River And Lower Neches-Angelina Rivers Segment																			
7. San Jacinto-Brazos	* *	Included With The Brazos IV Segment																			
8. Lavaca-Guadalupe	* * *	Included With The Lower Guadalupe River Segment And Lavaca River Basin																ACCOMPLISHED DURING FISCAL YEAR 1984		Reflects Progress Thru August 31, 1984		


TEXAS DEPARTMENT OF WATER RESOURCES
ADJUDICATION PROGRAM
CANADIAN
UPPER RED
RED
SALT & DOUBLE MT. FORK
MIDDLE RED
BRAZOS I
BRAZOS
UPPER TRINITY
LOWER RED
SULPHUR
CYPRESS
WEST FORK
TRINITY
UPPER SABINE
SABINE
CLEAR FORK
BRAZOS II
UPPER COLORADO
PECAN BAYOU
UPPER LEON
MIDDLE TRINITY
UPPER NECHES
UPPER ANGELINA
NECHES
LOWER SABINE
CLOSED BASIN
RIO GRANDE ABOVE FORT QUITMAN
CONCHO
COLORADO
MIDDLE COLORADO
BOSQUE
MIDDLE LEON
BRAZOS III
LOWER LEON
LOWER NECHES-ANGELINA
LOWER TRINITY
PECOS AND DEVILS
RIO GRANDE
SAN SABA
LITTLE
SAN JACINTO
SABINE
LLANO
BRAZOS IV
PEDERNALES
LOWER COLORADO
UPPER RIO GRANDE
UPPER GUADALUPE
BLANCO
SAN MARCOS
GUADALUPE
SAN ANTONIO
MEDINA
CIBOLO
LAVACA
FRIO
ATASCOSA
NUECES
UPPER NUECES
LOWER NUECES
MIDDLE RIO GRANDE
LOWER RIO GRANDE
TRIB.
NECHES-TRINITY
TRINITY-SAN JACINTO
SAN JACINTO-BRAZOS
BRAZOS-COLORADO
COLORADO-LAVACA
LAVACA-GUADALUPE
SAN ANTONIO-NUECES
NUECES-RIO GRANDE
GULF OF MEXICO
STATE OF TEXAS
Austin, Texas
Reflects Progress Thru August 31, 1984

necessary interrelationship of ground- and surface-water development for future State needs and the necessity of adequate ground-water supplies to meet future municipal and domestic requirements in certain areas.

Owners of land overlying defined ground-water reservoirs may adopt voluntary well regulation through mutual association in underground water conservation districts; Section 52.001, Texas Water Code provides the framework for these districts, and to date, 12 have been created, but only nine are currently active.

Impairment of a landowner's right in the percolating waters under his land, when this impairment is the result of a trespass on the land is, of course, actionable. To date there are only three legal actions available to a landowner in Texas for outside interference with his percolating water rights. The first is the common law right recognized in jurisdictions which apply the English rule. This right arises when there is malice or wanton conduct which results in a taking for the for sole purpose of injuring a neighbor. The second action recognized in Texas arises when artesian flow results in no beneficial use, and as such, is defined as "waste." Section 11.205 of the Texas Water Code defines "waste" in relation to artesian wells, and provides, among other exceptions, that waste will not exist if the water is "used for the purposes and in the manner in which it may be lawfully used on the premises of the owner of such well." The third action arises as a result of contamination of the quality of water in a landowner's well. Cases within the third category have arisen mostly in areas where it can be conclusively shown that oil and gas operations have allowed brines, oil, and other substances to escape into the percolating freshwater-bearing strata. See Continental Oil Company v. Berry, 42 S.W.2d 953, (TEX.CIV.APP.-Fort Worth 1932, writ ref'd).

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PART II

WATER RESOURCES AND WATER DEMANDS

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PART II

WATER RESOURCES AND WATER DEMANDS

In this section, the components and quantities of the State's water resources are identified and described. Methods, data, and assumptions whereby projections were made of future water quality protection and water supply needs of each area of the State are also presented and explained, along with the resulting projections of the State totals. Projections for individual zones and river basins are presented in Part III. The quantity of water that was estimated to have been used in 1980 is shown. Estimates are based upon reported use of water for municipal, commercial, and manufacturing purposes, and surveys of agricultural water use. Projections of quantities of water that will be needed in the future are shown here and in Part III for each decade from 1990 through 2030.

PROJECTING FUTURE WATER SUPPLIES

The source of water in each area of the State is precipitation, although everyday current supplies are obtained from storage in aquifers, storage in reservoirs, and flowing streams. In Texas, the particular climate and physiography combine to affect the distribution of precipitation across the State. Also, certain characteristics of the climate—temperature, drought, hurricanes, and other weather phenomena—affect the quantity of precipitation that occurs in different regions of the State. Weather, ground water, and surface water resources are described in the following discussion.

Weather and Climate

The climate of Texas is characterized by variations in the weather. There are wide variations in precipitation and temperature across the State. This is determined primarily by the confluence of warm, moist Gulf air and relatively cool, dry air from the continental United States. While the western half of the State has a semi-arid, continental-type climate, characterized by rapid and drastic fluctuations in temperature, the remainder of the State is influenced by a humid, subtropical climate, having moderate temperatures. Thus, the different parts of the State receive quite different quantities of precipitation annually.

Precipitation

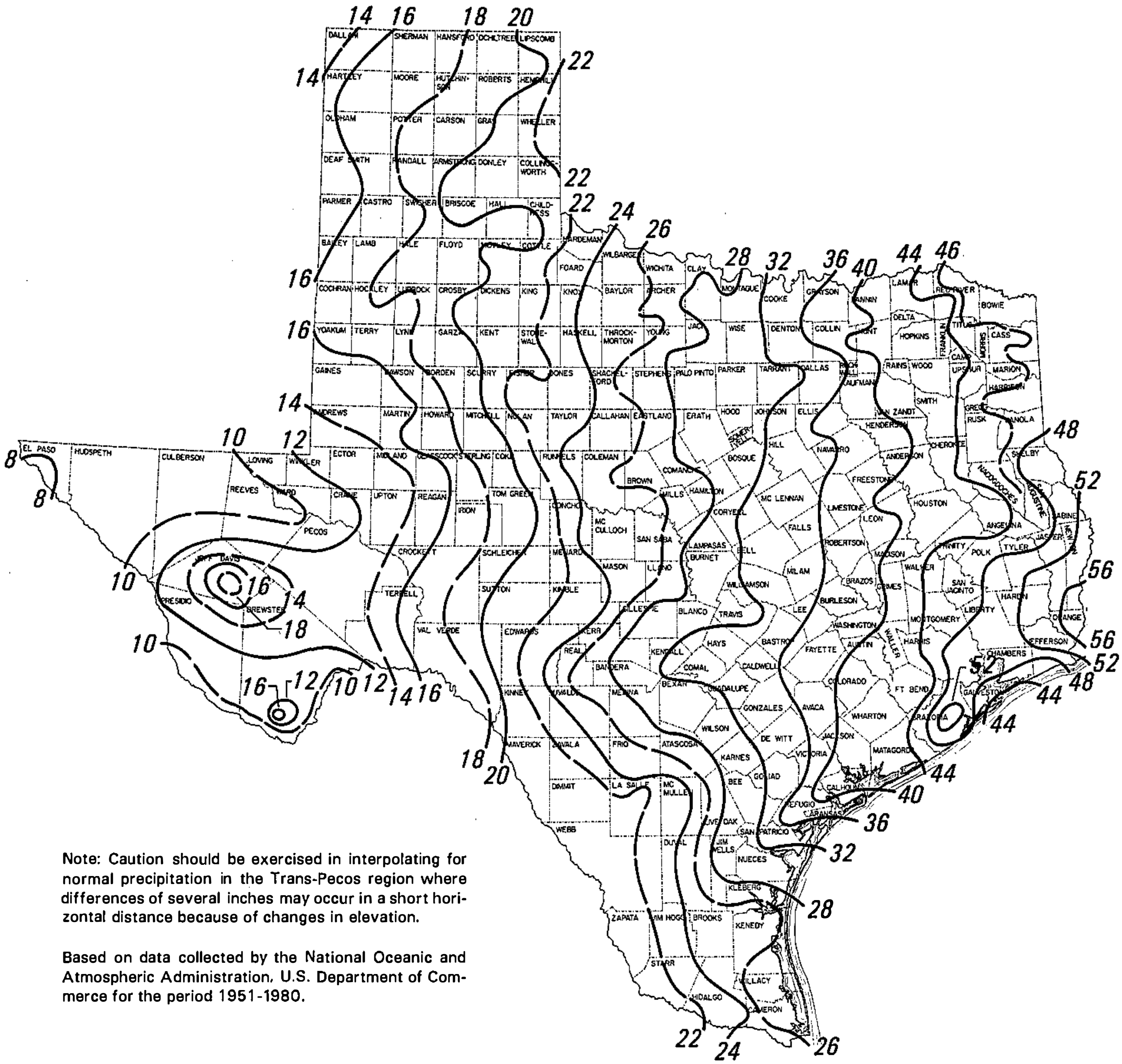
Because the Gulf is the major source of moisture for precipitation across the State, rainfall gradually decreases with greater distance westward from the Gulf. Generally, rainfall decreases from east to west across Texas at a rate of about one inch every 15 miles. For instance, average annual precipitation ranges from more than 56 inches at the eastern border to less than eight inches in the westernmost region of the Trans-Pecos (Figure II-1).

Variation in average annual rainfall is also a feature of the climate. The wettest year of this century in Texas was 1941, when there was a statewide average of more than 42 inches of rain. The driest year was in 1917, with only 14 inches of rain statewide. Although an integral part of the climate, these variations are difficult to predict.

Most precipitation in Texas is in the form of rain, although some snowfall occurs in North and West Texas. The heaviest snowfall occurs in the northern High Plains, although every few years the greatest annual snowfall will occur in the Red River Valley or in the mountains of the Trans-Pecos. Rarely is the snowfall ever substantial enough to contribute significantly to the quantities of water supplies in the State.

Drought

Drought is also a feature of the climate, during which there are long periods of time having little or no precipitation. Because it occurs at random, there is no predictable cycle of drought in Texas. The water supply is directly related to drought conditions, since the pattern of rainfall is interrupted and the loss and use of wateris increased with sustained, higher temperatures. At least 14 significant periods of drought of varying severity and geographical extent have occurred in Texas in the 20th century. The most severe drought on record occurred during the period 1950-1956.Beginning in the western part of the State, it spread across the remainder of Texas until about 94 percent of Texas' 254 counties was classified as disaster areas at the end of 1956. Another drought, nearly as severe as that in 1950-1956, began in 1916 and lasted three years.



Note: Caution should be exercised in interpolating for normal precipitation in the Trans-Pecos region where differences of several inches may occur in a short horizontal distance because of changes in elevation.

Based on data collected by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce for the period 1951-1980.

Figure II-1. Normal Annual Precipitation (Inches)

Because drought reduces the available water supply and increases the consumption requirements from water in storage, the water supply entities of Texas must be prepared to store and deliver sufficient quantities of suitable quality water to meet regular needs through the drought cycle. Management for drought conditions is done by establishing dependable water supplies through the installation of additional wells for immediate use or by constructing surface water storage facilities in which floodwater of high precipitation periods is stored for future use.

Hurricanes

Like drought, hurricanes are a facet of the climate and affect the quantity of water supplies where these occur. Tropical cyclones, particularly tropical storms and hurricanes, are a perennial threat to the Texas Gulf coastal region during the summer and autumn. Virtually all of the tropical cyclones that affect the Texas coast originate in the Gulf of Mexico, Caribbean Sea, or in other parts of the North Atlantic Ocean. Although the hurricane season in Texas extends from June to October, tropical cyclones are most frequent in August and September. These infrequently affect the Coast before mid-July or after mid-October. Hurricanes contribute large quantities of precipitation in addition to producing high winds, significant storm tides, and usually result in significant property damage and loss of life.

Temperature

Unlike precipitation, the average annual temperature decreases with increasing latitude. This change is most pronounced in the western half of the State which is influenced by drier, continental air, whereas the eastern half is influenced by moist, Gulf air. As a result of the differences in moisture, there are higher average annual high temperatures in the west, and this directly affects evaporation rates and the quantities of water required for people and economic activity. The relatively greater moisture content of the Gulf air in the eastern half acts to moderate the affects of heating.

Average annual temperature ranges from 53°F in the northwestern edge of the High Plains to 74°F along the Rio Grande in the southernmost section of the State. Except in the Trans-Pecos and along the eastern edge of the Edwards Plateau, where physiography plays an important role in the spatial variation of temperature, mean annual temperatures generally increase from north to south. Usually, January is the coldest month of the year, while July and August are the warmest.

Evaporation

Evaporation is a function of temperature and significantly affects the quantity of water in storage. Evaporation is a continuous process, even in the more humid sections of the State, but rates of evaporation vary considerably in the State. Mean annual net evaporation rates vary from zero inches in East Texas near the Sabine River to approximately 100 inches in the Trans-Pecos, near El Paso. While evaporation is largely offset by rainfall in the eastern part of the State, it is not offset in the western part of Texas because rainfall is much less. Lake surface evaporation rates are uniform moving from north to south across the State.

Maximum evaporation occurs throughout the State during the summer months, while the least evaporation usually takes place in winter. During wet years, when water is plentiful, net lake surface evaporation rates are low. During years of drought, evaporation from lakes and transpiration rates of vegetation increase and more rapidly deplete water supplies. Evaporation losses are an important consideration in reservoir design and in the volume of reservoir storage to meet water supply requirements in years of drought.

Physiography

The physiography of Texas affects the variation and distribution of precipitation. Areas of the State in the higher elevations have a cooler, drier climate because they are not as affected by the general circulation of moist, Gulf air that is characteristic for the lower, easternmost elevations of the State.

Texas is a part of four major physiographic subdivisions of North America—the Gulf Coastal Forested Plains, the Great Western Lower Plains, the Great Western High Plains, and the Rocky Mountain Region. Moreover, there are three major plains divisions within the State—the Staked Plains, or Llano Estacado, the North Central Plains, and the Gulf Coastal Plain (Figure II-2). Elevation increases from the Gulf Coastal Plain westwards through the Staked Plains.

The Staked Plains, reaching an elevation of aboutfour thousand feet above sea level in the Panhandle, is a part of the Great Western High Plains, an alluvial mantle extending east from the Rocky Mountains. In the Panhandle, and to a line marked by the caprock escarpment, the Staked Plains is known as the High Plains of Texas, characteristically level, relatively treeless, and semi-arid. Below the caprock escarpment that delineates the High Plains is the

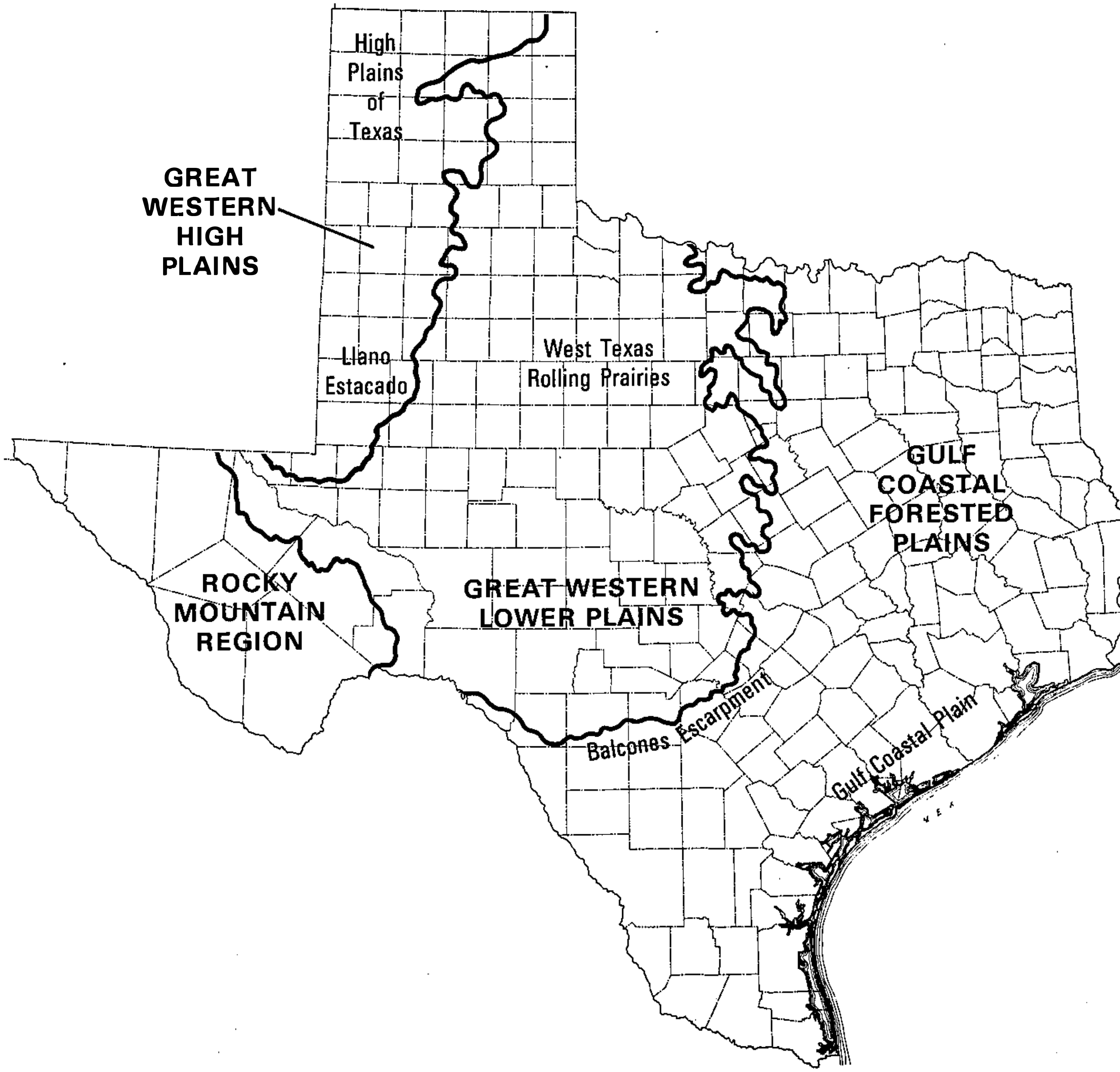


Figure II-2. Major Physiographic Regions of Texas

Edwards Plateau, roughly 35 thousand square miles of limestone, deeply dissected and rapidly drained, and ranging in elevation from about 2,600 feet above sea level in the west to about 700 feet in the east.

The Balcones fault system spreads across Central Texas from Del Rio on the Rio Grande, eastward to San Antonio and northeastward to Austin. This fault marks the boundary between the lowland, coastal plains and the upland plains and plateaus. Above the fault system, on the Edwards Plateau and through Central Texas, streams have eroded and cut through the land surface, while below the fault escarpment sediment loads have been released from which deep soils have been formed.

The North Central Plains is the southern extension of the Great Plains and includes the West Texas Rolling Prairies, Grand Prairie, and East and West Cross Timbers regions. Level to rolling topographically, the area is a typical prairie environment, with the occurrence of timber increasing to the east.

The Balcones fault system marks the western edge of the Texas Gulf Coastal Plain, a part of the Coastal Plains extending along the Gulf from the Atlantic to beyond the Rio Grande. Rising from sea level at the coast to around 550 feet above sea level below the fault system, the area is topographically rolling to hilly. It is marked by a heavy growth of pine and hardwood in East Texas. While in the more arid west, vegetation consists largely of post oak, further west, the prairies are treeless.

Ground Water

Aquifers presently supply 61 percent of the water used in Texas. An aquifer is a formation, group of formations, or part of a formation that is water-bearing. In the past, municipalities, industries, and irrigators, as well as rural inhabitants, have generally turned to this resource to satisfy water demands because of: (1) the widespread geographical occurrence of aquifers, (2) the absence of sufficient surface-water supplies or lack of facilities for storing and distributing available supplies, and (3) the relatively low costs of developing and pumping this resource as compared to the costs of constructing storage and treatment facilities for surface-water supplies in areas where both surface water and ground water exist.

Major Aquifers

During the period 1957 through 1962, the Board of Water Engineers, in cooperation with the U.S. Geological Survey, conducted reconnaissance investigations of the ground-water resources of the State. Data collected from these studies, as well as previous and subsequent investigations, resulted in the delineation of the major and minor aquifers in Texas (Figures II-3 and II-4).

A major aquifer is defined herein as one which yields large quantities of water in a comparatively large area of the State. These include the High Plains (Ogallala), Alluvium and Bolson Deposits, Edwards-Trinity (Plateau), Edwards (Balcones Fault Zone), Trinity Group, Carrizo-Wilcox, and Gulf Coast Aquifers. Collectively, these aquifers supply most of the ground water used in the State.

High Plains (Ogallala) Aquifer

The Ogallala Formation of Pliocene age occurs at or near the surface over much of the High Plains area of northwest Texas. The formation consists of alternating beds of silt, clay, sand, gravel, and caliche, reaching a maximum known thickness of more than 900 feet in southwestern Ochiltree County. The High Plains aquifer consists primarily of the Ogallala Formation, and includes all water-bearing units, mainly Cretaceous and Triassic sediments, with which it is in hydraulic continuity. However, the Canadian River has cut through the formation dividing it into two parts, the North Plains and the South Plains.

The zone of saturation in the aquifer ranges in thickness from only a few feet to more than 500 feet. The thickest saturated sections occur in the northeastern part of the South Plains. In the large irrigation area north and west of Lubbock, the saturated interval generally ranges between 100 and 300 feet. South of Lubbock, the saturated zone is generally between 50 and 150 feet thick.

Depth to water in the aquifer ranges between 100 and 200 feet throughout much of the South Plains, but, depths to water commonly exceed 300 feet in parts of the North Plains. Yields of wells range from less than 100 gpm (gallons per minute) to more than 2,000 gpm, averaging about 500 gpm.

Small quantities of natural recharge to the High Plains (Ogallala) Aquifer result from precipitation on the land surface and underflow from that part of the aquifer in New Mexico. Water moves slowly through the formation in a generally southeasterly direction toward the eastern escarpment of the High Plains.

Alluvium and Bolson Deposits

Deposits of alluvium occur in many parts of Texas, and generally consist of alternating and discontinuous beds of silt, clay, sand, and gravel of recent geologic age. In some

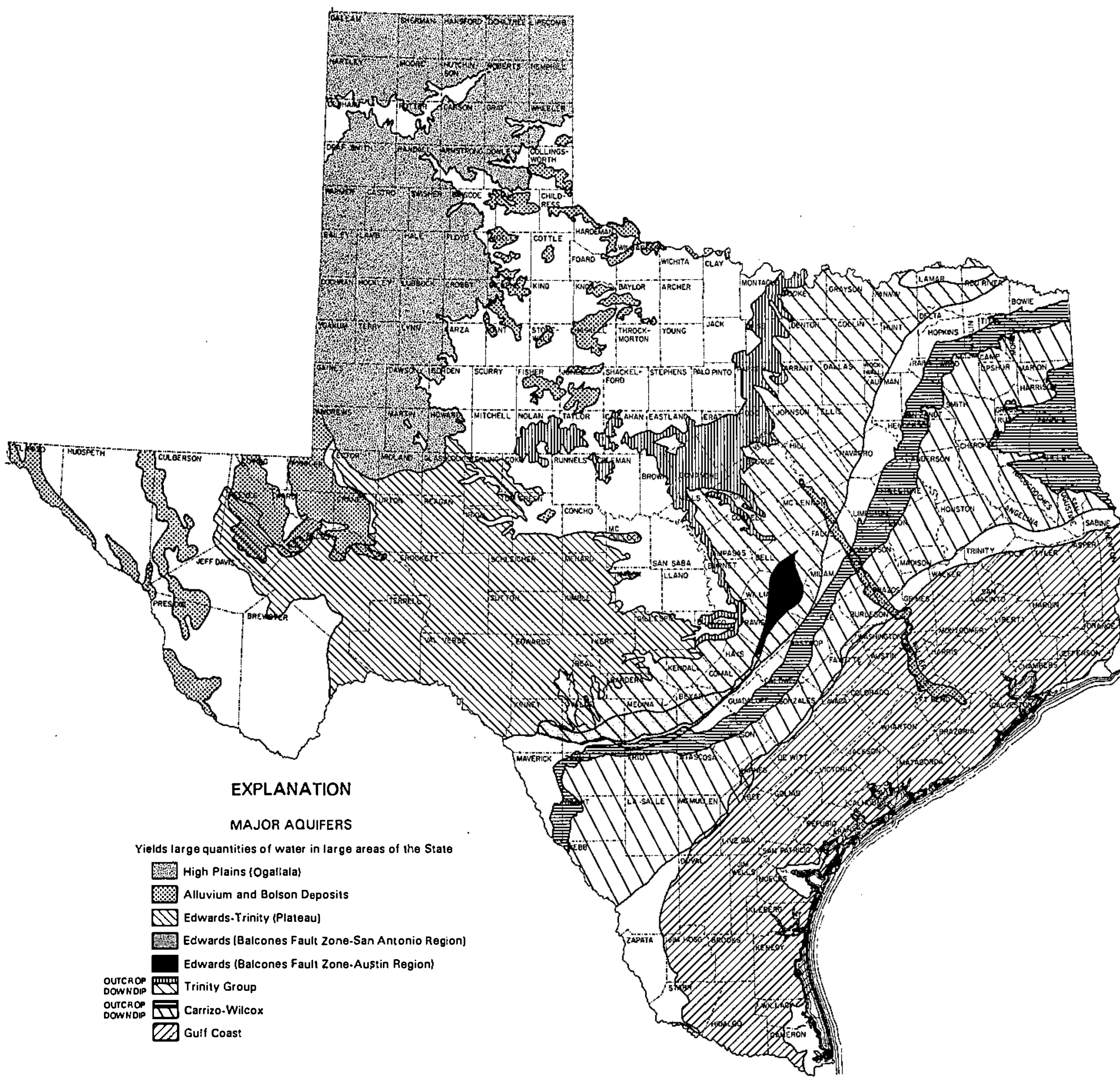


Figure II-3. Major Aquifers

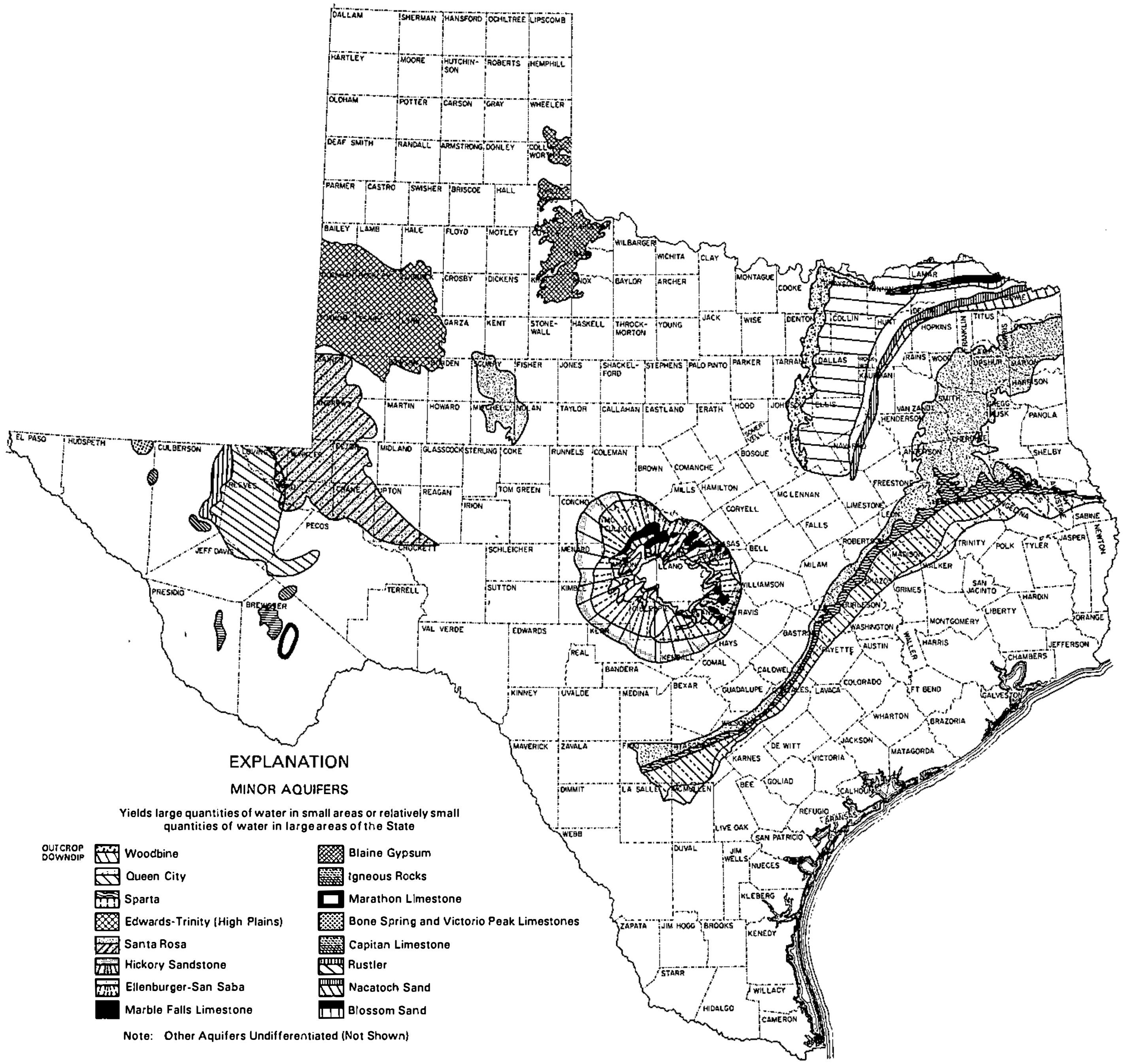


Figure II-4. Minor Aquifers

areas, these deposits contain comparatively large volumes of water, and the five largest and most productive of these local aquifers collectively make up a major aquifer in the Trans-Pecos area.

In the El Paso area and the El Paso Valley, alluvium and bolson deposits ranging to more than 9,000 feet thick contain fresh water to depths of about 1,200 feet. Large-capacity wells completed in this aquifer commonly yield between 1,000 and 1,500 gpm, supplying waterfor irrigation and municipal use.

Alluvium and Bolson deposits extending from northeastern Hudspeth County to northern Presidio County supply large volumes of waterfor irrigation. Large-capacity wells completed in the aquifer yield up to 2,500 gpm. At the present rate of pumpage, however, it is projected that these supplies will be largely depleted before the year 2020.

In the upper part of the Pecos River drainage system in Texas, deposits of alluvium ranging up to 1,500 feet or more in thickness yield large volumes of water used principally forirrigation. This aquifer also supplies municipal and industrial water needs in this region, including supplies for the Cities of Monahans and Pecos. Legal rights to the water in a large volume of the aquifer in northwestern Winkler and northeastern Loving Counties have been acquired by the City of Midland as a potential source of future supply for that city; however, these supplies can furnish only a part of Midland's projected future water needs.

Isolated areas of alluvium (principally erosional remnants of the Seymour Formation) furnish domestic, municipal, and irrigation supplies to areas of North and West Central Texas. These local aquifers in the upper Red and Brazos River Basins vary greatly in thickness, but in most areas the saturated interval is less than 100 feet. Pumpage at times and in local areas has exceeded the rate of recharge. Yields of large-capacity wells range from less than 100 gpm to 1,300 gpm, with the average beingabout 300 gpm.

Along the Brazos River, between northern McLennan County and central Fort Bend County, stream-deposited alluvial material ranging from less than one mile to about seven miles wide supplies water for irrigation and other purposes. Thickness of the saturated interval in the aquifer ranges to 85 feet or more, with the maximum thickness of saturation occurring in the central and southeastern part of the aquifer.

Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) Aquifer underlies the Edwards Plateau and extends westward into the Trans-Pecos region of Texas. The aquifer consists of water-saturated sand and sandstone of the Trinity Group and limestone of the overlying Fredericksburg and Washita Groups of Cretaceous age. These water-bearing units range to more than 800 feet in thickness. Large-capacity wells completed in fractured and cavernous limestone locally yield as much as 3,000 gpm.

The Edwards-Trinity (Plateau) Aquifer supplies small cities and communities of the area with water. Industrial supplies are also obtained from the aquifer locally, principally for petroleum recovery. Natural discharge of water from the aquifer constitutes a substantial part of the base flow of several streams, including the Pecos, Devils, Nueces, Frio, and Llano Rivers.

Water supplies of the Edwards-Trinity (Plateau) Aquifer have proved difficult to develop, however, because of the irregular distribution of permeability in the limestone beds and the variable thickness of the lowermost sand and sandstone beds. In heavily pumped areas, water levels have declined significantly. Sustained heavy pumpage over long periods would result in substantial depletion of the base flows of streams draining the plateau, thus reducing somewhat the surface-water supplies of these river basins, and recharge to the Balcones Fault Zone Aquifer.

Edwards (Balcones Fault Zone) Aquifer

The Edwards (Balcones Fault Zone) Aquifer extends from central Kinney County east and northeast into southern Bell County. It includes the Edwards Limestone and stratigraphically associated limestone beds of Cretaceous age. Conditions favorable for the development of extensive solution channels and cavities and the consequent accumulation of large volumes of water in these formations have resulted from faulting along the Balcones Fault Zone.

This aquifer supplies municipal and industrial water to numerous cities and towns, including the total municipal supply for the City of San Antonio. Capacities of wells operated by the city are among the largest in the world, some wells yielding over 16 thousand gallons per minute each. Industrial and irrigation water supplies are also pumped from the aquifer.

Some of the largest springs in the State result from the discharge of water from the aquifer. These include Leona Springs at Uvalde, San Pedro and San Antonio Springs in San Antonio, Comal Springs at New Braunfels, San Marcos Springs at San Marcos, Barton Springs at Austin, and Salado Springs at Salado.

The aquifer is recharged partly by precipitation on the recharge zone, storm runoff which enters the recharge zone, and streams which head in the Edwards Plateau. The West Nueces, Nueces, Frio, Sabinal, Medina, and Blanco Rivers and Seco, Hondo, and Cibolo Creeks, flow across the Balcones Fault Zone, losing water into the extensive fracture system of the aquifer. Water moves rapidly through the aquifer, and the volume of water in storage and the rate of springflow change rapidly in response to rainfall. For example, the depletion of water in storage resulting from continuous heavy pumpage during the drought years 1948-1956 was almost completely restored during the wet years 1957 and 1958.

Highly saline water, containing hydrogen sulfide gas, occurs in the Edwards and associated limestone beds south of the heavily pumped areas. The possibility of saline water intrusion and the necessity to maintain springflow at adequate levels for environmental and recreational purposes are constraints upon increased pumping from the aquifer, particularly during drought periods, as water needs increase.

Trinity Group Aquifer

The Trinity Group Aquifer extends over a large area of North and Central Texas. The thickness of the aquifer ranges from a few feet along its western edge to more than 1,200 feet in the eastern part. Yields of large-capacity wells range up to several thousand gpm. In thin sections of the aquifer, where water is withdrawn principally for irrigation and domestic use, most wells yield less than 100 gpm.

The Trinity Group Aquifer has been intensively developed for municipal and industrial water supply in the Dallas-Fort Worth area and formerly provided much of the municipal water supply for the City of Waco. In these heavily pumped areas, significant reduction in artesian head has occurred, thus lowering pumping levels and increasing pumping costs.

Carrizo-Wilcox Aquifer

The Carrizo-Wilcox Aquifer, one of the most extensive in Texas geographically, furnishes water to wells in a wide belt extending from the Rio Grande northeastward into Arkansas and Louisiana. The aquifer consists of hydrologically connected sand, sandstone, and gravel of the Wilcox Group and overlying Carrizo Formation.

The Carrizo-Wilcox Aquifer is recharged by precipitation and storm runoff on the outcrop areas and by streams which cross the outcrop area. The water-bearing beds dip beneath the land surface toward the Gulf, except in the East Texas structural basin where the formations form a trough and are exposed at the surface on both sides of the trough's axis. The net thickness of the aquifer ranges from a few feet in the outcrop to more than 3,000 feet downdip.

Water in the Carrizo-Wilcox Aquifer is generally under artesian pressure, and flowing wells are common in areas of low elevation. However, in heavily pumped irrigation areas, such as the Winter Garden area, and in municipal and industrial well fields, such as those north of Lufkin, water levels have declined and pumping costs have increased significantly.

Yields of wells vary widely, but yields of more than 1,000 gpm from large-capacity wells are common, and some wells yield as much as 3,000 gpm. Usable quality water occurs at greater depths (up to about 5,300 feet) than in any other aquifer in the State.

Water from the Carrizo-Wilcox Aquifer is used for irrigation in the Winter Garden area and for municipal and industrial use in Angelina and Nacogdoches Counties. The municipal and industrial use in these two counties has exceeded 20 million gallons of water per day.

Gulf Coast Aquifer

The Gulf Coast Aquifer underlies most of the Coastal Plain from the Lower Rio Grande Valley northeastward into Louisiana, extending about 100 miles inland from the Gulf. The aquifer consists of alternating clay, silt, sand, and gravel beds belonging to the Catahoula, Oakville, Lagarto, Goliad, Willis, Lissie, and Beaumont Formations, which collectively form a regional, hydrologically connected unit.

Fresh water occurs in the aquifer to depths of more than 3,000 feet, and large quantities of water are pumped for municipal, industrial, and irrigation use. In the Houston metropolitan area, from 300 to 350 million gallons is pumped daily for municipal and industrial use. Large-capacity wells yield as much as 4,500 gpm in this area. In the central and southern parts of the coast, the net thickness of water-bearing zones in the aquifer decreases, and yields of wells are somewhat less, although locally wells may yield as much as 3,000 gpm.

The aquifer is recharged by precipitation on the surface and seepage from streams crossing the outcrop area. The rate of natural recharge is estimated to be sufficient to sustain present levels of pumpage from the aquifer; however, in heavily developed areas withdrawals must be limited to quantities equal to local area recharge, otherwise the water table will be lowered further and additional subsidence will occur. In some areas where the aquifer is essentially undeveloped, substantial volumes of potential recharge are rejected. Problems related to withdrawal of water from the Gulf Coast Aquifer are: (a) land-surface subsidence, (b) increased chloride content in the water of the southwest portion of the aquifer, and (c) salt-water encroachment along the coast.

Minor Aquifers

The 16 minor aquifers in Texas are important and in some areas are the only sources of water supply. Minor aquifers are defined as those which yield large quantities of water in small areas or relatively small quantities of water in large areas of the State (Figure II-4).

Minor aquifers are the Woodbine, Queen City, Sparta, Edwards-Trinity (High Plains), Santa Rosa, Hickory, Ellenburger-San Saba, Marble Falls, Blaine, Igneous Rocks, Marathon, Bone Spring and Victorio Peak, Capitan, Rustler, Nacatoch, and Blossom. Bonham, Brady, Bryan, Burnet, Carrollton, Commerce, Crockett, Fredericksburg, Italy, and Kermit are examples of cities depending partially or entirely upon minor aquifers for a water supply.

Availability of Water

Current appraisals indicate that about 430 million acre-feet of ground water is recoverable from storage in the aquifers of Texas, using conventional water-well technology (Table II-1). Estimated average annual recharge to Texas aquifers is 5.3 million acre-feet. Annual ground-water use in recent years has ranged from 10.8 to 13.8 million acre-feet.

The quantities of water that can be obtained from each aquifer per unit time in the future, in this case average quantities per year, are the sum of average annual recharge and the quantities that can be withdrawn annually from storage. The former is determined by precipitation, aquifer characteristics, vegetative cover, and other factors. The latter, annual withdrawals from storage, are determined by annual demands for water, physical properties of each aquifer that affect water yield, the number and size of water wells, and the length of time wells are pumped. Projections of annual ground-water withdrawals from most aquifers for the period 1983 through 2029 were based upon estimates of annual water demands, recharge, projected demand for water in future years, and specific physical limitations of each aquifer (Table II-1). For the Gulf Coast Aquifer, pumpage estimates were limited to that quantity which could be withdrawn annually without unacceptable levels of subsidence. For the Edwards (Balcones Fault Zone) and most other aquifers, annual pumpage is estimated at the annual recharge rate (Table II-1). For the Ogallala, Bolson, and some alluvium aquifers of Western Texas, average annual recharge is quite low and average annual demand exceeds recharge manyfold. Thus, withdrawals to meet annual needs are from the stocks or reserves that have been accumulating in storage over long periods of time. The average annual rate of withdrawal can be varied widely, thus lengthening or shortening the period of time the aquifers can serve as a source of water supply in the future. The estimates of annual withdrawal from these aquifers are based upon data about the quantity of withdrawal in the recent past and projected future water demands in the local areas that they serve. It is emphasized that the annual quantities of ground-water supply that could be available from aquifers having water in storage can vary significantly from the estimates presented here, if water users' demands differ from those used as a basis for these computations; i.e., if annual overdraft is increased or decreased from that estimated herein. This, of course, can only be done until such aquifers are depleted, at which time the maximum average annual supply would be equal to average annual recharge.

Quality of Water

The quality of water in the major and minor aquifers of Texas varies according to location, type, and lithologies of the individual aquifers. In the eastern portion of the State usable-quality water generally occurs at greater depths than in other areas of Texas. Isolated aquifers, such as the High Plains (Ogallala), Edwards-Trinity (Plateau), and certain of the Alluvium aquifers, tend to have water which lies within a specific quality range. Aquifers that are overlain by successively younger formations contain water in which the amount of dissolved solids increases at greater depths. The chemical quality of ground water is largely dependent on the lithology of the aquifer; limestone aquifers contain water high in concentrations of calcium, magnesium, and bicarbonate; aquifers containing large amounts of gypsum contain water high in concentrations of calcium and sulfate; and in aquifers composed primarily of sand and gravel the quantity of dissolved solids generally is considerably less than in other types of aquifers.

The quality of ground water in some areas is thought to be threatened by disposal of wastes, in other areas by increases in mineralization as a result of recycling of irrigation return flows and seepage losses, and in some areas by saline water intrusion caused by modification of the natural hydrodynamics of aquifers as water is withdrawn.

Major Aquifers

The High Plains (Ogallala) Aquifer contains water generally ranging between 300 and 1,000 milligrams per liter (mg/l) of dissolved solids, of which calcium, magne-

Table II-1. Estimates of Ground-Water Supplies With Projections of Ground-Water Withdrawals, High Case, 1990-2030.

Aquifer	Approximate Annual Recharge	Approximate Quantity Recoverable From Storage As of 1980	Projected Average Annual Ground-Water Supplies (Annual Recharge and Storage Depletion)[1] 1990	2000	2010	2020	2030	Approximate Remaining Quantity Recoverable from Storage 2031
Major								
High Plains, (Ogallala)	438,900	385,480,700	6,543,400	8,219,500	7,659,800	6,015,000	4,575,600	152,512,900
Alluvium and Bolson Deposits	434,000	32,265,500	952,100	989,700	1,027,500	1,016,900	469,900	3,014,200
Edwards-Trinity (Plateau)	776,000	[6]	776,000	776,000	776,000	776,000	776,000	[6]
Edwards (Balcones Fault Zone)[2]	438,700[3]	[6]	438,700	438,700	438,700	438,700	438,700	[6]
Trinity Group	95,100	795,500	110,100	110,100	110,100	110,100	95,100	0
Carrizo-Wilcox	644,900	9,909,200	828,700	828,700	828,700	828,700	644,900	0
Gulf Coast	1,229,800[4]	[6]	1,229,800	1,229,800	1,229,800	1,229,800	1,229,800	[6]
Minor								
Woodbine	26,100	[6]	26,100	26,100	26,100	26,100	26,100	[6]
Queen City	682,100	[6]	682,100	682,100	682,100	682,100	682,100	[6]
Sparta	163,800	[6]	163,800	163,800	163,800	163,800	163,800	[6]
Edwards-Trinity (High Plains)[5]	—	886,000	—	—	—	—	—	886,000
Santa Rosa	23,500	[6]	23,500	23,500	23,500	23,500	23,500	[6]
Hickory Sandstone	52,600	[6]	52,600	52,600	52,600	52,600	52,600	[6]
Ellenburger-San Saba	29,400	[6]	29,400	29,400	29,400	29,400	29,400	[6]
Marble Falls Limestone	26,400	[6]	26,400	26,400	26,400	26,400	26,400	[6]
Blaine Gypsum	142,600	[6]	142,600	142,600	142,600	142,600	142,600	[6]
Igneous Rocks	10,700	[6]	10,700	10,700	10,700	10,700	10,700	[6]
Marathon Limestone	18,300	[6]	18,300	18,300	18,300	18,300	18,300	[6]
Bone Spring and Victorio Peak Limestones	17,000	[6]	17,000	17,000	17,000	17,000	17,000	[6]
Capitan Limestone	12,500	375,000	19,400	19,400	19,400	19,400	12,500	0
Rustler	4,000	[6]	4,000	4,000	4,000	4,000	4,000	[6]
Nacatoch Sand	1,500	[6]	1,500	1,500	1,500	1,500	1,500	[6]
Blossom Sand	700	[6]	700	700	700	700	700	[6]
Permian and Pennsylvanian (undivided)	2,400	[6]	2,400	2,400	2,400	2,400	2,400	[6]
TOTALS	5,271,000	429,711,900	12,099,300	13,813,000	13,291,100	11,635,700	9,443,600	156,413,100

SOURCE: Texas Department of Water Resources.

[1] Estimated withdrawals for the projected high case of water demands. Estimates shown here are annual rates of supply available at each decadal point in time. Estimates of annual supply rates for intervening years can be obtained by interpolating between decadal points.

[2] Includes San Antonio and Austin Regions.

[3] The estimate provides for spring flow at San Marcos Springs and protection against water quality deterioration.

[4] The estimate provides for minimum land-surface subsidence.

[5] Part of this aquifer's availability is included in the High Plains (Ogallala) Aquifer.

[6] Not determined due to lack of sufficient data.

sium, and bicarbonate are the principal constituents. The water is hard but suitable for most uses. Comparatively small, widely distributed areas of saline water occur, principally associated with large saline playas in the southeastern part of the South Plains where the water table is shallow. In these areas, solution of salt deposits and evaporation are largely responsible for the increase in the salinity of the ground water.

The Alluvium and Bolson Deposits Aquifer occurs in many parts of Texas with water quality varying correspondingly. In the Trans-Pecos area most of the water contains between 1,000 and 4,000 mg/l of dissolved solids. The quality of ground water in North Central Texas varies widely but generally ranges from less than 500 to more than 2,500 mg/l of dissolved solids. High concentrations of nitrate, which are considered to be undesirable for human consumption, occur in this area. Salinity of the ground water has increased in some of the heavily pumped areas. The chemical quality of water in the Brazos River alluvium varies widely, even within short distances, and in many areas concentrations of dissolved solids exceed 1,000 mg/l.

The Edwards-Trinity (Plateau) Aquifer contains water that varies widely in concentrations of dissolved solids. The water is generally hard with the principal dissolved solids being calcium, magnesium, and bicarbonate. The salinity of the ground water generally increases toward the west, where the aquifer is overlain by younger geologic formations.

The Edwards (Balcones Fault Zone) Aquifer contains water with an average dissolved solids concentration of about 300 mg/l. Toward the west, the water is generally somewhat more mineralized. The water contains calcium, magnesium, and bicarbonate, and consequently is hard. This aquifer is extremely sensitive to pollution in recharge areas due to lack of soil cover and almost immediate response to recharge.

The Trinity Group Aquifer's concentration of dissolved solids generally does not exceed 500 mg/l throughout its western extent. Toward the east, where the water-bearing zones become deeply buried, usable quality water occurs to depths of about 3,500 feet, and dissolved solids concentrations range from 500 mg/l to about 1,500 mg/l near the fresh-saline water interface. In some areas, improper well-completion methods and failure of well casings have allowed saline water in overlying beds to enter the fresh water-bearing zones.

The Carrizo-Wilcox Aquifer yields fresh to slightly saline water throughout most of its extent in Texas. Water in the deeper, heavily pumped areas of the aquifer contains sodium and bicarbonate and is, therefore, comparatively soft. However, hydrogen sulfide and methane gas occur locally, and iron, frequently in objectionable quantities, is common throughout much of the northeastern extent of the aquifer. Where geologic formations overlying the aquifer contain saline water, as in the Winter Garden area, improper water well completion practices, failure of well casings from corrosion, and decline in the artesian head have resulted in interformational leakage of saline water.

The Gulf Coast Aquifer generally yields water ranging from 500 to 1,500 mg/l dissolved solids. Throughout most of the eastern part of the aquifer the water is low in dissolved solids, generally containing less than 500 mg/l. Sodium and bicarbonate are commonly the principal constituents, and the water is comparatively soft. The presence of iron and dissolved gases and slight acidity of the water are local problems that frequently require appropriate pretreatment. Water generally is more saline in the southern part of the aquifer, and in some areas highly saline water overlies the fresh water and also underlies the aquifer at relatively shallow depth. In the Lower Rio Grande Valley, water pumped from the aquifer for irrigation and municipal use contains between 1,000 and 1,500 mg/l of dissolved solids.

Minor Aquifers

Minor aquifers contain some of the same minerals found in major aquifers, such as calcium, magnesium, bicarbonate, sodium, chloride, sulfate, nitrate, iron, and dissolved gases such as hydrogen sulfide. The Woodbine, Edwards-Trinity (High Plains), Ellenburger-San Saba, Marble Falls, Marathon, Bone Springs and Victorio Peak, Capitan, and Rustler are all limestone aquifers, containing water which is hard and high in calcium, magnesium, and bicarbonate minerals. Additionally, the Edwards-Trinity, Bone Springs and Victorio Peak, Capitan, and Rustler aquifers have high concentrations of chloride and sulfate ions in some areas.

The Woodbine, Queen City, Sparta, Santa Rosa, Hickory, Nacatoch, and Blossom are sandstone aquifers and contain chloride and sulfate ions. The Queen City and Hickory contain high concentrations of iron. Hydrogen sulfide gas is abundant in the Queen City Aquifer. Additionally, the Woodbine is generally high in concentrations of chloride and sulfate ions.

Water from the Blaine Aquifer is high in dissolved solids, chiefly calcium and sulfate.

Protection of Ground-Water Quality

Much of the ground-water resources in Texas is vulnerable to quality degradation from a variety of man's activities unless consideration is given to protecting it. To establish quality criteria, measures of chemical, physical, and bacterial constituents must be specified, as well as standard methods for reporting results of water analyses.

The Department assists the Railroad Commission of Texas by making recommendations to the oil and gas industry and the Commission for the protection of usable-quality ground water during the exploration for and production of oil, gas, and other minerals, as well as during the disposal of oil-field brine by injection into subsurface formations. Additionally, recommendations are made to the Railroad Commission for the protection of usable-quality ground water in surface mining and in-situ gasification operations regulated by the Commission.

The Department issues permits to regulate the disposal of municipal, industrial, and mining wastes by underground injection to protect the quality of ground and surface water. The agency also regulates sulfur and salt solution mining, as well as uranium leach mining operations. The Water Well Drillers Board is provided administrative, technical, and legal assistance by the Department. This is accomplished by maintaining records of licensed water-well drillers, conducting investigations of alleged violations of the Texas Water Well Drillers Act, and making recommendations for the proper plugging of abandoned water wells. The Department makes investigations of alleged ground-water contamination or conditions which might cause or threaten to cause deterioration of the quality of underground water in the State. A statewide ground water quality monitoring network is maintained in which standard chemical analyses are made periodically to determine changes in quality.

Surface Water

State waters are defined by Texas water law as the ordinary flow, underflow, and tides of every flowing river, natural stream, and lake; and of every bay or arm of the Gulf of Mexico; and the storm-water, floodwater, and rainwater of every river, natural stream, canyon, ravine, depression, and watershed in the State. For the purposes of water planning and administration, surface-water resources are considered to include the waters flowing in Texas streams, as well as those waters in interstate streams which are allocated to Texas under interstate compacts and international treaties.

River Basins

Texas has 15 river basins and 8 coastal basins. Each basin is designated as a planning area for purposes of calculating in-basin water supplies and for projections of in-basin water requirements for the 50-year foreseeable future. Also, since Texas river basins cross climatic zones as they traverse the State in a northwest to southeasterly direction, the individual basins are further subdivided into 43 relatively homogeneous zones (Figure II-5).

Reservoirs

There are 184 major reservoirs in Texas, each with a capacity of 5,000 acre-feet or greater. In addition, 5 reservoirs are under construction and when completed will bring the total number of reservoirs to 189. Of this total, 148 or 80 percent will have been developed without federal funds. Conservation storage in the 189 reservoirs is estimated to be about 32.3 million acre-feet of water (includes only Texas share of interstate and international reservoirs), with an additional 17.5 million acre-feet of flood control storage (see Part III). However, the estimated dependable water supply in year 2,000 from the State's major water supply reservoirs is about 11 million acre-feet annually. This volume represents the maximum safe yield which can be withdrawn each year through an extended drought.

Hydrology

Atmospheric moisture precipitates to earth in the form of rain, sleet, or snow. Upon reaching ground surface, the precipitation can evaporate back to the atmosphere, penetrate the soil layers of the root zone where plants capture it for use and through transpiration return it to the atmosphere, penetrate the soil layers to the water table and become part of the ground waters, or run off the land surface into watershed drainages which contribute to streamflows. Thus, the surface waters of Texas are primarily derived from direct rainfall runoff, plus spring flows emanating from the State's aquifers.

The runoff from rainfall has averaged 52 million acre-feet per year in Texas over the 1941 through 1980 historical period, but was only 23 million acre-feet annually during the 1950 through 1956 drought interval. Approximately 50 percent of the total Texas runoff originates in the eastern quarter of the State where the average runoff rate is about 650 acre-feet per square mile. Runoff rate decreases across the State to near zero in large areas of West Texas, and, about 16 percent of the total runoff in Texas is in the coastal areas, where the possibilities for capture and use are limited because reservoir sites are generally not available in this topographically flat region. However, the runoff contributes freshwater inflows to Texas bays and estuaries which are essential to the production of fish and shellfish.

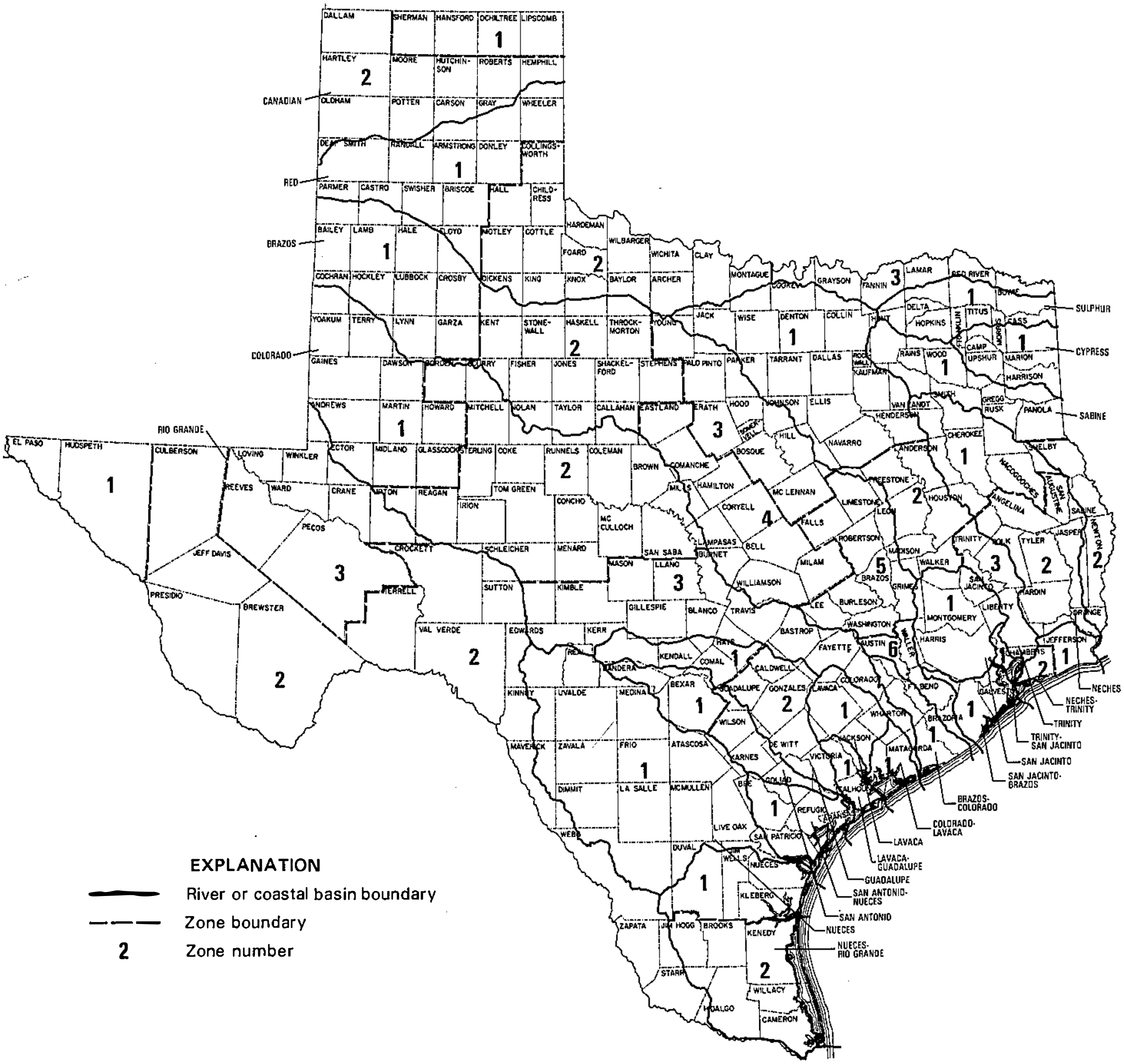


Figure II-5. River and Coastal Basins and Zones

Availability of Water

Since Texas streamflows are highly variable, and in some cases are intermittent, the requirement for dependable water supplies has necessitated the construction of reservoirs to capture and store a portion of the normal and flood flows. The quantity of water continuously available from each reservoir is referred to as the "firm yield." The firm yield of a reservoir is defined as the quantity of water that can be annually withdrawn or released from the impoundment over a period of time which spans the length of the most severe drought recorded in the catchment area. The firm yield depends on inflows to the reservoir, capacity and shape of the reservoir, evaporation and seepage, and any required outflows from the impoundment.

Firm yields of existing and potential reservoirs in each river basin are computed in an upstream to downstream order. Each reservoir in the basin is assumed to be operated over the critical drought period so as to maximize the capture of runoff from the watershed. Water spilled from upstream impoundments and return flows from upstream water users are included in the water available for downstream storage. In this way, flow depletions resulting from upstream land-use activities and instream construction of reservoir and floodwater retention structures can be considered in calculating the availability of future downstream flows.

An increasingly important component of the State waters is return flow from nonconsumptive water uses. Return flows generally originate as wastewater discharges or treated effluents from municipal, industrial, and agricultural water users. Return flow projections are essential to both determining water availability and evaluating wastewater reuse potentials. In addition, the location or spatial distribution of return flows throughout the State can have a significant impact on the future availability of surface waters in some zones of Texas river basins. Therefore, total consumptive use or reuse of State waters in some zones may not be desirable because of the resultant flow depletions in other zones.

Sedimentation

Texas streams can carry large volumes of sediment produced by erosion in the contributing watersheds, particularly during heavy rainfall and flood events. Some of this sediment is trapped in the first downstream reservoir, gradually reducing its storage capacity. Currently, storage volume for an estimated 100 years of sediment is included in the design of new reservoirs. However, it is though that improvement in overall river basin development can be realized by construction of sediment catchment basins above major water supply reservoirs, as well as by river channel stabilization, improvement in grass cover on rangelands, reforestation, and increased use of other soil conservation techniques in the contributing watersheds. Information about sediment loadings to the watercourses is useful for planning land conservation measures, designing instream structures, and analyzing the transport and deposition of some pollutants and toxic materials.

Quality of Water

The physical, chemical, and biological characteristics of water define its quality. Although there has been rapid population growth (three million people between 1970 and 1980), accompanied by increased water use in Texas, the quality of the State's surface waters has improved significantly. Much of this improvement is directly related to the Texas Water Quality Management Program and advances in wastewater treatment by industries and municipalities. The fact that these improvements have been accompanied by water-dependent State growth demonstrates that rising levels of water quality and economic activity are occurring simultaneously in Texas.

Water Quality Management Programs

The Texas Water Quality Management Program is designed to provide long-range direction and planning for the protection and improvement of the State's surface-water quality. In practice, the program is organized into seven basic components: (1) assessment of water quality problems, (2) inventory of stream water quality, (3) development of a multi-year management strategy, (4) development of detailed local and statewide work plans, (5) implementation of the work plans, (6) evaluation of progress, and (7) reassessment of the water quality program.

An important part of the water quality program involves the State's management strategy, which includes environmental goals for the next three to five years, identification of priority water quality problem areas, cost estimates for control of the problems, identification of responsible entities, and a summary of anticipated funding from federal and State sources. A major emphasis of the strategy is on solving specific water quality problems in specific locations, consistent with current State laws and applicable national laws such as the Federal Clean Water Act. Also, the Texas Department of Water Resources funds projects with water quality management and construction grants and loans that control pollution and contribute to the solution of priority problems identified in the State's strategy.

Texas water quality standards have been established for maintenance of the quality of surface waters, and as goals for water quality management under State laws and policies. These standards contain two parts: (1) general criteria applicable to all surface waters, and (2) explicit numerical criteria for water quality parameters that are applicable to specified surface waters for maintenance of identified desirable water uses. The standards pertain to water quality degradation attributable to man's activities, and not that which is related to natural phenomena. The concentrations of many dissolved and suspended surface water quality constituents are largely the result of natural geographic variations in precipitation, evaporation, geology, vegetation, and the quality of spring flows from the State's aquifers.

The general criteria apply limitations on taste and odor producing substances, radioactive materials, oil, grease, and related residues, and against conditions whereby floating debris, suspended solids, turbidity, toxic materials, nutrient concentrations, or water temperatures that would adversely affect biological species or man's use of the waters. However, the numerical criteria establish exact quantitative limits on water quality parameters such as temperature, pH (acidity), dissolved oxygen, chloride, sulfate, total dissolved solids (salts), and fecal coliform bacteria. The numerical criteria are applied to specific surface-water areas on the basis of possible uses which are deemed desirable. These uses include contact recreation, noncontact recreation, propagation of fish and wildlife, and domestic raw water supply. For example, surface-water streams and pools suitable for contact recreation, such as swimming, are not to have a logarithmic mean fecal coliform count that exceeds 200 bacteria per 100 milliliters of water; whereas, noncontact recreation waters should not exceed an average logarithmic mean fecal coliform content of 2,000 per 100 milliliters.

Another important part of the State's water quality program involves designation of Texas stream segments and the inventory of water quality in these segments on at least a biennial basis. For water quality management purposes, the 23 river and coastal basins of the State have been divided into 311 stream and coastal segments with a total 16,115 stream miles. The Texas Department of Water Resources has determined that 244 of the 311 segments comply with the applicable stream standards, or are projected to be in compliance following implementation of best practicable wastewater treatment plans by industries and municipalities (Plate 2). These segments are classified as effluent limited. However, the remaining, noncompliant segments are classified as water quality limited, because monitoring data indicate that violations of the applicable State water quality standards continue to occur or they have been placed under special Board order for more stringent treatment requirements.

The purpose of the stream segment inventory is to evaluate water quality conditions, trends, and projections of the State's surface waters, to determine whether: (1) the water quality is adequate to provide for the protection and propagation of balanced populations of fish and wildlife; (2) the water quality is suitable to allow recreation in and on the water; (3) this level of water quality can be expected by 1984; or (4) the desired water quality level can be reasonably attained at some later date. The inventory also includes an assessment of nonpoint source pollution problems and useful information on ground-water use, availability, quality, and activities which may be impacting this water resource. Basically, the inventory provides a means by which the State can assess the effectiveness of the water quality management program and develop recommendations for changes in the federally approved program. The inventory is also used in preparing state-federal water quality reports in cooperation with the U.S. Environmental Protection Agency under the Federal Clean Water Act.

As an adjunct to the State's Water Quality Management Program, waste load allocation studies are performed on each of the water quality limited segments to determine stream assimilative capacity. Another object of the studies is to determine the theoretical treatment level each discharger in a particular segment would be required to provide, in order for that segment to be brought into compliance with the State's stream standards. In addition, the waste load evaluations provide a basis for discharge permit parameters. The waste load allocations require updating and continuous study in order to assure that they remain viable and adequately serve the State's water quality management program.

Waste Discharge Programs

An essential part of the State's water quality management program involves the establishment of effluent standards for wastewaters and the issuance of waste discharge permits. Also, any activity which results in a waste discharge into the State's navigable waters requires that Texas certify to the U.S. Environmental Agency (EPA) that the discharge complies with all applicable provisions of Federal Clean Water legislation. This allows EPA to issue a National Pollutant Discharge Elimination System (NPDES) permit concurrent with the State's waste discharge permit. The Department of Water Resources has promulgated a set of effluent quality standards, required under the federal law, which are consistent with treatment classes and are necessary to meet required treatment levels. Also, specific water quality protection plans are being developed for Texas surface waters that include wastewater treatment requirements and other water quality management methods, based on information the State has collected concerning both point and nonpoint pollution sources in Texas.

In addition, Texas has initiated a Hazardous Waste Management Program that satisfies both State requirements, under the Texas Solid Waste Disposal Act, and national requirements of the Federal Resource Conservation and Recovery Act. Since federal law allows a state program to be implemented in lieu of a federal program, the Texas program is being implemented and operated by the Texas Department of Water Resources and the Texas Department of Health, with financial assistance and oversight from the U.S. Environmental Protection Agency.

Methods to Extend and to Increase Water Supplies

Additional quantities of both surface and ground water can be made available through the use of one or more existing technical and management practices. Increased water use efficiency in agriculture and industry, reduced per capita use of municipal and commercial supplies, and reduction of leakage and other forms of waste can allow existing supplies to meet the needs of a larger number of people and support larger levels of industry and agriculture. In cases where ground-water supplies are declining, water conservation can allow existing levels of water-using activities to be continued for longer periods of time than will otherwise be possible. Through more effective water conservation, present water supplies could be extended to meet some of the water supply needs of the State's growing economy. However, it is clear that water conservation cannot meet all of the growing needs for water. Thus, it will be necessary to increase the use of ground water, where this is possible, to develop additional surface water where possible, to continue the research and development of desalting and weather modification technologies, with a view toward using these methods to increase water supplies in some areas, and to consider importing water from outside the State. Each of these water management and potential water development methods are described and explained below.

Water Conservation by Individuals

Due to the fact that supplies of surface and ground water are limited in some parts of the State, demands for water are increasing, and costs of securing new supplies are rising, it is necessary for individuals to practice water conservation. In this sense, water conservation means the efficient use of water and the reduction of waste. Thus, conservation involves the use of technologies and practices to reduce per capita water use by people and quantity of water used per unit of products produced by industry and agriculture. Water conservation methods include widespread distribution of conservation information to the public, water pricing policies that encourage conservation, and the organization and operation of local area water conservation districts.

Municipal and Commercial Water Conservation

Many water conservation measures are available to reduce the quantities of water used in residential, commercial, and institutional purposes for drinking, bathing, cooking, toilet flushing, lawn watering, fire protection, swimming pools, and sanitation.

For residential water use, most water is used in the bathroom and for exterior purposes such as watering lawns and shrubbery and washing cars. While exterior water use can be reduced significantly with the use of native vegetation, in-home water use can be reduced as much as 35 percent using presently available technology. These residential conservation measures include the repair of plumbing to stop leakages, the use of low-flow shower heads, low-flush and dual flush toilets, faucet aerators and spray taps, efficient lawn watering equipment, and water-efficient landscaping. City ordinances that govern plumbing codes, lot sizes, drainage grades and slopes, and landscaping can also be used to influence the quantities of water used within a city.

Many of the water conservation techniques and practices mentioned above can also reduce water use for commercial establishments, such as office buildings and other places of work. These practices are also somewhat effective for those establishments using large quantities of water such as cafeterias, restaurants, laundries, and car washes. However, effective conservation in these types of establishments requires careful controls of water-using equipment and may require modification of production processes.

Public education and information are needed in order to change habits and behavior of the water-using public, thereby reducing waste and encouraging the use of equipment that is more water efficient. Examples of these conservation measures include shutting off faucets when shaving or brushing teeth, using dishwashers and clothes washers for only full loads, and watering lawns in the mornings or evenings to reduce losses from evaporation. Some water-efficient appliances such as dishwashers, clothes washers, low-flow shower heads, and devices to reduce the quantity of water required for toilets are available at minimal additional costs.

Industrial Water Conservation

Water conservation is being practiced by many of Texas' major water-using industries to reduce energy and water costs. Generally, water for cooling or for processing operations accounts for the large majority of industrial water use.

The quantity of freshwater used for cooling can be reduced through the substitution of air cooling devices for those requiring water or the use of saline or brackish water in place of freshwater. Furthermore, processes can be altered to reduce waste heat or apply it to other purposes to conserve energy as well as water. In addition, municipal and commercial sewage effluent can be substituted in some areas for some freshwater used for cooling. However, reuse of treated effluent by industry is somewhat limited, since a proportion of this water may be required for downstream water rights, instream flow needs, and maintenance of bays and estuaries.

Agricultural Water Conservation

Declining ground-water supplies, rising costs of pumping, and limited supplies of surface water are requiring that water conservation practices be applied within irrigated agriculture. The purposes of agricultural water conservation are to allow existing, but exhaustible, ground-water reserves to support present irrigated acreages for longer periods of time in the future, to reduce costs of production, and to the extent possible to allow growth of irrigation in future decades in order to meet growing market demands for food and fiber.

Water savings can be realized by using pipelines and concrete linings of ditches to eliminate seepage and evaporation losses common with earthen irrigation ditches. Significant reductions in water use can be achieved with the use of efficient irrigation systems; the efficiency depends on an even application of water at the proper rate and time. While sprinkler systems are more efficient than gravity application methods, drip and trickle irrigation or subirrigation reduce water use appreciably. Sprinkler systems average 70 percent efficiency, although wind is a major consideration in obtaining higher efficiency. Drip or trickle irrigation applies water to the base or root zone of each plant, using plastic tubes with small outlets near the plant. Water use is reduced because water is applied in smaller quantities, and runoff and evaporation from wet soils are eliminated. Subirrigation involves the use of perforated, small-diameter plastic pipe that is buried beneath each crop row. Like drip or trickle irrigation, subirrigation has higher capital costs than sprinkler or gravity systems.

The timeliness of water application is equally important with respect to reducing water use. Some crops can be grown under controlled stress during certain stages of growth without adversely affecting yields. Since water is applied only at critical stages, water use is reduced.

Several other conservation practices include row dams to hold water in the furrows of row crops, stubble mulch tillage, minimum tillage, and no-till planting to keep plant residue on the surface of the soil in order to reduce erosion, increase infiltration, and reduce evaporation loss. Narrow row spacing of crops and careful timing of planting dates can also reduce water use. In addition, improved varieties of plants, requiring less water and resistant to disease, are becoming available. Crops that require less water can be substituted for those having greater water requirements, when market conditions and production costs are favorable. Satisfactory weed and brush control can also reduce water use. Water is lost to plants having little or no economic value such as mesquite, saltcedar, cottonwood, and willow.

Water Reuse and Recycling

Limited water supplies and pollution control laws that require better quality wastewater discharges are encouraging the reuse and recycling of water in place of additional freshwater supplies. While recycling involves recirculating relatively clean water in internal processes, reuse concerns the further use of wastewater from external or other sources.

Currently, recycling is a common practice in all process industries in Texas. For example, in the pulp and paper industry, water is used without additional treatment for different stages in processing. Wastewater reuse is most evident in the use of treated sewage effluent for irrigation and cooling electric power generators. However, because the discharges used for reuse add to the water supply for downstream users, there are some limitations on the widespread application of wastewater reuse.

Water Pricing

It has been suggested that by increasing the price of water, the quantity used would decrease, and thus the development of new supplies could be delayed or eliminated altogether. While increased price has resulted in a reduction in the quantity of various goods and services purchased in normal markets, it is not known to what extent water prices would have to be increased in order to accomplish a given level of reduction in water use in Texas.

In the past, surface water has been available to municipal customers at a price equivalent to the amortized cost of facility construction plus the costs of maintaining and operating water supply systems; that is, water has been priced at the cost of production. In the case of water supply from ground-water sources, the cost to customers also includes a component to repay costs that have been incurred to secure water rights. However, pricing policies vary among systems. Most systems charge a fixed price per month for a given quantity of water with a declining price for additional quantities, while for others, a price is charged for a minimum quantity with an increasing rate for additional quantities. The latter policy also has been used to discourage water use during peak demand, usually during summer months. Thus, several pricing options are available to individual system operators, if price is to be chosen as a local area conservation tool.

Conservation Institutions

In Texas, some local water resources associations were organized as a mechanism for the efficient use, development, protection, and management of surface- and ground-water resources. These include underground water conservation districts, whose purpose is to prevent waste, protect the quality, and conserve or save ground-water supplies. This is accomplished primarily through regulating the spacing of wells within the district boundaries, by enjoining wasteful water management practices such as allowing water to flow into roadside drainage ditches, by promoting the use of tailwater recovery pits, and by public education programs about water construction methods. Ground-water pumping is currently regulated through a permit system in the Harris-Galveston Coastal Subsidence District to prevent or control land subsidence. Similarly, there are surface water conservation districts, river authorities, and water supply districts that act to store floodwaters and convert these to water supplies. The State Soil and Water Conservation Board administers local Soil and Water Conservation Districts and associated soil and water conservation programs and water quality protection planning for some rural areas. Organizations such as these are expected to have a major role in conserving water supplies in many areas of the State in the future.

Conservation Management Methods

In some areas of the State long-term water supplies can be increased through the joint use of ground- and surface-water supplies. In parts of South Texas and in West Texas, where precipitation is light and surface-water supplies are extremely limited, ground water has been developed and with continued use will ultimately be exhausted. In Gulf coast areas ground-water development and use has lowered water tables and resulted in subsidence. In both types of environments, the development and use of supplemental surface-water supplies can serve to reduce the severity of declining ground-water supplies. In the latter case, average annual recharge to aquifers can be withdrawn in future years without further subsidence, but additional supplies of water to meet growing needs should be obtained from surface-water sources. In the case of arid regions where ground water is being mined and will ultimately be exhausted, surface-water reservoirs can be used to supplement local area supplies, particularly for municipal and industrial purposes. Even though such projects may have very low quantities of dependable supplies, the average supplies are greater and can be drawn upon to meet a part or all of the water supply needed for short periods of time, leaving ground water in storage for later use. In the traditional sense of yield of reservoirs, such projects would be overdrafted in the short run in order to use the water before evaporation returned it to the atmosphere. By using such projects in this manner, exhaustible ground-watersupplies would be saved for later use. Several cities in West Texas could benefit from this type of water management. Projects are being planned on the basis of this principal.

The use of treated municipal wastewater for some industrial purposes and for agriculture reduces the demand for water from original sources, and in effect, is a water conservation tool. Recharging aquifers with highly treated effluent can increase the effective supply of water is some areas. This practice is being adopted by El Paso.

In addition to water management methods mentioned above, the system operation of reservoirs within a basin, and the system operation of neighboring basins can increase the yields of such basins. Using the principals of system operation, downstream reservoirs are overdrafted to meet downstream needs. Water is retained in storage in the upstream reservoirs and released for downstream use after other downstream supplies have been depleted. In this manner, downstream reservoirs will have more vacant conservation volume in which to capture and store flows than would otherwise be possible. Likewise, if conveyance facilities are developed between neighboring basins, floodwaters can perhaps be moved into vacant conservation storage in neighboring basins and thereby increase water supply yields.

Water Supply Development

The construction of dams and reservoirs and the development and use of ground-waterresources have been and continue to be the primary methods of increasing water supplies. Although water conservation is a viable method to extend watersupplies, the development of additional sources will be required to ensure adequate future water supplies for the State. Each method is described briefly below.

Surface-Water Development

About 64 percent of the dependable yield of Texas reservoirs is being used to meet current needs; the remainder is committed for expanding municipal and industrial needs of the next 20 to 30 years in areas which can be served by these supplies. However, these supplies will not meet the projected future needs within their respective locations, with a few exceptions, and of course cannot meet all future needs in neighboring and more distant locations. A part of projected future needs of some basins can be met if additional reservoir sites within these basins and in nearby basins are developed. Reservoir sites have been identified, and the time of need for water supply from each site and costs of developing each site have been estimated. These estimates are shown in Part III.

Development of Texas' remaining 65 major reservoir sites will add about 4.3 million acre-feet of dependable water supply and 1.0 million acre-feet of water yield from recapturable, treated wastewater return flows. However, parts of sites suitable for reservoirs are being converted to other uses that would conflict with future water development. Some sites have significant quantities of lignite which must be mined before reservoir development can proceed. Some sites have environmental concerns which must be resolved.

Ground-Water Development

Ground water is presently providing 61 percent or 10.9 million acre-feet of water each year in the State. In 1980, the estimated total quantity of water that could be recovered from storage in both major and minor aquifers across the State was approximately 430 million acre-feet. Like surface-water supplies, ground-water resources are unevenly distributed and recharged at unequal rates. For example, the High Plains (Ogallala) Aquifer in the High Plains region contains about 89 percent of the State's ground water, but receives only eight percent of the estimated annual recharge of the State's major aquifers (Table II-1).

The continued long-term development and use of ground water is limited by the fact that more ground water is being removed in many areas of the State than is being replaced by natural recharge. In these areas, the resource is being mined, while in some other areas of the State, the ground water resources are not completely developed. It is expected, however, that ground water will continue to be an important source of water in the future.

Ground-water resources include not only the water itself, but also the storage capacity of aquifers and the capability of aquifers to transmit water from areas of recharge to points of withdrawal. Since some aquifers can be artificially recharged through the use of recharge dams and injection wells, some additional water supply development is possible. Where these conditions do not exist, the continued use and development of ground water requires programs of conservation to extend ground-water supplies. However, it is emphasized that in many areas now using ground water the reserves will ultimately be exhausted, even though more aggressive water conservation programs are carried out. In other areas ground water can continue to be an important part of the long-range supply. Specific estimates are given in Part III.

Desalting

The conversion of brackish and saline water resources to potable water can produce new sources of freshwater. Desalting is a process by which this saline and brackish water is converted to freshwater by the removal of dissolved salts, other inorganic materials and particulates, as well as viruses and bacteria. These processes include distillation, electrodialysis, and reverse osmosis. In distillation, freshwater is condensed from water vapor produced from heating saline water, while electrodialysis is an electrically accelerated process that separates salts from saline water through a membrane. In reverse osmosis, freshwater is produced from a saline solution by pumping the solution through a membrane filter under pressure.

Recent research and development have reduced the costs of converting saline water to freshwater so that such conversion is currently being used commercially for municipal and industrial supplies at approximately 650 locations in the United States and 1,600 locations in other countries. Today, there are 71 desalting plants in Texas producing about 52 acre-feet of water per day for municipal and industrial purposes. Of these, the majority is for industrial purposes followed by those producing boiler feedwater for electric power generation. Seven plants produce about 2.5 acre-feet of water per day for municipal use in Dell City and several suburban areas.

In some parts of Texas desalting may prove to be the most economical and feasible means to supplement municipal water supplies or to comply with federal drinking water standards. This could include the use of brackish and saline ground and surface water as well as seawater and is applicable in much of the Panhandle, West and Western

Central Texas, the Lower Rio Grande Valley, and along the coast. Nevertheless, some constraints do exist to its widespread use. Because desalting is an energy-intensive process, the costs of energy may be a limitation. Furthermore, one of the important considerations of a desalting system is the disposal of waste brine, since this increases the costs of the project.

Weather Modification

Efforts to artificially induce or modify precipitation with the use of silver iodide, frozen carbon dioxide, and other means may be a potential way to increase water supplies in the future. Although weather modification includes techniques to increase rain or snow, suppress hail, dissipate fog, and to mollify severe storms; in Texas, weather modification has involved the seeding of clouds to increase rainfall. While a number of independent research projects indicate that rainfall can be increased as much as 10 to 50 percent in the western United States, in the target area of a cloud-seeding project conducted in West Texas during the 1970's, approximately 28 percent more rain was reported than was observed in neighboring areas in the same years. Although promising, these techniques are not yet proven, and additional research is required in order to appropriately consider weather modification as a viable method to increase water supplies. If weather modification is developed into a viable water supply tool, it will be necessary to also develop legal and institutional arrangements for its administration.

Importation

Water supplies of several areas of the State are insufficient to meet projected long-term needs. Rapid metropolitan growth in Houston has resulted in the development of surface water to supplement and replace ground-water use. Agriculture and municipalities in the Winter Garden area are competing with San Antonio for water from the Edwards Aquifer. In addition, areas in East Texas will require more water to meet population growth and to support the production of lignite, while ground-water mining for municipalities and agriculture in the High Plains is depleting the Ogallala Aquifer. El Paso and other areas within the Rio Grande Basin will also need water from other sources. To meet the expanding water needs of the State, it is important to consider all alternatives to supplement these diminishing supplies, including the importation of surplus water from outside the State. Efforts are being continued to locate excess supplies, to evaluate the feasibility and costs of transporting water into the State, and to provide arrangements that are mutually beneficial to Texas and the areas from which water might be imported.

PROJECTING FUTURE WATER DEMANDS

In this section, each major water-using purpose is identified, defined, and explained, and a brief explanation is given of the methods, procedures, data, and assumptions used in making projections of future water demands for each purpose. The major water-using purposes are: municipal and commercial, industrial, steam-electric power, agriculture, mining, hydroelectric power, navigation, bays and estuaries, instream flows, parks and fish hatcheries, and public recreation. Projections of future demands for each purpose are presented in Part III for each zone of each river basin within the State, for each decade from 1980 to 2030. Projections are made for two different rates of growth, referred to in the discussion as "low" and "high."

Municipal and Commercial Water Demand

With the exception of some light manufacturing operations, the municipal and commercial water use category contains the quantity of water used by business establishments, public offices and institutions (except municipally-owned steam-electric generating plants), private residences and the maintenance of their grounds, fire protection, and other users supplied from municipal systems. Light manufacturing water use is counted in the municipal category, in distinction to the industrial use category, since the characteristics of water use—drinking, sanitation, air-conditioning—in these manufacturing firms more closely compare to the characteristics of municipal use than to the characteristics of industrial use. Of the 17.9 million acre-feet of water used in Texas in 1980, municipal and commercial use accounted for 15.6 percent or 2.8 million acre-feet.

Future municipal and commercial requirements are based upon population projections and per capita water use data. Projections of population were made for each Texas county by decade to the year 2030. Within the constraint of the overall county projections, the future population of cities and towns located within counties was also projected, along with that portion of each county's population residing in rural areas. The county, city, and rural-area projections were grouped into their respective zones and river basins in order to be able to project water demands for each of these water resource areas. State projections of population are the sum of the 254 individual county projections.

Two sets of population projections were made: one, the high case, uses vital statistics from each Texas county and net migration data of the 1970's, and a low case is based on the same vital statistics data but with net migration characteristics that reflect migration patterns of the

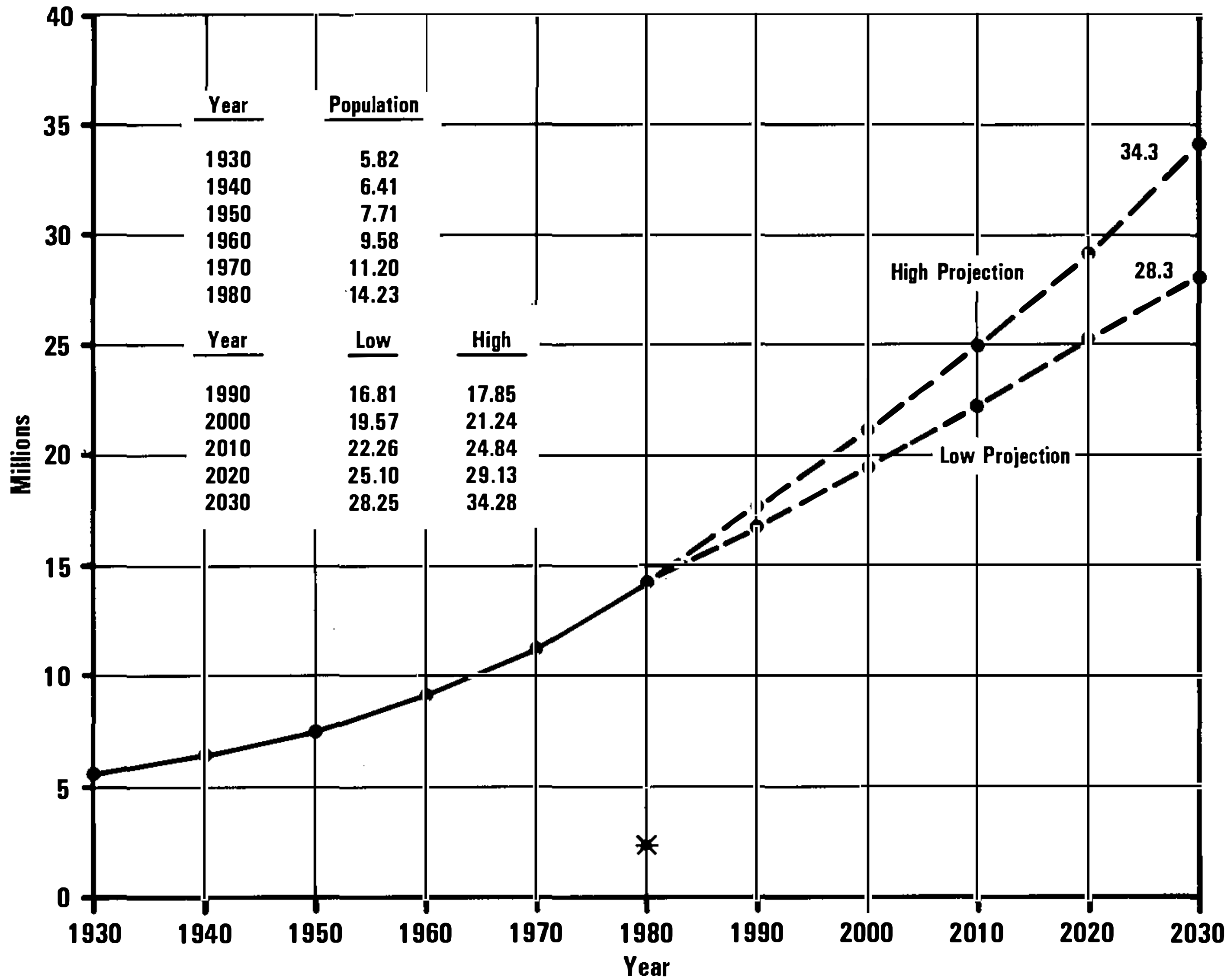


Figure II-6. Texas Population, With High and Low Projections to 2030

past three decades (1950-1980), which has the effect of reducing the influence of the very high rate of immigration into Texas in the latter portion of the decade of the 1970's.

In the high set of projections, the State population total is over 21 million by 2000, increasing to 29.1 million by 2020, and to over 34 million by 2030 (Figure II-6 and Table II-2). The slowing of the growth rate after 1990 reflects anticipated changes in fertility, migration, and economic variables which affect population changes. Texas growth is projected to continue to outpace almost all other states, however, with a doubling of present population by about the year 2020.

The low set of projections has a slower rate of growth over its entire range with the State population increasing from 14.2 million in 1980 to 28.3 million in 2030. Under the conditions of this set of projections, the population of Texas in the year 2000 is estimated at 19.6 million persons.

Per capita use of water is projected for each city and each county, based on water use data reported by the municipal and commercial suppliers within each county. Thus, the climatological, economic, and other factors affecting water use for municipal purposes in the different areas of the State are taken into account within the respective water use reports.

Although per capita water use for individual cities differs from the State average of all cities, the long-term average daily per capita water use in Texas cities has been

Table II-2. Texas Population with Low and High Projections to 2030.

Year	Low Case Population (millions)	Low Case Rate of Growth (percent)*	High Case Population (millions)	High Case Rate of Growth (percent)*
1930	5.8	—	5.8	—
1940	6.4	10.3	6.4	10.3
1950	7.7	20.3	7.7	20.3
1960	9.6	24.7	9.6	24.7
1970	11.2	16.7	11.2	16.7
1980	14.2	26.8	14.2	26.8
1990	16.8	18.3	17.8	25.4
2000	19.6	16.7	21.2	19.1
2010	22.3	13.8	24.8	17.0
2020	25.1	12.6	29.1	17.3
2030	28.3	12.7	34.3	17.9

SOURCE: U.S. Bureau of the Census with projections by the Texas Department of Water Resources. * Rate is per 10 years.

increasing at about four gallons per person per decade since the early 1960's. In 1960, per capita water use in Texas was reported at 128 gallons per day. In 1974, per capita water use was 144 gallons per day, and in 1980 was 176 gallons per day. Average per capita water use is projected to be 156 gallons per day in 1990 and 160, per day in 2000.[1]

For planning purposes, municipal system water requirements were projected for two cases of future population and two different per capita use rates—low and high population projections and average and drought condition per capita water use rates, with the estimated potential effects of water conservation factored into each case. Projections were made for individual cities and for rural areas of each county (Appendix A).

The differences between the low and high population projections for each city are due to projected differences in net immigration to each city. The low projection is based on average net immigration rates for the decades of the 1950's, 1960's, and 1970's. The high population projection is obtained by using the same immigration data, but without dampening or reducing the high rates of the late 1970's, as is done when making the low projections.

[1]Actual per capita municipal water use in 1980 is higher than projected average per capita use in 1990 and 2000 due to extremely hot, dry weather conditions throughout most of Texas during the summer of 1980. Measured against the long-term trend, actual useage in 1980 was about 20 percent higher. In contrast, 1960 was an exceptionally cool, wet year.

The differences between the average and drought condition per capita water use rates are due to expected differences in water use between normal and drought seasons. The per capita water use in a city during years of normal precipitation is best estimated by the average per capita water use computed from water use reports for such years. However, during drought years per capita water use increases because temperatures are higher, causing a higher water demand by all water-using functions, and during droughts the lack of precipitation causes water users to have to obtain more water from storage than would otherwise be necessary. Thus, municipal water systems must be prepared to meet average condition demands at all times, and must also be prepared to either meet drought condition demands or to ration water during drought periods. Managers of each system are free to decide whether or not to try to meet drought condition demands. Obviously, a larger quantity of water will be needed than is needed for average weather and climate conditions. Information from Texas municipal water systems indicates that during drought years per capita water use is greater than during average years by a quantity which is approximated by two standard deviations above average per capita use. Thus, for planning purposes the drought condition per capita water use statistic is chosen to be the average per capita water use plus the estimate of two standard deviations of State municipal water use.

The high set of projected municipal water requirements is obtained by using the high set of population projections and drought condition per capita water requirements, with per capita use held constant in 2010, 2020, and 2030 at the per capita drought rate projected for 2000. This projected flattening of the per capita rate after the year 2000 would be a result of water conservation. The low set of projected water requirements is based on the low population projections and average climatic conditions, with per capita use held constant in 2010, 2020, and 2030 at the per capita rate for average conditions in 2000.

The potential effects of conservation practices on municipal and commercial water use, mentioned above and discussed in more detail in Part IV, play an important role in determining the future per capita water use rates applied in estimating future municipal and commercial water requirements. For the high set of projections, based on per capita usage under drought conditions, the adoption of water conserving practices and installation of water saving devices directly enter into the computation of estimated future requirements in that per capita water use in the years 2010, 2020, and 2030 are held constant at the use rate projected for 2000. That is, the long-term temporal increase in per capita water use rates statistically observed in Texas is projected to stop growing after the year 2000. The period of time between the present and the year 2000 is anticipated to be needed for homeowners and commercial managers to adopt practices and install equipment designed to reduce water use and for public authorities to adopt changes and enact codes directed toward water pricing, plumbing, fixtures, allowances for graywater usage, and for public education programs. The use of drought condition per capita water use rates in preparing the High Case projections is designed to provide planning data useful in making engineering determinations of the necessary size of water supply projects and water treatment and distribution facilities. Decisions regarding facility sizing are made by local authorities in response to local conditions and the needs and preferences of their water customers.

The Low Case projections, based on average condition per capita water use rates, with no future increase in average use rates anticipated beyond the year 2000, continues the effects of conservation practices factored into the High Case projections. However, systems engineered and built to meet only average condition demands will be strained beyond their limits in the event of a drought or a hot, dry summer and would not be expected to meet all the demands placed upon it. Thus, in addition to implemented conservation practices, drought contingency plans designed to reduce water use in the event of drought or excessive demand on a water supply or treatment and delivery system will have to be put in effect. Such plans, discussed in detail in Part IV, must have the effect of restricting and rationing water use.

The projections of municipal and commercial water requirements for the low case increase from the 1980 statewide level of 2.8 million acre-feet to a total of 3.5 million acre-feet per year in 2000 and to 5.1 million acre-feet annually by 2030 (Table II-3 and Figure II-7). For the high case, water requirements for municipal and commercial purposes are projected to increase to 5.1 million acre-feet annually in 2000 and to 8.2 million acre-feet annually in 2030. Projections of municipal and commercial water requirements by decade for each zone and river basin area of the State are presented in Part III.

Industrial Water Demand

Since the 1940's, the Texas economy has expanded and the economic base has been broadened from petroleum and agriculture to petroleum, agriculture, electronics, machinery and equipment, construction, trades, communications, and many types of professional and business services. During the 1970's, chemicals, petroleum refining, metals, and oil field machinery experienced rapid growth in production, employment, value of output, and wages paid. These and other industries used 1.5 million acre-feet or 8.5 percent of total water used in Texas in 1980. For planning purposes it is necessary to make projections of the quantities of water that will be needed by industry in future years.

While the basic industries remain a solidly significant portion of the Texas industrial base, it is not anticipated that all of them can maintain the high rates of growth of the recent past. Primarily, the abundantly available and low-cost input resources that gave Texas a comparative advan-

Table II-3. Municipal and Commercial Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements Low Case	High Case
	(millions of acre-feet)	
1980[1]	2.81	2.81
1990	2.96	4.20
2000	3.51	5.08
2010	3.99	5.93
2020	4.50	6.95
2030	5.06	8.18

[1]Reported municipal and commercial use. The summer of 1980 was extremely hot and precipitation was low for about four months. Reported water use for 1980 was greater than average, but was below the estimated quantity that would have been used if a drought had prevailed for the entire year.

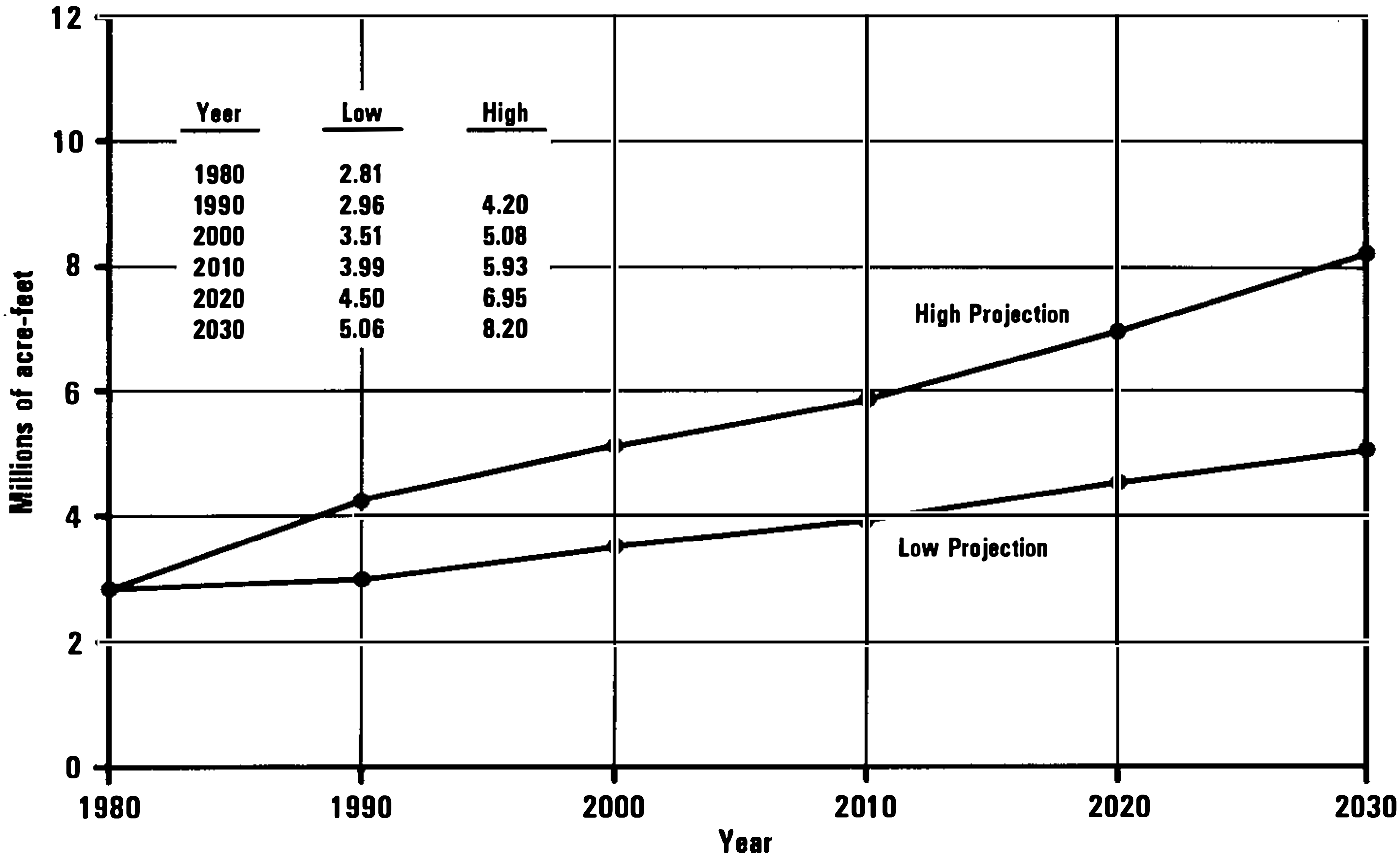


Figure II-7. Projected Municipal and Commercial Water Requirements, High and Low Series, 1980 to 2030

tage in attracting and developing these industries are either becoming scarce in Texas or are becoming relatively less costly elsewhere, especially outside the United States. For example, the production of aluminum and bulk plastics initially were attracted to Texas by the availability of inexpensive electricity, oil, and natural gas. None is as inexpensive in Texas today as has been the condition in the past. Similarly, the production of ferrous metals and oil field materials and machinery are mature industries and their future will to an extent parallel drilling and production of Texas' crude oil and natural gas. Thus, slower growth is expected for these industries than has occurred in the past. Other factors, especially world market conditions, now impact Texas industry more directly and intensely than in the past. National economic conditions and rates of growth are steadily becoming more important determinants of industrial growth because the structure of Texas industry is beginning to resemble that of the Nation, as diversification increases within Texas. All of these factors impinge upon water requirements for industry in the future.

Water used for industrial purposes is distinguished from water used for municipal and commercial purposes in that it is an integral part of the production process. In addition to drinking and sanitary water uses, industrial water requirements serve such process-specific purposes as cooling, boiler feed, cleaning and washing, pollution control, and extraction and separation of desirable materials from by-products and waste materials. Incorporation of water into the final product also is a major aspect of industrial water demand, especially in the production of food and beverage products.

Of the total quantity of water used by industry, five major groups of industries accounted for over 90 percent of total usage in 1980. Organized into industrial groups by the Standard Industrial Classification (SIC) System and ordered by their respective share of industrial water use, the five major industrial water using industries are: (1) chemicals (SIC 28), 36.6 percent; (2) petroleum refining (SIC 29), 19.4 percent; (3) primary metals (SIC 33), 15.0 percent; (4) paper products (SIC 26), 12.7 percent; and effectiveness, of the maximum reduction in water needed for production in the five largest water-using industries operating in Texas. Adoption of these feasible water conserving techniques was stretched out over a future period of time to allow for an adoption path consistent with an installation lag-time and for ordinary practices of replacement of worn out equipment with new, more efficient equipment. The low set of manufacturing requirements projections has factored into them the full measure of feasible reductions in water required per unit of output; the high set was adjusted, to reflect the effect of conservation, by one-half this measure of practicable possible gain in water use efficiency.

From a 1980 statewide total of 1.5 million acre-feet, industrial water demands in the low case are projected to increase to 2.4 million acre-feet annually by 2000 and 4.2 million acre-feet annually by 2030. The potential high demand projections are 2.7 million acre-feet annually and 5.0 million acre-feet annually for 2000 and 2030, respectively (Table II-4 and Figure II-8). These projections indicate an anticipated increase in industrial water requirements in Texas for the year 2000 of between 58.6 percent and 78.9 percent, comparing 1980 actual use with the amounts projected for requirements in 2000, low and high case, respectively. By the year 2030 this same comparison to base-year usage indicates increases of 178.3 percent and 229.6 percent, respectively, a near tripling of requirements for the low case and more than tripling for the high case. Part III contains projections of future industrial water demand by decade for each zone and river basin of the State.

Steam-Electric Power Water Demand

Steam-electric power plants require large volumes of water, principally for condenser cooling. Water in small quantities is also required for boiler feed makeup, sanitation and grounds maintenance, and in the case of coal and lignite fueled plants, for flue gas scrubbing (air pollution control), dust control at the fuel handling facilities, and for ash removal. In instances where a mine is associated with the plant, as is common at Texas lignite-fired plants, water will also be required for the mining operations. Consumptive (evaporative) water requirements for power plant cooling typically range from one-third to one-half gallon of water for each kilowatt-hour of electricity produced. The actual quantity depends on the specific type and design of the power plant and most importantly on the type of cooling system used. Consumptive water requirements for all other minor purposes will add about 10 percent to the per kilowatt-hour consumptive requirements for cooling.

Table II-4. Industrial Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements	
	Low Case	High Case
	(millions of acre-feet)	
1980[1]	1.52	1.52
1990	1.97	2.12
2000	2.41	2.72
2010	2.86	3.31
2020	3.47	4.08
2030	4.23	5.01

[1]Reported and estimated industrial water use in 1980. Projections to 1990 and beyond were based upon plant utilization data which were corrected for underutilization in 1980 due to the economic recession that began in mid-1980.

The most commonly used cooling systems are recirculating cooling reservoirs, evaporative cooling towers, once-through cooling systems, and multipurpose reservoirs used as cooling reservoirs. In all of these systems, from 20 to 60 gallons of water are circulated through the power plant condenser for each kilowatt-hour of electricity produced. The water is then cooled and recirculated, as in the case of evaporative cooling towers and recirculating cooling reservoirs, or it is discharged into a lake where only a small portion of the same water is recirculated through the plant.

Water requirements for steam-electric power generation were based on projections of electric power demand, the energy source used for generation, and the spatial location of generating capacity. The water coefficients used were based on engineering analyses of the thermodynamics of power plant operations, including an analysis of secondary water uses. For plants in the design phase of development, specific engineering design coefficients pertaining to water requirements were used, whenever available, in estimating future water requirements. For generating capacity scheduled for placement for which design work had begun, future water requirements were based upon the types of fuel anticipated for use in the basin and zone of plant location and upon an advanced plant engineering design appropriate for each fuel type. The projections of electric power demand to the year 2000 are based on projections made by the power industry, and projections beyond 2000 are based on data developed by the Department of Water Resources. Population projections were used to estimate electric power demand in residential, commercial, and institutional sectors, and manufacturing projections were used to estimate power demand in the industrial sectors.

Two cases, low and high, of power demand were made based on different rates of growth (Table II-5 and Figure II-9). The projections of future installed net thermoelectric generating capacity indicate that the net capacity in

(5) food products (SIC 20), 7.2 percent. Since future water use in the industrial use category is expected to be dominated by these five industrial groups, future projections of water requirements will depend on the level of production and rate of growth of these industries in the future. Based upon data, advice, and judgments by representatives of these industries, a growth outlook for each industry was developed for use in making projections of future water requirements. The growth projections are as follows:

Chemicals (bulk)—Major changes in markets and worldwide competition from new petrochemical complexes pose a long-term threat to Texas' position in the industry. Texas producers expect to maintain rapid growth in output for the short term, ten to twenty years; however, significant long-term expansion of capacity is unlikely. The compound annual growth rate projected for chemicals during the decade of the 1980's is 4.94 percent per year, which includes an allowance for reutilization of excess productive capacity that existed in 1980. For the decade of the 1990's the projected compound annual growth rate is 3.79 percent per year; for the period 2000-2030 the projected growth rate is 2.79 percent per year.

Petroleum Refining—Demand for products is heavily impacted by improved energy use efficiency in transportation and by substitute energy sources in the long term. Little growth is projected for this sector. Petroleum Refining output is projected to grow at a compound annual growth rate of 1.26 percent per year during the 1980's and at 0.42 percent per year during the 1990's, where each growth rate reflects exclusively the utilization of excess capacity existing in 1980—no new facilities will be installed. No growth is projected during the period 2000 to 2030.

Primary Metals—Annual growth rate of output from Texas producers is influenced by: (1) foreign competition, (2)eventual decline in demand from oil and gas exploration markets, (3) the use of recycled aluminum which requires relatively little water per unit of output, and (4) prohibitive process-energy costs which render primary metals' production uneconomical in the State. Modest growth is projected for Primary Metals during the decade of the 1980's, 3.0 percent per year, including recovery of excess plant capacity, slowing to 0.5 percent per year compound annual growth during the 1990's. No growth is projected for this sector beyond the year 2000.

Pulp and Paper—Available Texas timber resources will constrain the long-term growth rate of the industry, although growth in market demand for paper products is expected to remain strong. The eventual substitution of other methods of communication such as electronics and alternative methods of packaging may result in a dampening effect on industry growth. This sector is projected to grow at a compound annual rate of 4.01 percent per year during the 1980's, including reutilization of existing excess capacity, and at 2.0 percent annually during the 1990's. In the period 2000 to 2030, compound annual growth is projected to be 0.9 percent per year.

Food Processing—Texas industry is anticipated to grow faster than the national average for food products. Over the long-term, output will be slowed somewhat as population growth rates slow, yet steady growth is likely. The Food Processing sector is projected to have reasonably steady compound annual growth of 2.38 percent per year during the 1980's, 2.64 percent per year during the 1990's, and 2.15 percent per year for the period 2000-2030.

As with the projections of future municipal water requirements, a low and a high set of future industrial water requirements projections was made. The principal characteristics that distinguish between the low and high set of projections are the different rates of overall industry growth in Texas and the rate of implementation of industrial water conservation techniques.

Two rates of growth in output were projected for Texas industries and, thus, projections were obtained of two different volumes of industrial water requirements to support the respective levels of industrial output. The two growth rates, a low and a high, reflect different underlying growth patterns in national and international economic activity as well as a smaller or larger share of national and international markets held by Texas producers. Also factored into the low and high series of industrial water requirements projections were two different rates of gain in industrial water-use conservation: a modest rate of gain was applied to the high set of requirements projections, a more accelerated rate of gain into the low set.

Considerable gains have been made in recent years in reducing the amount of water used per unit of final output manufactured. By changing machinery and equipment, production processes, or mix of inputs, efficiencies in water use can be achieved. Current developments, the state of existing available technologies and management practices, and continuing attention to potential production cost savings from using less water in production of manufactured goods point to the potential for further reducing water intake required per unit of industrial output, especially in those industries in Texas that are heavy users of water. Estimates were made, within the constraints of existing state-of-the-art technologies and cost

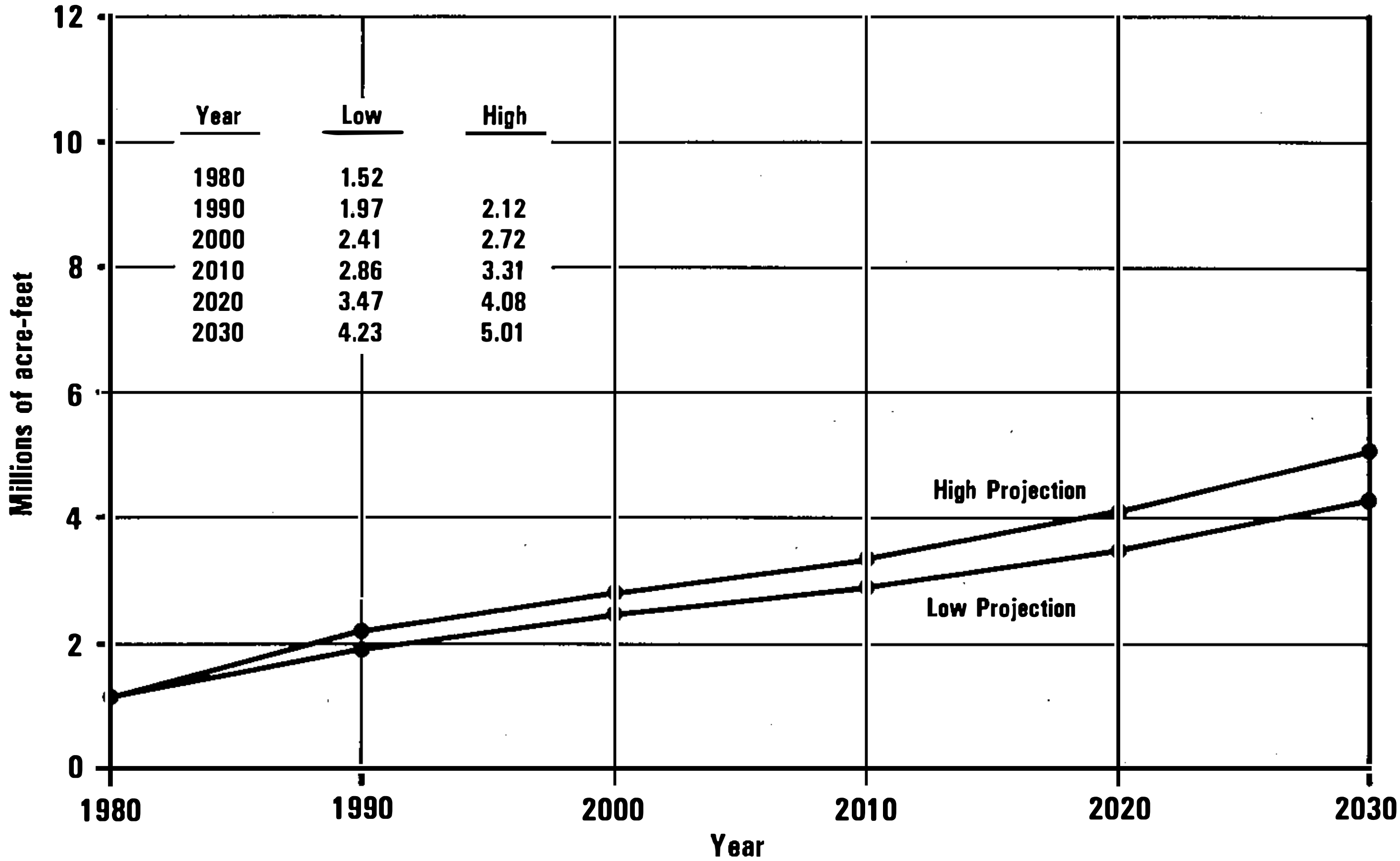


Figure II-8. Projected Industrial Water Requirements, High and Low Series, 1980 to 2030

Texas will grow from 50.7 thousand megawatts in 1980 to between 88 thousand and 100 thousand megawatts in the year 2000, then increase to between 120 and 152 thousand megawatts by the year 2030, low and high case, respectively.

Table II-5. Steam-Electric Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements	
	Low Case	High Case
	(millions of acre-feet)	
1980[1]	330.0	330.0
1990	535.0	535.0
2000	717.4	816.7
2010	835.4	1,017.0
2020	975.6	1,217.0
2030	1,118.6	1,417.5

[1]Reported and estimated steam-electric water requirements for 1980.

At present, natural gas is still used as the primary fuel for about 65 percent of the electricity generated in Texas, but coal, lignite, and uranium will be the major fuels in the future. In 1980, Texas had 5,300 megawatts of lignite-fired generating capacity and 6,431 megawatts of coal-fired generating capacity. By 1990, an additional 8,759 megawatts of new lignite capacity, 3,324 megawatts of new coal-fired capacity, and 4,800 megawatts of nuclear capacity will be added to the system, according to the utility industry plans. Between 1990 and the year 2000, lignite is projected to fuel two-thirds of the new plants, while coal will fuel the remainder. This will place total projected lignite-fueled generating capacity in Texas at between 24 and 33 thousand megawatts in the year 2000. Beyond the year 2000, lignite is projected to continue to play a significant role, but lignite-fueled capacity is projected to peak at 65 thousand to 75 thousand megawatts around the year 2015. Then, because of limited lignite resources, lignite generating capacity is projected to decline to around 40 thousand megawatts by the year 2030. Coal is projected to account for most of the remaining capacity.

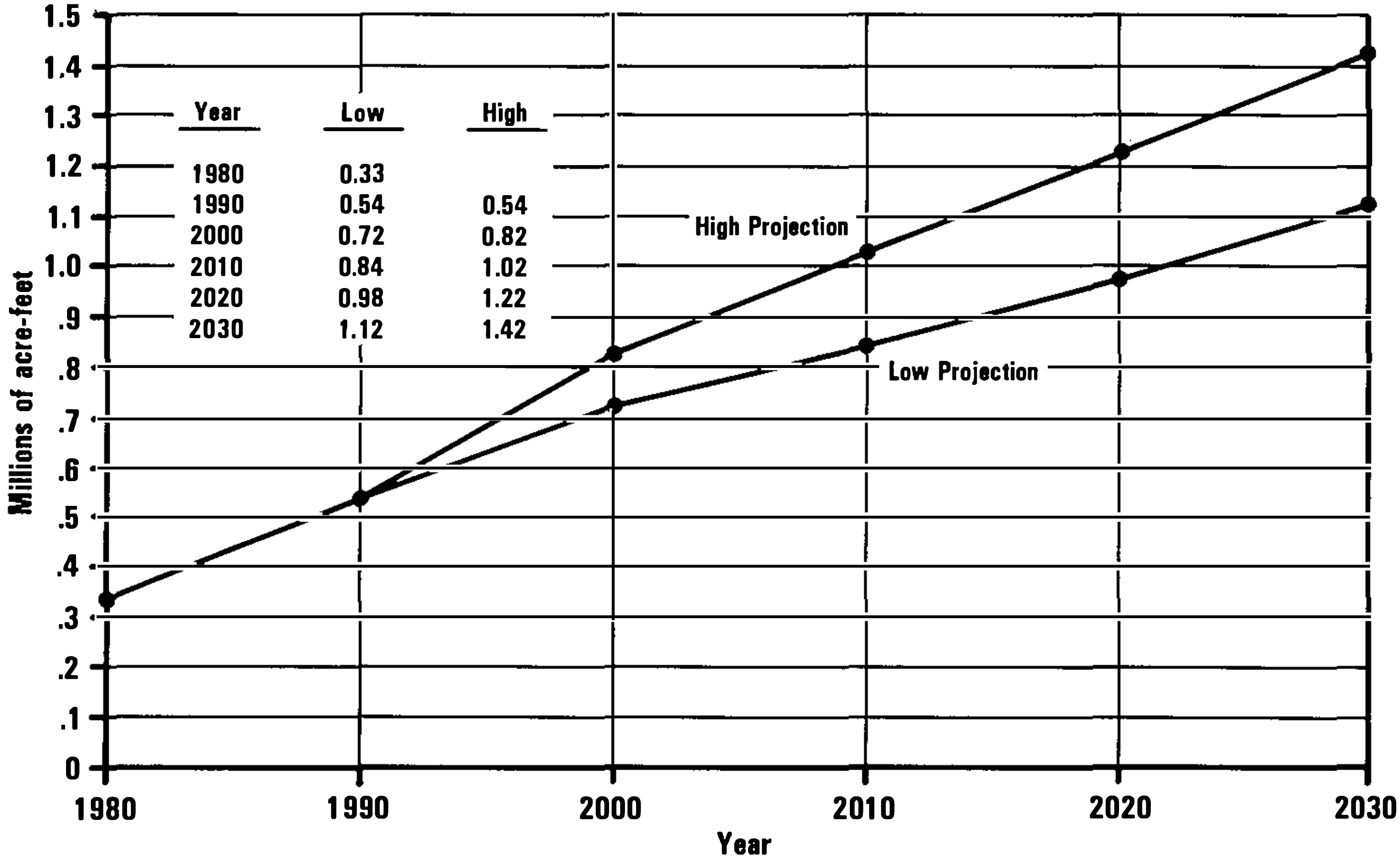


Figure II-9. Projected Steam-Electric Water Requirements, High and Low Series, 1980-2030

The distribution of generating capacity was based on announced power plant locations, historical development by basin, projected demand for power, availability of local fuel sources such as lignite, environmental factors, and institutional constraints.

Total (cooling and other needs) consumptive water requirements (evaporation) for steam-electric power production were projected to increase from 330 thousand acre-feet in 1980 to between 717 and 817 thousand acre-feet annually in 2000, and to between 1.1 and 1.4 million acre-feet per year in the year 2030, low and high case, respectively. Although large volumes of water must be circulated through power plant condensers (20-60 gal/kw-hr), most of the water is returned to its source. Only the quantity of water that is evaporated is shown when projecting steam-electric power plant water requirements. However, for operating purposes, it is necessary that the total quantity of water required for circulation be available. The projections of Part III take this latter factor into account.

Surface water is projected to continue to constitute the major portion of steam-electric power water use, increasing from 277 thousand acre-feet per year in 1980 to between 580 and 641 thousand acre-feet per year in the year 2000, and to between 900 thousand and 1.14 million acre-feet per year by 2030. Ground-water use is projected to triple from current levels of 53 thousand acre-feet per year to between 140 thousand and 176 thousand acre-feet annually by the year 2000, and then nearly double again by the year 2030 to between 150 thousand and 274 thousand acre-feet per year. Treated municipal effluent is currently used at four major power plants in Texas for cooling water and other purposes. In 1980, these four plants used over 14 thousand acre-feet of treated effluent.

As indicated, the future water requirements specified above account only for the volumes of water consumed (evaporated) in the respective decades in steam-electric power generation. Since nearly all the water used in power generation is for cooling purposes and only a small portion of this is evaporated, the pass-through requirements are a large multiple of that volume of water evaporated. Pass-through requirements for power plants operating in Texas range from 20 to 60 gallons per kilowatt-hour. A typical value for plants using fresh surface water cooling systems, such as cooling ponds or once-through cooling, is around 40-50 gal/kw-hr. This translates to about 100 gallons of total water pass-through requirements for each gallon of water actually consumed by surface water cooled power plants.

Based on the future projections for evaporative requirements in steam-electric power generation, the range of low and high projections for total pass-through requirements in the year 2000 is from 50 million to 65 million acre-feet. For the year 2030, the projected range of requirements is from 80 million to 115 million acre-feet. This estimate of total pass-through requirements is made only upon water supplied from a surface-water source, since water supplied from a ground-water source is based on total withdrawals and, thus, includes both evaporation and recirculated flow. Total pass-through requirements measure the volume of water required to satisfy the operational needs of steam-electric power generation (cooling and other minor water requirements) but overstate by several magnitudes the amount of water consumed from available supplies, since most of the total withdrawal is returned to its source and again becomes a part of available supply. Thus, the actual water required throughout the life of a plant operating from surface water is that amount initially needed to fill the cooling pond and generate the system plus those amounts needed to make up for evaporation losses. Projections of consumptive water requirements for steam-electric power generation for each area of the State are presented, by decade, in Part III.

Agricultural Water Demand

Texas ranks first in the Nation in the production of cotton and cottonseed, grain sorghum, wool and mohair, and in the total numbers of cattle, sheep, and goats. Texas is also a leading producer of hay, pecans, peanuts, citrus, commercial vegetables, rice, and wheat. Over 40 percent of Texas crop sales is directly attributable to irrigation. Of all major water use categories, agriculture accounts for the largest proportion of water used in Texas.

In 1980, agricultural water use was approximately 12.9 million acre-feet, 72 percent of the 17.9 million acre-feet total water use in the State. Of this total, irrigation of crops, orchards, and pasture accounted for 12.7 million acre-feet to irrigate 8.1 million acres, and livestock use on farms, ranches, and in feedlots was about 0.24 million acre-feet. Irrigation in Texas was about 6.7 million acres in 1958 and increased until reaching a peak in 1974, when 8.6 million acres was irrigated. The acreage irrigated in 1980 was about six percent less than in 1974.

Approximately 38 million acres of land in the State is physically suited to irrigation, including the 8.1 million acres presently irrigated. Some land included in this estimate is located such that irrigation development might not be feasible, depending upon costs of supplying water. Urban development continues to expand onto irrigable land, especially in the Houston-Galveston, El Paso, San Antonio, and Lubbock areas, in the suburbs of smaller cities, and in the Lower Rio Grande Valley.

The quantity of land previously irrigated and still equipped for irrigation, but not irrigated in 1980 due to poor profit prospects, is approximately 2.0 million acres. Much of the previously irrigated land is in the rice-producing area of the Coastal Prairie, Reeves and Pecos Counties, and a few counties in the High Plains. Most of this acreage would be readily available for irrigation in the future if economic conditions improve.

In estimating the future water needs of irrigated agriculture, the following factors were considered: the total acreage suitable for irrigation, acreage currently in irrigated production, the 1980 water use per acre, the maximum potential reduction of water use through technological improvements and conservation practices, the economics of dryland versus irrigated production, and the Nation and world's potential food demands. One projection of water demand for irrigated agriculture, low case, was derived by holding projected future acreages irrigated at the 1980 levels, with per acre application rates reduced through time to reflect the effects of technological improvements, conservation measures, and reductions in canal losses for irrigation operations served from surface-water sources. The future agricultural water demand required to continue irrigation of the same number of acres irrigated in 1980, 8.1 million acres, making allowance for reduction in application rates, is 10.1 million acre-feet in year 2000 and 11.1 million acre-feet in 2030. These low-case projected requirements reflect a reduction from the 12.7 million acre-feet used in 1980 of 20 and 13 percent, respectively, in 2000 and 2030 (Table II-6 and Figure II-10).

For the high case projection of demand for irrigation water, data about the number of acres that could be irrigated and still pay a positive return above that of dryland production were controlling factors. In addition, technological improvements and conservation measures were considered in developing the rate of water applied per acre, as well as factoring in reductions in canal loss rates for surface water supplied irrigation. The projected demand at this higher level is 16.2 million acre-feet per year for 13.9 million acres irrigated in 2000, and 15.0 million acre-feet

Table II-6. Irrigation Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements[1] Low Case	High Case
	(millions of acre-feet)	
1980[2]	12.7	12.7
1990	10.2	12.3
2000	10.1	16.2
2010	10.6	16.2
2020	10.7	16.5
2030	11.1	15.0

[1]Irrigation water requirements for all years include an estimate for water lost in conveyance from a surface-water source to the field.
[2]Reported and estimated irrigation water use in 1980.

annually with 11.5 million acres irrigated in 2030. The high case projections of future irrigation water demand represent an increase over 1980 usage of 28 and 18 percent, respectively, for years 2000 and 2030. The corresponding percentage increases in acreage in irrigation in the two future time periods are 72 and 42 percent, respectively. Whereas the low case projections were based on constant 1980 irrigated acreages coupled with improved water use efficiencies and conservation, the high case projections were based on an analysis of profitability of irrigation, taking into account projected future agricultural prices and production costs coupled with the same improvements in water use efficiency and conservation. Specific low and high projections are shown for each zone and river basin area in Part III.

Livestock water use in 1980 was 244 thousand acre-feet, supplied both from local surface- and ground-water sources (Table II-7). Projections of livestock water demands are based on maintaining Texas' share of National livestock production until limited by availability of land for grazing. Feedlot cattle, hogs, dairy, and poultry sectors are not limited by this acreage requirement. Livestock water demands for the period 2000-2030 are approximately 332 thousand acre-feet annually. Distribution of these demands into county, basin, and zone seg-

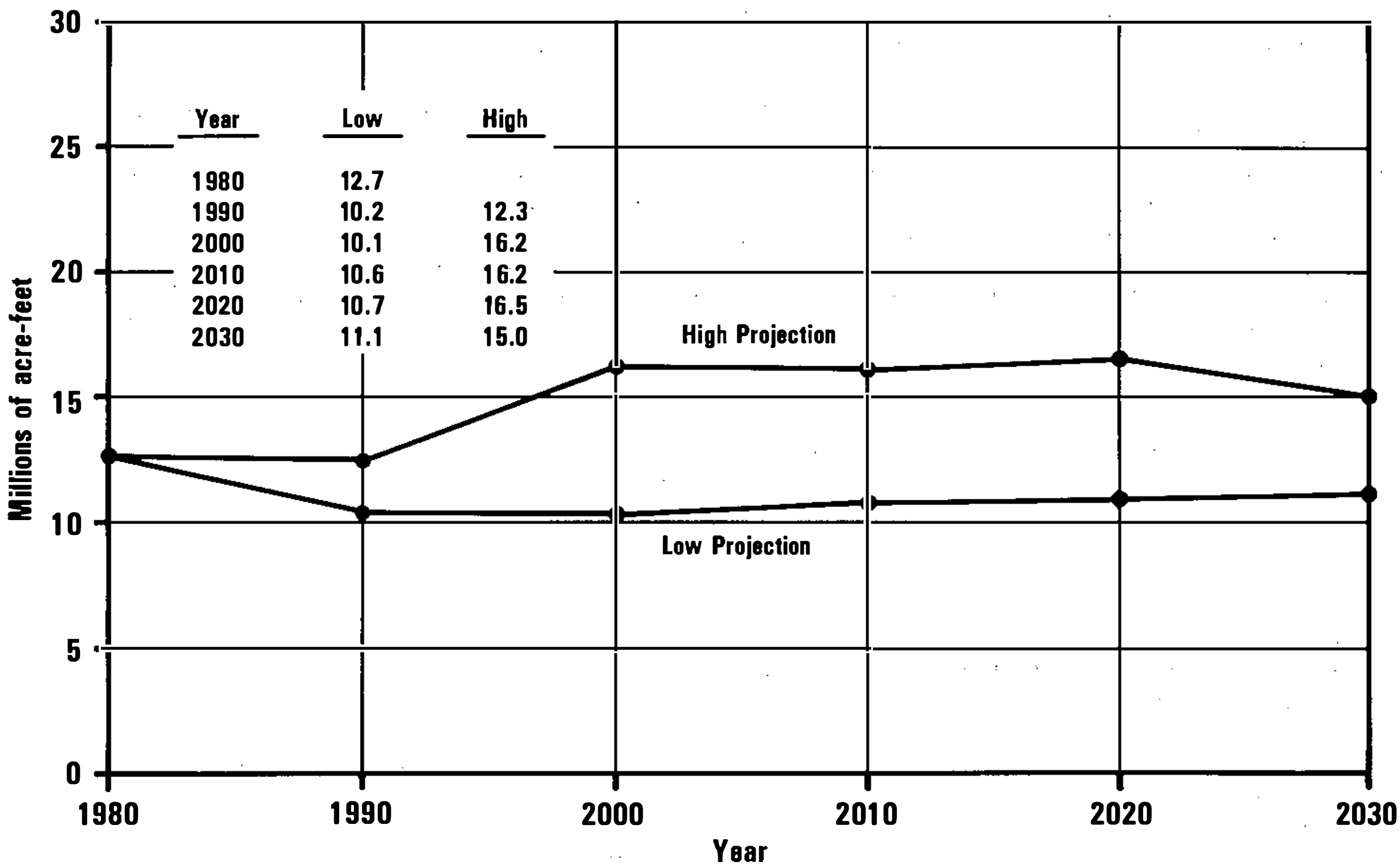


Figure II-10. Projected Irrigation Water Requirements, High and Low Series, 1980-2030

ments is similar to the current distribution with the exception that livestock water use is not expected to increase in the major metropolitan counties.

Table II-7. Livestock Water Use in 1980 with Low and High Projections of Requirements to 2030.

Year	Projected Water Requirements[1] (thousands of acre-feet)
1980[2]	244.0
1990	287.5
2000	331.7
2010	331.7
2020	331.7
2030	331.7

[1]Only one set of projections was made for future livestock water requirements.
[2]Reported and estimated water use in 1980.

Mining Water Demand

Mining activities in Texas include the production of crude petroleum, natural gas, uranium, salt, sulfur, construction materials, and the extraction and processing of lignite for the production of synthetic fuels. In 1980, the Texas mineral industry was foremost in the production of crude petroleum and natural gas in the United States and ranked fifth nationally in the value of output for a wide variety of important nonfuel minerals. Texas is a leading producer of nonmetals (Frasch sulfur, clay, gypsum, salt, stone, and sand and gravel); however, petroleum production accounts for most of the freshwater presently used in the mining sector.

Mining was categorized into fuels, metals, and nonmetals for purposes of projecting the future freshwater needs of this sector of the Texas economy. The principal use of water in mining is for the recovery of petroleum by fluid injection, commonly known as secondary recovery. Both saline and freshwater are used for secondary oil recovery and maintenance of oil reservoir pressure. Estimates contained herein are for freshwater. The development of sand and gravel resources and the recovery of minerals other than petroleum also require the use of freshwater for the separation of desirable materials from by-products and waste; however, consumptive use of freshwater in these operations is small in comparison to requirements for the fuel industry.

The crude petroleum and natural gas producing industries utilized 126 thousand acre-feet in the secondary and enhanced recovery of oil and for natural gas processing out of a total for all mining purposes of 239 thousand acre-feet of freshwater in 1980. Fluid injection operations have increased production from 30 percent in 1965 to around 60 percent in 1980 of the total volume of oil produced within the State. Calculations indicate that an estimated three thousand acre-feet of freshwater will be required in Texas by the year 2030 for secondary and enhanced recovery of oil. Brackish water, saline water, or freshwater can be used for injection operations, and the choice is usually dictated by the economics of water supply and operation and maintenance costs. The projection of water requirements for secondary recovery operations was based on an evaluation of the amount of oil available which can be produced by water injection. Much of the total water requirement for secondary oil recovery can be satisfied by saline water commonly produced with oil and gas in the State, by the recycling of water used in secondary recovery projects, or by locally available brackish or saline waters, principally from ground-water sources.

A significant decrease in water demand for secondary and enhanced oil recovery is the result of depletion of known and projected newly discovered quantities of oil available to be produced, increasing use of saline or brackish waters for pressure maintenance and enhanced recovery operations, and improving technological advances that reduce demand for freshwater.

On account of recent development in international energy markets and declining domestic oil and gas production, synthetic fuels are being seriously considered as a substitute for conventional fossil fuels. Since lignite reserves in Texas are significant, there are tentative plans to construct synthetic fuel plants in the State. With the exception of experimental pilot plants, there were no synthetic fuels operations in Texas in 1980. It is estimated that by the year 2000, however, water use for the production of synfuels should represent 16 percent of State mining water requirements. By the year 2030, synthetic fuels are estimated to be the second largest category of mining water use in the State and to require 33 percent of estimated total mining freshwater needs.

Metal and nonmetal mining activities in Texas accounted for approximately half of mining freshwater use in 1980 and are estimated to represent 60 percent of mining freshwater requirements in 2030. The projected demand in 2030 takes into account the projections of a decline in the production of petroleum and natural gas, significant development of synthetic fuels, and increases in demand for construction materials in the metropolitan areas.

For mining water use, only a single set of projections were made, not a high and low case as in other use categories (Table II-8). In this single projection, mining water requirements, fuels, metals, and nonmetals combined, in

Table II-8. Mining Water Use in 1980 with Projections of Requirements to 2030.

Year	Projected Water Requirements[1] (thousands of acre-feet)
1980[2]	239.0
1990	231.9
2000	267.7
2010	321.4
2020	375.3
2030	387.2

[1]Only one set of projections was made for future mining water requirements.
[2]Reported and estimated water use in 1980.

year 2000 are estimated to be about 268 thousand acre-feet annually and about 387 thousand acre-feet in 2030. These projected demands, compared with the 239 thousand acre-feet used in 1980, indicate an increase of 12 and 62 percent, respectively, in the two future time periods. Mining water projections for each area of the State are presented in Part III.

Hydroelectric Power Water Use

Presently, Texas has 22 hydroelectric power plants with an installed hydroelectric generating capacity of 546 megawatts (Table II-8). In 1980, these facilities provided only about one-half of one percent of the electricity generated in the State. A new 32 megawatt unit is under construction at Amistad Reservoir on the Rio Grande, and several hydroelectric units on the Guadalupe River are being reactivated.

Although water is not consumed (evaporated, etc.) in the generation of hydroelectric power, large volumes of water must flow through the turbine of a plant in order to operate the generator. In 1980, total flow through hydroelectric turbines in Texas exceeded 11 million acre-feet. With the construction of additional reservoirs in Texas, water used for hydroelectric power plants in 2030 is expected to be more than double the current quantity of use; however, such use will be a by-product of other water-using activities, and is not considered an additional consumptive demand upon State water supplies.

Navigation Water Use

Texas navigational facilities are primarily located within the coastal area. Along the Gulf coast there are 12 Texas ports which will accommodate deep-draft vessels (30-45 feet), and 13 Texas ports for shallow-draft vessels (6-14 feet). The Intracoastal Waterway connects ports of Texas to other Gulf and Atlantic states by a protected, shallow-draft channel. Extensions from this canal connect important industrial areas with other coastal navigation channels and sea lanes. Existing and planned navigational facilities in Texas do not have regulated freshwater flow requirements.

There is inland navigation currently on the downstream reaches of the Sabine, Neches, Trinity, Brazos, and Colorado Rivers, but very little water release from reservoir storage is required to maintain adequate navigational depths. Normal streamflows plus impoundment releases for other purposes are expected to continue to satisfy these navigation needs. Also, there is some potential for additional inland navigation on Texas rivers, such as the Cypress, Red, Trinity, San Jacinto, Neches, and Sabine, which would necessitate providing locks and adequate freshwater flows around dams. Streamflow might also be needed to maintain satisfactory navigation depths in these rivers. However, no estimates of the flows needed are presented here because the inland navigation projects are not envisioned in the near future.

Bay and Estuary Freshwater Needs

Texas coastal environments contain natural and man-made resources of significant economic importance to the State. In particular, these areas contribute multiple-use inputs to the Texas economy in several forms that include, but are not limited to: (1) a navigation network of national importance; (2) a resource base of State importance for minerals, seafoods, and recreational opportunities; and (3) a natural source of ecological treatment for many nutritive wastes and by-products. Total annual economic values are at billion dollar levels in each major category such as shipping, oil and gas production, fishing, and recreation and tourism. Freshwater requirements for municipal, industrial, agricultural, and other uses in the coastal areas have been included in Part III of this report. The following discussion identifies inflow relationships and estimates the freshwater needs of Texas bays and estuaries.

Major Estuarine Systems

The coastal bays are estuarine areas where seawater from the Gulf of Mexico mixes with freshwater discharged from Texas streams and rivers to create highly productive and diverse natural environments. Texas has 11 major river basins, 10 with headwaters originating within the State, which are associated with bays and estuaries of primary or secondary importance. There are seven major and several minor estuaries located along the 400 miles of Texas Gulf coastline (Figure II-11). Major bays are contained in the Sabine-Neches, Trinity-San Jacinto, Lavaca-

Table II-9. Hydroelectric Power Plants in Texas, 1980.

Basin	Dam	Reservoir	Capacity (Megawatts)
Red	Denison	Lake Texoma	70[1]
Sabine	Toledo Bend	Toledo Bend	85[2]
Neches	Sam Rayburn	Sam Rayburn	52
Brazos	Morris Sheppard	Possum Kingdom	22.5
	Whitney	Whitney	30.0
Subtotal			54.5
Colorado	Buchanan	Buchanan	36
	Roy Inks	Inks	12
	Alvin Wirtz	LBJ	52
	Max Starke	Marble Falls	32
	Mansfield	Travis	84
	Tom Miller	Austin	14
Subtotal			230
Guadalupe	TP-1	Dunlap	3.6
	Abbot (TP-3)	McQueeny	2.0
	TP-5	Molte	2.5
	H-4	H-4	2.4
	H-5	H-5	2.4
	Seguin	TP-4	2.4
Subtotal			16.1
Rio Grande	Red Bluff	Red Bluff	2.3
	Amistad	Amistad	66.0
	Eagle Pass	(Canal)	9.6
	Falcon	Falcon	31.5
Subtotal			109.4
Texas Total			615.0

SOURCE: Texas Department of Water Resources

[1]Part of the power generated at Denison Dam is sold in Oklahoma.

[2]Part of the power generated at Toledo Bend Dam is sold in Louisiana.

Tres Palacios, Guadalupe, Mission-Aransas, Nueces, and Laguna Madre estuaries. Riverine estuaries that flow directly into the Gulf include those of the Brazos, San Bernard, Colorado, and Rio Grande rivers. Texas estuarine systems are generally characterized as drowned river mouths (the result of an ancient rise in sea level), and are complimented by elongate barrier islands that enclose approximately 1.5 million surface acres of open water bay area and at least an additional 1.1 million acres of marshlands and tidal flats. Scientific and engineering studies have been made on each estuary in recent years to better understand the importance of freshwater to each estuarine system, and for estimation of the seasonal timing and quantities of freshwater flow needed by each estuary.

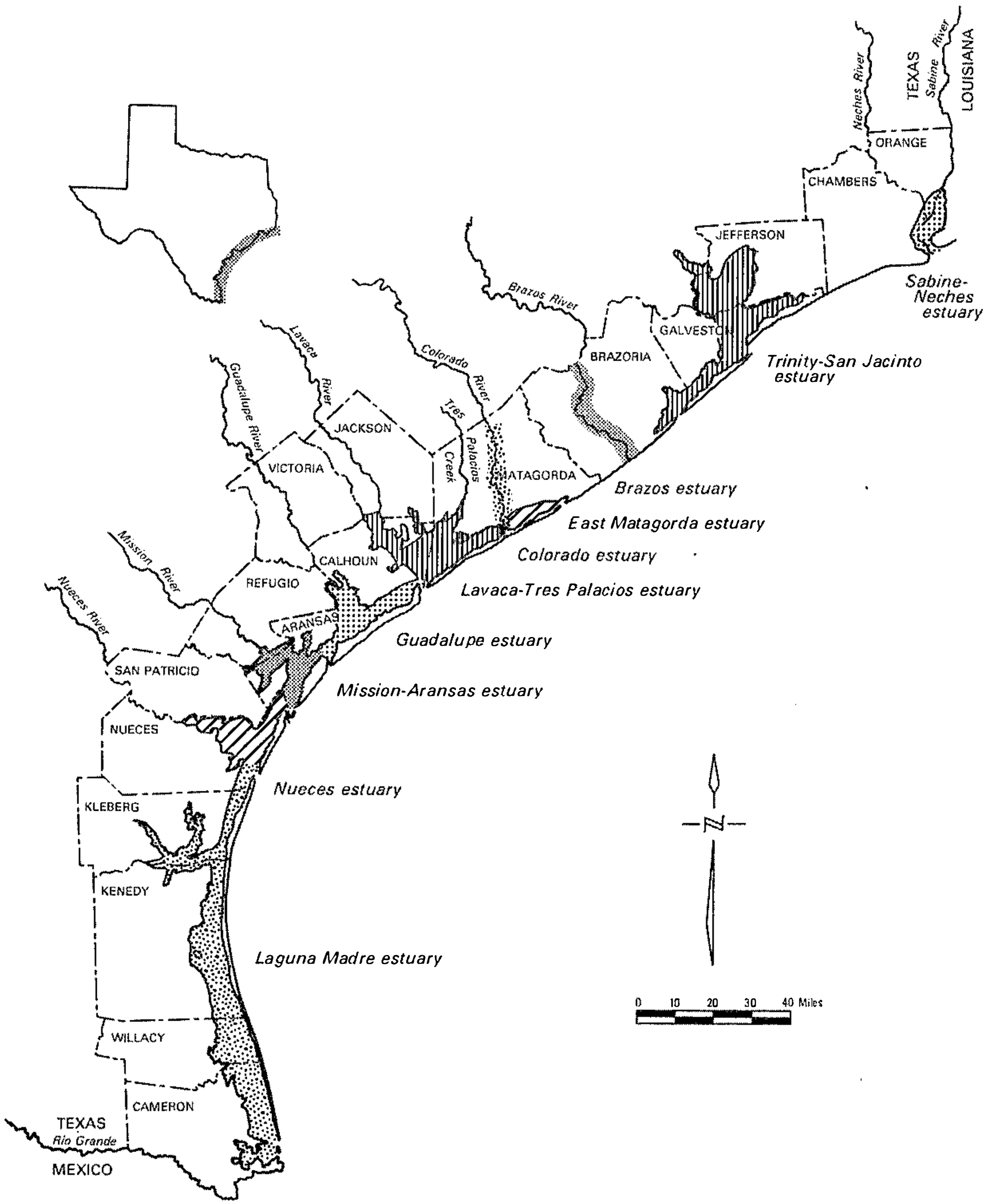


Figure II-11. Location of Texas Estuaries

Freshwater Inflow Factors

The inflow of freshwater is widely recognized as an essential factor in maintaining the biological productivity of Texas bays and estuaries. Virtually all of the coastal fisheries species are considered estuarine dependent, while the estuaries themselves are dependent upon freshwater inflows for nutrients, sediments, and a viable salinity gradient that allows inhabiting organisms to survive, grow, and reproduce. In addition, it is known that periodic estuary flushing by high inflows inundates river delta marshes, stimulates the cycling of nutrients, transports food materials, and removes or limits many pollutants, parasites, bacteria, and viruses harmful to estuarine-dependent organisms. These effects and the relationships among them are described below.

Hydrology

The inflows of fresh surface waters to Texas coastal areas include flows measured at the most downstream gaging station of each Texas stream (called "gaged" flows), and inflows that usually originate as local runoff from rainfall on ungaged coastal watersheds (referred to as "ungaged" flows). Therefore, sources of freshwater flow to Texas estuaries are: (1) gaged inflow from rivers, streams, and creeks, as measured at their most downstream gaging stations before entering the estuaries; (2) ungaged rainfall runoff, primarily from the surrounding coastal basins; (3) return flows, usually from municipal, industrial, and agricultural water users in ungaged areas; and, (4) direct precipitation on the estuary. The measurement or estimation of each inflow source is necessary in order to quantify the relationships among freshwater inflows and changes in the estuarine environments. Historically, total annual freshwater inflow to the seven major Texas estuaries from their combined river and coastal drainage basins has averaged almost 30 million acre-feet per year, but minimum annual gaged river flows have been as little as 4.1 million acre-feet under drought conditions. Freshwater inflow to the estuaries can be diminished by climate, evaporation, ground-water (aquifer) recharge, and consumptive water use. The timing of inflows to the bays can also be affected by these factors. To realize estuarine benefits, freshwater inflows should be at seasonally appropriate levels in each Texas estuary. For example, adequate springtime inflows are important for production of many fish and shellfish species, while high inflows during cold periods can be detrimental to most organisms overwintering in the estuaries.

Circulation and Salinity

The distribution of water quality constituents and living resources in Texas bays is determined to a large extent by the movements of water within the estuarine systems. Perhaps the most direct and apparent effects of freshwater inflow occur as a result of changes related to estuarine salinity. For example, the concentration of salts can interact with other environmental factors to stimulate species-specific biotic responses, such as reproduction or migration. Salinity also affects species adaptation to the environment, species distribution patterns, biological community diversity of the ecosystem, and ultimately species evolution. In addition, the evaluation of upstream water development projects or wastewater discharges into the bays often focuses on changes in the circulation and salinity patterns of Texas bays and estuaries. The effects of freshwater inflow on estuarine circulation and salinity have been studied and the results taken into account for the estimation of freshwater needs.

Nutrients and Water Quality

The biological productivity of Texas estuaries is dependent upon the availability of essential nutrients, including carbon, nitrogen, and phosphorus, as well as trace elements like silicon, potassium, zinc, manganese, and others. In addition, important water quality factors include the presence of sufficient dissolved oxygen for the respiration of aerobic organisms like fish and shellfish, and the absence of toxic chemicals which can limit survival, growth, and reproduction of estuarine-dependent organisms. Fortunately, the water quality of Texas estuaries is generally considered to be good, except in some modified environments such as harbors and ship channels where chronic problems can persist. Nutrients required in large quantities, like nitrogen, are quickly depleted from the coastal environments. Consequently, a deficiency in this essential nutrient can limit the ecosystem's productivity. Three natural sources of nutrients to estuaries are streamflows, rainfall, and seawater exchange, although the latter two are not considered major sources of nutrients to Texas estuaries. Freshwater flows from the rivers and streams that empty into the bays and estuaries of Texas are recognized to be the primary source of nutrients responsible for the biological productivity of the coastal environments.

Critical Periods

Because adequate freshwater flow during critical periods is more beneficial to ecological maintenance than abundant flow during noncritical periods, the time of inflow can be extremely important to Texas bays and estuaries. Biologically, seasonal timing of freshwater inflows can affect the production of associated wetland areas, the utilization of nursery habitats by juvenile fish and shellfish, and the transport of sediments and nutritive food materials (especially detritus) to the estuary. As a result, the freshwater inflow needs of Texas estuaries are not static annual requirements. In fact, dynamic fluctuation about the productive range, seasonally and annually, are both realistic and desirable for the estuaries. However, extended periods where inflow conditions consistently fall below maintenance levels can lead to degraded estuarine environments, loss of important nursery habitats for seafood species, and a substantial reduction in the potential for natural assimilation of organic and nutritive wastes. Critical periods in the life cycles of ecologically or economically important coastal species were also taken into account when estimating the freshwater needs of Texas estuaries.

Primary and Secondary Production

Fundamentally, biological communities are energy-nutrient transfer systems. Primary producers (plants) transfer nutrients and energy to secondary producers (animals) through feeding relationships within an estuary's food web. Each bay and estuary has characteristic plant and animal assemblages. Since these species respond to changes in their environment, such as variations in water quality or the rate of freshwater inflow, they can be useful as indicators of major fluctuations in primary and secondary production, and the general "health" of an estuarine ecosystem. Freshwater needs of the bays and estuaries include levels of inflow that are estimated to maintain the primary and secondary production of Texas coastal environments.

Fisheries

The coastal fisheries may be divided into two major components—finfish and shellfish. Both are harvested in large quantities by sport and commercial fisherman along the Texas coast. Prominent coastal fisheries species include brown shrimp, white shrimp, blue crab, bay oyster, spotted seatrout, red drum (redfish), black drum, croaker, sheepshead, flounder, and sea catfish. Distribution of the finfish catch is approximately 72 percent inshore in Texas bays and 28 percent offshore in the Gulf of Mexico. The shellfish harvest is of an opposite distribution with about 79 percent offshore and 21 percent inshore. However, regardless of where they were caught, virtually all of the Texas coastal fisheries species are considered estuarine-dependent during at least some portion of their life cycles.

Economic and Other Values of Coastal Areas

Texas bays and estuaries are the source of market and nonmarket products and services. For example, some nonmarket values of the coastal environments include the benefits associated with waste assimilation, use as a source of industrial cooling waters, buffering of inland areas from flood and storm impacts, and aesthetic values. Resources which have market values include oil and gas production, shipping, fishing, and recreation and tourism. However, they are not all equally dependent on freshwater inflow to the estuaries for their future use and continuity. Renewable natural resources, such as water and fisheries, can be extracted from the coastal environments for indefinitely long periods of time, if properly managed; whereas, nonrenewable resources like minerals are finite in natural supply and with continuous extraction will ultimately be depleted. Shipping and some tourism are not dependent upon freshwater inflow, but sport and commercial fishing, tourism associated with coastal fishing, hunting, or nature studies, and the food supplies of migratory waterfowl depend on adequate inflows of freshwater.

Commercial Fishing

The commercial harvests of fish and shellfish species dependent on Texas estuaries were recently reported to have totaled about 113 million pounds (over 90 percent shellfish) in 1981, with a direct dockside landings value of $174.8 million. At this level of fishing activity, the total annual economic impact is approximately $544.5 million, which reflects the gross business, personal income, and tax revenue values to the State's economy. The Texas shrimp harvest accounted for 94 percent of the 1981 dockside landings value, and was approximately 36 percent of the total shrimp catch in the United States. Overall, Texas ranks fourth among the states in the value of its commercial seafood landings.

Recreation and Tourism

The environments and abundant natural resources of the bays and estuaries provide a wide variety of recreational opportunities to both residents and visitors of the Texas coast. There are approximately 15 million visitors to the coast each year, but the economic values derived from this tourism are difficult to estimate. Water-oriented recreational activities such as fishing, boating, and swimming are readily available coastwide on the 1.5 million acres of open water bay area. Also, adjacent marsh wetlands and contiguous inland areas contain birds, mammals, and other wildlife resources that provide opportunities for hunting, sightseeing, nature studies, and aesthetic benefits to the public. For example, over two-thirds of the ducks and geese on the central flyway of North America overwinter on the Texas coast, to the enjoyment of thousands of waterfowl hunters. Another recreational activity of both residents and tourists that depends on freshwater inflows to Texas bays and estuaries is sport fishing. It has been estimated that sports fishermen catch between 4 and 10 million pounds of coastal fish annually, with the total economic impact to Texas in 1979 valued at $709 million.

Cultural and Scientific Values

The bays and estuaries are additionally valuable for their cultural and scientific resources. For example, scientific values accrue to the State because it has one of the most diverse estuarine regions in the world. The estuarine systems here vary from the low salinity environments characteristic of the northeast part of the Texas coast, to the extreme, high salinity bays and lagoons of the southwestern coast. In particular, the Laguna Madre is one of only three oceanic, hypersaline (salinity higher than seawater), lagoonal areas known to exist. Cultural resources, such as historical sites and archaeological discoveries, are also common along the Texas coast and link our present cultural heritage to the past. Some living resources, like the Whooping Crane, are rare and endangered, but find safe repository in the natural environments of Texas bays and estuaries.

Estimates of Freshwater Inflow Needs

The physical, chemical, and biological relationships to freshwater inflow were integrated and used to compute the flows needed to meet specific objectives for marsh inundation (nutrient cycling), salinity gradients, and fisheries harvests. These objectives provide a range of options that include the survival, maintenance, and enhancement of Texas bays and estuaries.

Four different levels of inflow were selected for estimation. The long-term ecosystem need (Level I) has the objectives of meeting estimated salinity viability limits and marsh inundation (nutrient cycling) requirements. Summing across the seven major Texas estuaries, the quantity of freshwater needed is an average of 13.6 million acre-feet per year of gaged river flows. By comparison, gaged river flows to Texas estuaries during the 1941 through 1976 historical period have averaged 23.7 million acre-feet per year. Effects of Level I inflows on the coastal fisheries are not projected to be significantly different overall from the average historical harvests, but effects on individual species can vary.

The long-term freshwater need for maintenance of the coastal fisheries (Level II) has the same objectives as Level I, plus requires sufficient inflows to give predicted fisheries harvests at the 1962 through 1976 average levels. The Level II need is estimated to be an average of 9.6 million acre-feet per year of gaged river flows, but does not include flows to Sabine Lake where data were not adequate to make estimates beyond the Level I subsistence need of 5.7 million acre-feet per year.

Level III, the long-term inflow need for enhancement of selected fisheries species also has the same basic objectives as Level I, but additionally includes the objective of providing sufficient freshwater inflows to maximize the harvest of an important fisheries species or species group in each estuary. This level of inflow is estimated at an average of 9.9 million acre-feet per year of gaged river flows to all major Texas estuaries combined, except for the Sabine-Neches estuary where again no estimate was possible. Fisheries production was projected to increase almost 18 percent coastwide with this inflow regime.

Lastly, a short-term freshwater inflow need (Level IV) was computed which has as its objective meeting only the monthly salinity viability limits of estuarine-dependent organisms ecologically characteristic of each estuary. Adding up the 12 monthly estimates for an annual cycle, and summing across all seven major estuaries, gives a short-term minimum inflow need of 4.7 million acre-feet per year. At this minimum level of inflow, Texas coastal fisheries harvests are projected to decline overall by one-quarter to one-half of the average historical production. Estimates of freshwater inflow need for individual estuaries are given in Part III of this report.

Instream Flows

The phrase "instream flow needs" refers to the quantity of water flowing within a natural stream which is necessary to maintain the stream's values for instream beneficial uses that include: (1) navigation, (2) hydropower (3) livestock water, (4) water quality maintenance, (5) maintenance of fish and wildlife habitat, (6) recreation, and (7) aesthetic enjoyment. Traditional and legal differences between instream and offstream uses have historically favored the latter, except for the paramount public right of navigation which is established by the Commerce Clause of the United States Constitution.

Purpose

In Texas, diffuse surface waters which originate from natural precipitation become State waters when they reach a stream watercourse or drainage channel. As property of the State, the waters are subject to the appropriative rights doctrine governing their use. To conserve and properly utilize State waters, current State law prioritizes the beneficial uses in the Texas Water Code. Preference for appropriation is given in the Code as: (1) domestic and municipal, (2) industrial, (3) irrigation, (4) mining, and recovery of minerals, (5) hydroelectric, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses. Although uses of instream flows are not given the highest preference they are recognized by the Code within beneficial uses (5) through (8). These would implicitly include protection of riverine fish and wildlife, as well as maintenance of freshwater for the bays and estuaries. However, the instream flows needed for divergent beneficial uses cannot be generalized into a single standard. It is inevitable that Texas streams will provide for multiple water uses, and that tradeoffs will occur to obtain maximum benefits from this limited public resource.

Permits issued by the Texas Water Commission provide that State waters can be appropriated for one or more of the previously listed beneficial uses. Some uses are nonconsumptive, such as navigation and hydroelectric power generation, and can be compatible with instream flow needs of fish and wildlife. Other purposes of water use may not be compatible because they are generally offstream consumption uses, such as waters supplied for irrigation, industrial, and municipal activities.

Stream Water Sources

Texas river systems have water sources that include spring-feeding aquifers, ground-water seeps, and return flows from offstream uses. The characteristics of these instream flows are greatly influenced by climatological conditions and human water demands. Since Texas encompasses large arid areas, a significant percentage of State streams exhibit a naturally intermittent flow pattern with extended periods of little or no flow, while other stream segments have historically had their base flows almost constantly supplied by discharges from the State's major and minor aquifers. However, present and future demands on some of these aquifers may exceed the rate of recharge, and can diminish or even result in complete cessation of spring flows.

Return flows from offstream water users are primarily composed of treated effluents and wastewater discharges. These flows must meet water quality standards set by the Texas Department of Water Resources and can serve as a dependable source of water for many of the State's stream segments which ordinarily would cease to flow during dry seasons. Thus, instream benefits have been created for fishing, hunting, and habitat maintenance by these flows.

Instream benefits are also obtained from construction of reservoirs throughout the State. Texas reservoirs have provided benefits to downstream environments through releases for hydroelectric power generation, alleviation of salt water intrusion, recreation, and municipal, industrial, and agricultural water uses. Structural reservoir features, such as multi-level outlet works, can allow selection or blending of discharge waters for optimal water quality. In addition, operational criteria have been established for some reservoirs to provide a minimum continuous instream flow for maintenance of downstream fish and wildlife habitats. Discharge schedules have also been studied for meeting instream recreational demands, as well as maintenance of Texas bays and estuaries, but water rights permits must be issued on the basis of specific conditions in each case.

Parks and Fish Hatcheries Water Needs

Programs in wildlife management have helped to maintain favorable conditions for wildlife populations in Texas. The Texas Parks and Wildlife Department presently operates 17 wildlife management areas within the State for preservation and research purposes. These areas provide aquatic and terrestrial habitat for the large populations of wildlife species native to the various geographical areas of the State.

The fisheries resources of Texas have long provided one of the more popular forms of outdoor recreation, sport fishing. In recent years, efforts of the Fisheries Division of the Texas Parks and Wildlife Department have been directed toward sustaining a balance of fish populations in the reservoirs, streams, and coastal waters which provide habitat for the more popular species sought by sport fishermen. The Department presently operates 11 freshwater fish hatcheries and one saltwater fish hatchery with a total pond area of 532 acres. Water rights for these facilities total more than 14.5 thousand acre-feet annually; this is a nonconsumptive use of water. An expansion of the hatchery systems over the next ten years has been proposed which would require an additional 5,000 to 6,000 acre-feet of water annually. These proposed facilities would be located in areas having sufficient water to meet their needs.

Recreational land resources in Texas include more than two million acres, of which 92 percent is State-owned and operated land. Wildlife management areas administered by the State account for more than 50 percent of the recreational land resources, with the remaining land area including State parks, historical sites, and designated scenic areas. Sufficient water supplies to maintain these established areas are now and can continue to be obtained from locally available sources. However, when locating additional recreation areas, careful attention should be given to the selection of sites having sufficient water rights.

Recreation and Tourism Water Needs

The State's water resources provide an important recreation resource for the people of Texas as well as for out-of-state visitors. Water-oriented recreation facilities in Texas are operated by private developers and public agencies, the latter of which includes the Corps of Engineers, the Bureau of Reclamation, the Texas Parks and Wildlife

Department, Texas river authorities, special districts, and municipalities.

Although recreation is a nonconsumptive use of water, the magnitude of recreational use of the State's water resources is a viable indicator of the value to Texans of these resources for recreational purposes. In 1980, almost 57 million people visited reservoirs in Texas under the management of the U.S. Army Corps of Engineers, representing an increase of approximately 16 million visitors since 1976.

Texas has 184 lakes and reservoirs which have a conservation storage capacity of five thousand acre-feet or more each, and almost one million acres of water surface. These lakes provide a variety of recreational activities ranging from fishing to sightseeing, with fishing, the most popular activity, accounting for more than 48 percent of all visitation in 1980.

The present level of use of water-oriented recreation facilities indicates that as Texas' population increases, the use of water-oriented recreation facilities can be expected to rise significantly. The 1980 Texas Outdoor Recreation Plan (TORP), prepared by the Texas Parks and Wildlife Department, provides a planning guide for meeting future recreational needs throughout the State. By the year 2000, the 1980 Texas Outdoor Recreation Plan estimates that recreation demand for fishing, boating, skiing, and swimming will increase by 227 million annual activity days. Increased demand for these activities will require an additional 51.8 thousand surface acres of reservoirs. Accommodation of this additional requirement is within the total number of water surface acres to be added in Texas by the year 2000.

PART III

CURRENT WATER USE, FUTURE WATER REQUIREMENTS, AND PROPOSED WATER SUPPLY DEVELOPMENT AND WATER QUALITY PROTECTION IN THE RIVER AND COASTAL BASINS OF TEXAS

INTRODUCTORY OVERVIEW

In Parts I and II, water supply and related problems have been identified; State and federal statutes and institutions which govern or impact water resources development and use have been briefly described; planning methodology and planning data have been described; and the importance of water for the economic, environmental, and social well-being of Texas has been presented.

In Part III, analyses of current water use and projections of water requirements and water-related needs to meet the State's foreseeable 50-year future needs are presented. Projections are made of available ground- and surface-water supplies and use of these sources of supply to meet projected needs in each river and coastal basin of the State, including planning subareas as shown in Figure II-5. Water resource development needs and alternatives are assessed with respect to time of need, quantity of water supply, water quality protection needs, and flood protection elements. Each basin analysis draws together local, State, and federal water resource development and potential development into a complete description and accounting for the basin. In effect, the sum of the individual basin analyses and projections represent a statewide overview of the extremely complex and highly fragmented water resources program in Texas. A statewide tabulation of the specific basin analyses has been made (Table III-1).

Attention is given to water rights in the form of a summary of the present structure of surface- and ground-water-law in Texas and the current status of water rights adjudication activities being carried on by the Texas Department of Water Resources under provisions of the Water Rights Adjudication Act of 1967. A summary of the number of appropriative rights, claims, and filings and associated quantities of surface water involved, as of December 31, 1983, is also provided for each river and coastal basin of the State.

On the basis of new and revised projections of population and economic growth and associated water needs, water resource projects considered necessary to meet future needs to the year 2030 and intervening decades are specifically identified and described in the discussion of problems and needs within each river and coastal basin of the State. These include additional or enlarged reservoirs and new or enlarged water-delivery systems to convey raw water supplies from existing or new sources to areas of current or projected need. Existing supplies as well as additional projects identified as necessary to meet projected needs will not provide for any significant expansion of irrigated agriculture in Texas. In fact, because of competition for available supplies, declining ground-water reserves, urban growth, and the necessity to improve management of the State's aquifers through more careful development to avoid land subsidence and saline-water intrusion into the freshwater bearing zones, irrigated agriculture may decline in some areas, particularly in parts of the coastal region and West Central Texas, as well as the High Plains. The problem of sustaining irrigated agriculture in the High Plains is addressed in Part IV.

Figures II-3 and II-4 illustrate the geographic distribution of major and minor aquifers in Texas. A major aquifer is herein defined as one which produces large quantities of water in a comparatively large area of the State, whereas minor aquifers produce significant quantities of water within smaller geographic areas. Minor aquifers are important in that they presently constitute the only significant source of water supply in some regions of Texas. Estimates have been made for each county of the quantities of water in storage in each aquifer, the average annual recharge to each aquifer, and the quantity of water recoverable from storage in each aquifer. Using this information, estimates have been made of the annual long-term quantities of water supply that might be obtained from the aquifers within each county to meet local area water demands.

Table III-1. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Statewide

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Texas																		
Population			14,229.2			17,846.1			21,239.4			24,840.3			29,127.4			34,276.6
Municipal	1,290.3	1,522.9	2,813.2	1,306.1	2,896.3	4,202.4	1,440.3	3,640.3	5,080.6	1550.4	4,383.7	5,934.1	1,636.7	5,316.5	6,953.2	1,604.1	6,573.4	8,177.5
Manufacturing	248.6	1,271.4	1,520.0	167.3	1,955.1	2,122.4	191.2	2,526.7	2,717.9	219.0	3,095.4	3,314.4	255.4	3,823.6	4,079.0	288.1	4,725.6	5,013.7
Steam Electric	53.0	277.0	330.0	71.9	463.1	535.0	175.8	640.9	816.7	239.6	777.4	1,017.0	267.8	949.2	1,217.0	274.1	1,143.4	1,417.5
Mining	178.4	60.7	239.0	137.8	94.1	231.9	120.6	147.1	267.7	142.8	178.6	321.4	155.5	219.8	375.3	156.2	231.0	387.2
Irrigation	8,957.0	3,749.4	12,706.4	8,407.7	3,918.0	12,325.7	11,631.6	4,579.2	16,210.8	11,342.8	4,854.5	16,197.3	11,767.6	4,746.2	16,513.8	9,907.1	5,111.8	15,018.9
Livestock	119.6	124.3	243.9	128.4	159.1	287.5	140.8	190.9	331.7	134.3	197.4	331.7	120.4	211.3	331.7	103.8	227.9	331.7
State Total Water	10,846.9	7,005.7	17,852.6	10,219.2	9,485.7	19,704.9	13,700.3	11,725.1	25,425.4	13,628.9	13,487.0	27,115.9	14,203.4	15,266.6	29,470.0	12,333.4	18,013.1	30,346.5

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Generally speaking, the annual quantity of ground-water supply available is estimated as the average annual recharge plus the estimated annual quantity of water that would be withdrawn from recoverable storage in order to meet projected future annual needs of each area. However, the annual supply estimates from some aquifers have been constrained to the quantities, which if withdrawn, would not result in degradation of the aquifer through salt-water intrusion or other effects or would not result in land subsidence in coastal areas. Estimates for each area are based on water use data recently reported by those who use water from the aquifers of each respective area, and from projections of future annual water demands of each area. In the case of aquifers having very little recharge, the projected future annual supplies decline and the aquifers will ultimately be depleted. The time at which this will occur depends upon the quantities of water withdrawn annually. In other cases, where recharge is greater, the dependable annual ground-water supplies are greater and of longer duration. Exceptional cases are described briefly.

The projected average annual supply available from the High Plains (Ogallala) Aquifer was estimated by imposing a set of projected ground-water demands and are projections of the annual quantities of ground-water withdrawals that the aquifer is hydrologically capable of supplying under the conditions of the demands projected. The annual quantities of supply estimated for this aquifer are not estimates of the aquifer's safe annual yield because of the very low recharge to this aquifer. Given the "High Series" projected demands from 1980 through 2030, the High Plains (Ogallala) Aquifer is estimated to be capable of supplying 234.55 million acre-feet of ground water from storage with 150.93 million acre-feet of water remaining in storage in January, 2031. On an average annual basis the aquifer receives about 438.9 thousand acre-feet of recharge which means that the projected average annual demands are 19 times greater than the average annual recharge to the aquifer.

The projected average annual ground-water supplies available from the Alluvium and Bolson Deposits Aquifers in El Paso County, using projected high case water demands are 143.7 thousand acre-feet in 1990, 181.4 thousand acre-feet in 2000, 219.1 thousand acre-feet in 2010, 208.5 thousand acre-feet in 2020, and 60.0 thousand acre-feet in 2030. (Note: Will not correlate with Table II-1 because the data pertain only to El Paso County.) These annual supplies were estimated using fresh water storage depletion analyses which assumed that only one-half or about 5.38 million acre-feet of the 10.76 million acre-feet of fresh water in storage could be removed without serious ground water quality degradation in both the Hueco Bolson and Mesilla Bolson Aquifers. Under these conditions, availability of fresh water from the two bolson aquifers is reduced after the year 2000, primarily, in about the year 2003 from the Mesilla Bolson Aquifer and in about the year 2020 from the Hueco Bolson Aquifer. Any additional ground water removed from the bolson aquifers would have to be desalted because of its high salinity. The storage depletion analyses for the two bolson aquifers took into consideration that the aquifers would receive about 26,000 acre-feet of average annual recharge and that by 2030 the Hueco Bolson Aquifer would annually receive about 20,000 acre-feet of artificial recharge.

The annual supplies available from the remaining Alluvium and Bolson Deposits Aquifers, the Trinity Group Aquifer, the Carrizo-Wilcox Aquifer and the Capitan Limestone Aquifer through the year 2029 were projected to include the aquifers' average annual recharge plus quantities from storage which could be safely removed without creating adverse effects due to excessive drawdowns and saline-water encroachment. In the year 2030, the safe annual yields of these aquifers would be reduced to their average annual recharge if the use rates projected for the 1980 through 2030 period actually occur.

The annual yield of the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region was estimated by using a mathematical model of the aquifer in the Guadalupe, San Antonio, and Nueces River Basins. The model analysis indicated that the safe yield of the aquifer in the three basins should be limited to about 425.0 thousand acre-feet per year if satisfactory levels of spring flows from the aquifer are to be preserved. Under a 425.0 thousand acre-feet annual withdrawal rate and a recharge sequence which included a severe drought period, the model analysis indicated that San Marcos Springs would be able to continue flowing and Comal Springs would go dry. However, extreme water-level declines would not occur, and the potential for saline-water encroachment would be greatly reduced. The annual yield for the Edwards (Balcones Fault Zone) Aquifer in the Austin Region (Colorado and Brazos River Basins) is 13.7 thousand acre-feet and is equal to the aquifer's average annual recharge rate within that region. The total projected average annual ground-water supply available from the aquifer, therefore, is 438.7 thousand acre-feet.

For long-range planning purposes, the projected average annual ground-water supplies available through the year 2030 from the Edwards-Trinity (Plateau) Aquifer, the Gulf Coast Aquifer, and the fifteen other minor aquifers are equal to the average annual recharge rates of these aquifers. The quantities of ground-water available from storage in most of these aquifers have not been estimated because sufficient data are not available. The annual yield for the Gulf Coast Aquifer was estimated using an aquifer model analysis in which water-level drawdowns would be constrained in order to minimize land surface subsidence, fault movement, and saline-water encroachment. Ground water available from the Queen City Aquifer in the Trinity, Neches, Sabine, Cypress, and Sulphur River Basins is only suited for irrigation, steam-electric power generation (cooling), mining and stock watering purposes, because this water has inherently high concentrations of iron and high acidity (low pH). Also the ground water available from the Rustler and Blaine Gypsum Aquifers has extremely high concentrations of sulfate, making them suitable only for irrigation purposes.

Many of the major reservoir projects which are urgently needed now, or will be needed before the year 2000, are federal projects which have been authorized by Congress. These projects are identified in the discussions of each river and coastal basin and are listed in Part V. These projects are in various stages of post-authorization planning, design, and construction in accordance with specific provisions of the authorizing documents and established procedures and policies of the federal government and the principal construction agencies for civil works projects. The current status of those authorized federal projects identified is briefly discussed. However, the complexities of implementation of a multipurpose federal project, from authorization to construction, including procedures for local sponsorship, cost-sharing, and contractual procedures, preclude a detailed explanation of the status of each project. Additionally, since most projects must conform to the provisions of the National Environmental Policy Act of 1969 (NEPA), environmental assessments and environmental impact statements for these projects must be prepared in accordance with guidelines established by the Council on Environmental Quality and are in various stages of completion, including public review and comment and public hearing processes.

Other projects for which a clear need has been established to meet current or projected water supply needs are local projects, which are sponsored and financed entirely through local efforts or will receive financial assistance from federal sources or through the Texas Water Development Fund. These projects are in various stages of implementation, ranging from very preliminary planning to construction. The environmental impacts of local projects in the planning and design stage, or which are under construction, and which have received State financial assistance from the Texas Water Development Fund have been assessed or are currently being assessed through methodology described in the Department's Rules.

Reconnaissance-level studies have been performed to identify several alternatives for developing additional water supplies and delivering these supplies from areas of projected surplus to areas which will unquestionably have critical water supply shortages long before the year 2030; however, additional feasibility studies are necessary. Multireservoir and multibasin operation studies utilizing highly specialized and computerized systems analysis approaches are required in order to find potential solutions to some of these problems. Such analyses will be done in cooperation with local sponsors as the need arises. In addition to addressing the physical, hydrologic, and economic feasibility of various alternative water development and conveyance facilities for meeting long-range water supply needs, the mathematical simulation capabilities presently available can be used to address the full range of environmental interactions and consequences of each alternative under consideration.

It is emphasized that this reanalysis and reassessment of Texas water and water-related problems and needs has been based, with few exceptions, upon an analysis of the firm yields of existing, planned, and potential reservoirs in each basin. Through such an analysis, it is assumed that the total dependable supply which each reservoir will yield, under the particular configuration of upstream development imposed upon the basin, is "removed" each year from all reservoirs. Thus, except where consideration has been given to passage or "releases" of water to satisfy specific downstream needs or vested water rights, such an analysis does not provide a true representation of the volume of water diverted from each reservoir for specified uses at any particular point in time—unless, of course, the full dependable yield is actually being diverted and utilized. Streamflow below a reservoir project is a function of the operating criteria for the reservoir, project purposes, and the volume of water diverted for use. For example, water is normally released from the flood-control pool until the reservoir's "normal" operating level is attained. Streamflows within a developed and regulated river basin and the flows available below the most downstream reservoir in the basin at any point in time during a given hydrologic sequence can be estimated with reliable accuracy only through laboriously detailed simulation of the operation of each reservoir in the basin, with projected water demands placed upon each reservoir corresponding with the projected water requirements for the particular period of time. Utilizing existing mathematical modeling capabilities, river basin operation simulations are being carried on for proposed and potential water-resource development configurations and future water-use projections described herein. Existing water rights, as well as water rights adjudication activities, are being given careful consideration in these simulation analyses. These studies are providing estimates—using the current state-of-the-art mathematical simulation techniques—of the volume as well as the temporal and spatial distribution of instream flows and inflows to Texas major estuarine systems in the future.

Financing reservoir development in Texas has historically relied upon federal appropriations, with local commitments to long-term repayment of those costs allocated to project purposes such as water supply, hydroelectric power generation, and certain recreation facilities. The Texas Water Development Fund and local bonding have supplied most of the remaining funds with which water development, including delivery and storage facilities, have been financed in Texas. A brief discussion of current federal cost-sharing policies and procedures, rapidly changing attitudes and programs at the federal level which may significantly alter these policies and procedures, and financing needs and alternative methods of financing to accomplish the necessary water development and management needs in Texas is presented in Part V. The estimated costs of major new reservoir projects considered necessary to meet the water needs of the State are also shown in Part V. These cost estimates also identify the tentative reimbursable costs for water supply in federal multipurpose projects—such costs must be borne by the local sponsor or sponsors of the projects. However, environmental and financial elements are not addressed in empirical detail. The general nature of interactions between water development and management, and the methodology for measuring these environmental interactions and changes, and the types of data required for environmental impact analyses are presented in Part II. Detailed project-by-project and basin-by-basin environmental analyses require significant time and funding and must be done for each project prior to project implementation.

1. CANADIAN RIVER BASIN

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1. CANADIAN RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Canadian River heads in northeastern New Mexico, flows eastward across the Texas Panhandle into Oklahoma, and merges with the Arkansas River in eastern Oklahoma. Major streams joining the Canadian River in Texas are Punta de Agua Creek near the northeast corner of Oldham County, Big Blue Creek near Borger, and Palo Duro Creek 20 miles southwest of Perryton. Total basin drainage area in Texas is about 12,700 square miles. For planning purposes, the Canadian River Basin has been divided into two zones (Figure III-1-1).

Surface Water

Average runoff in the Texas part of the basin during the period 1941 through 1970 was approximately 15 acre-feet per square mile. The average runoff for the 1941-70 period within contributing drainage areas was about 19 acre-feet per square mile. The lowest flows for consecutive years from 1941 through 1970 occurred during three periods. During the years 1952 through 1954, 1963 through 1964, and 1966 through 1967, average runoff was approximately six acre-feet per square mile, two acre-feet per square mile, and two acre-feet per square mile, respectively.

Flooding in the Canadian River Basin is an infrequent occurrence. Floods which do occur are most often of the "flash" variety and are characterized by rapid rise and fall and high flow velocities. Flooding also occurs periodically due to ponding of water in the playa lakes.

The Canadian River at the New Mexico—Texas State line is moderately saline during periods of low flow. The low flow of the main stem generally contains dissolved-solids concentrations ranging from 2,000 to 3,000 milligrams per liter (mg/l). By contrast, runoff from storm events generally contains less than 300 mg/l; however, the discharged weighted average dissolved solids concentrations in the river at the State line generally ranges from 500 to 1,000 mg/l.

Overall, stream quality degrades somewhat as the Canadian River traverses Texas. Although increased streamflow results in a more uniform quality, the discharge-weighted averages of the river remain between 500 and 1,000 mg/l west of Potter County. As the river flows eastward, it cuts through Permian age formations, drains oil and gas producing areas, and receives municipal and manufacturing return flows, all of which locally degrade water quality. The discharge weighted average dissolved solids concentrations of the river just above Lake Meredith is about 1,000 mg/l. Water stored in Lake Meredith in recent years has contained between 300-340 mg/l chloride, 260-300 mg/l sulfate, and 1,000-1,150 mg/l total dissolved solids. Total dissolved-solids concentrations of the river below Lake Meredith generally exceed 1,000 mg/l. In contrast, many tributaries such as Palo Duro Creek, Red Deer Creek, and Rita Blanca Creek have excellent water quality, with dissolved-solids concentrations commonly below 500 mg/l.

Ground Water

The High Plains (Ogallala) Aquifer underlies most of the Canadian River Basin. In 1980, the saturated thickness of the High Plains Aquifer within the basin ranged from about 20 feet to 540 feet. Yields of large-capacity wells average about 700 gallons per minute (gpm); although locally, wells produce up to 1,200 gpm. Generally, the water has less than 1,000 mg/l total dissolved solids. However, in some areas of the basin ground water of the High Plains Aquifer has fluoride concentrations which exceed Environmental Protection Agency—Texas Department of Health primary standards for fluoride.

Slightly to moderately saline water occurs locally in the lowermost saturated deposits of the Ogallala Formation. Development of the aquifer in such areas has caused saline-water encroachment to the wells. Future development of the aquifer within or adjacent to such areas could result in saline-water encroachment.

Population and Economic Development

The population of the Canadian River Basin was reported at 167.5 thousand in 1980. Amarillo is the largest city in the basin with an in-basin population of over 53.2 thousand. The economy of the Canadian River Basin is based on oil and gas production, agriculture and agribusiness, and varied manufacturing activities. Amarillo serves as a regional center for transportation, distribution, and marketing.

Water Use

Municipal water use in the Canadian River Basin totaled 33.4 thousand acre-feet in 1980, of which 87

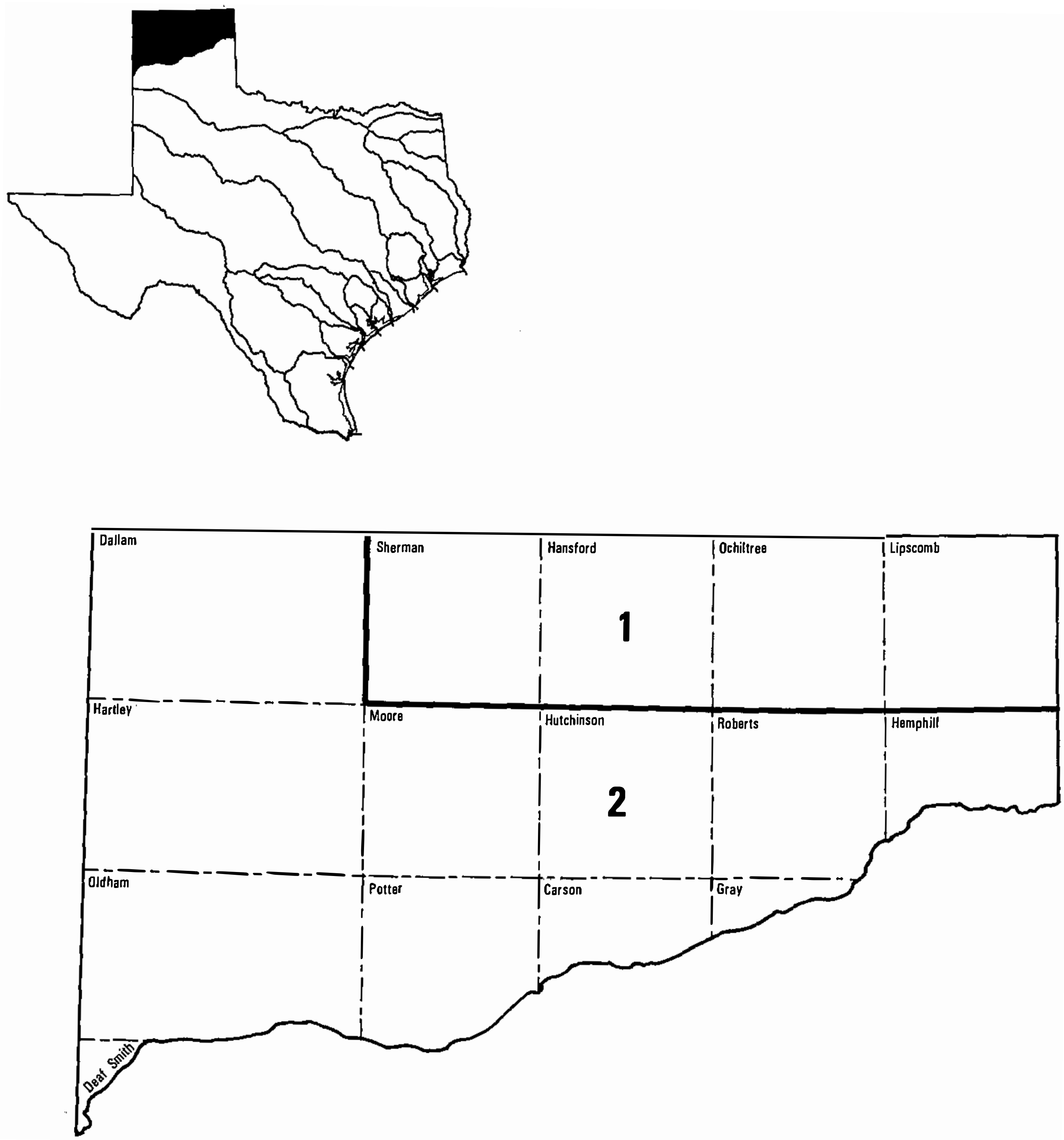

Figure III-1-1. Canadian River Basin and Zones

percent occurred in Zone 2. The City of Spearman used 20 percent and the City of Perryton used 29 percent of the total municipal water use in Zone 1. Almost 41 percent of the municipal water requirement in Zone 2 was attributed to the City of Amarillo (Potter County).

Freshwater use by manufacturing industries in the basin in 1980 was 35.0 thousand acre-feet. Use was almost totally concentrated in Gray, Hutchinson, and Moore Counties of Zone 2. Manufacturing industries in these counties accounted for 90 percent of the total basin use and included the chemicals and petroleum refining industries.

In 1980, there was 1,564 megawatts of installed steam-electric power generating capacity in the Canadian River Basin. Two power plants used a total of 8.7 thousand acre-feet of treated effluent from the City of Amarillo for cooling and other purposes in 1980. In addition, 3.6 thousand acre-feet of ground water was withdrawn from the Ogallala and 2.1 thousand acre-feet of water was diverted from Lake Meredith for steam-electric power production in the Canadian River Basin in 1980. All plants were located in Zone 2 of the Basin.

Irrigated acreage in the basin has increased from 356 thousand acres in 1958 to 1.3 million acres in 1980. Most irrigated acreage produces wheat, grain sorghum, and corn. In 1980, water used for irrigation in the basin totaled 1.7 million acre-feet, of which all but one thousand acre-feet was supplied by ground water from the High Plains Aquifer. Zone 1 of the basin contains about 41 percent of the irrigated acreage, with 534.3 thousand acres using 765.3 thousand acre-feet of water in 1980. Zone 2 contains the remaining 757.2 thousand acres, utilizing 984.2 thousand acre-feet of water in 1980.

Mining water use in the Canadian River Basin is primarily for the extraction of fuels (petroleum and natural gas). An estimated total of 7.0 thousand acre-feet of freshwater was withdrawn for mining in 1980. The most intensive use of water for fuel production is concentrated in Hutchinson County, which accounts for approximately 40 percent of the total mining water use in the basin.

Livestock water use in the Canadian River Basin in 1980 was 15.7 thousand acre-feet. Of this total, ground water provided approximately 12.4 thousand acre-feet, and surface water supplied 3.3 thousand acre-feet. A total of 5.6 thousand acre-feet (4.6 thousand acre-feet of ground water; 1.0 thousand acre-feet of surface water) was used in Zone 1 of the basin and an additional 10.1 thousand acre-feet was used in Zone 2 (7.8 thousand acre-feet of ground water; 2.3 thousand acre-feet of surface water).

Return Flows

In 1980, municipal and manufacturing return flows in the Canadian River Basin totaled 14.6 thousand acre-feet. Zone 1 accounted for only 358 acre-feet of return flows, and the Zone 2 total was 98 percent of the basin total (14.2 thousand acre-feet). Industrial returns comprised approximately 64 percent of the basin total during 1980.

Although a considerable volume of irrigation water is used (1.7 million acre-feet in 1980), irrigation return flows are negligible. Most of the irrigation water applied but not consumed is either reused as tailwater or percolates deeply into the soil.

Current Ground-Water Development

In 1980, approximately 1,825.1 thousand acre-feet of ground water was used in the Canadian River Basin. Of this amount, 774.8 thousand acre-feet was used in Zone 1 and 1,050.3 was used in Zone 2. Practically, all of this ground water was withdrawn from the High Plains (Ogallala) Aquifer which is the primary fresh to slightly saline water-bearing formation in the basin.

Of the 1,825.1 thousand acre-feet of ground water used in the basin, approximately 1,748.5 thousand acre-feet or 96 percent was used for irrigation and about 53.7 thousand acre-feet or 3 percent was used for municipal and manufacturing purposes.

Withdrawals of ground water from the High Plains Aquifer in 1980 are estimated at about 33 times the aquifer's annual natural recharge in Zone 1, and about 18 times the annual natural recharge in Zone 2 of the basin. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage, which has caused significant water-level declines.

Current Surface-Water Development

Since 1952, development and use of the surface-water resources of the Canadian River Basin have been governed by provisions of the Canadian River Compact among the states of New Mexico, Oklahoma, and Texas.

There are presently two major reservoirs in the Canadian River Basin in Texas. Rita Blanca Lake is on Rita Blanca Creek and Lake Meredith is on the Canadian River. Rita Blanca Lake, constructed by the U.S. Soil Conservation Service, is operated by Dallam and Hartley Counties for recreational purposes. The reservoir has a capacity of 12.1 thousand acre-feet and a surface area of 524 acres.

Lake Meredith, completed in 1965 by the U.S. Bureau of Reclamation for water supply and flood control, is operated by the Canadian River Municipal Water Authority (CRMWA). The lake, which has 500 thousand acre-feet of conservation storage, 364 thousand acre-feet of sediment storage and 543 thousand acre-feet of storage capacity allocated to flood control, effectively controls all of the developable surface-water resources of the Canadian River in Texas in accordance with provisions of the Compact. Under provisions of the water supply contract between the Canadian River Municipal Water Authority (CRMWA) and the Bureau of Reclamation, the 11 member cities of the Authority are allocated specific annual quantities of water from the reservoir for municipal and manufacturing uses totaling 103 thousand acre-feet annually. In times of water shortage, allocations are adjusted proportionally by the CRMWA Board of Directors. Member cities include Lubbock, Plainview, Amarillo, Borger, Pampa, Levelland, Brownsfield, Slaton, Tahoka, O'Donnel, and Lamesa. Water supplies are conveyed by an east aqueduct, which serves Borger and Pampa; and the main aqueduct, which extends southward through Amarillo and Lubbock to Lamesa. Laterals from the main aqueduct serve Plainview, Slaton, and O'Donnel. The southwest aqueduct extension from Lubbock serves Levelland and Brownsfield.

Under provisions of the water supply contract, annual allotments of water from Lake Meredith to the Cities of Amarillo, Borger, and Pampa in the Canadian River Basin are 38.17, 5.72, and 7.38 thousand acre-feet, respectively. In the water short year 1980, actual deliveries of water through the aqueduct system to Amarillo, Borger, and Pampa were 20.83, 3.87, and 4.35 thousand acre-feet, respectively.

Water Rights

A total of 185,863 acre-feet of surface water was authorized or claimed for diversion and use in the Canadian River Basin as of December 31, 1983 (Table III-1-1). Municipal uses totaled 110,460 acre-feet, or 60 percent of total authorized or claimed water in the basin (Table III-1-2). Zone 2 accounted for the greater portion of authorized or claimed water use, with 173,326 acre-feet, or 94.5 percent of the total amount of water authorized and/or claimed in the basin (Table III-1-2).

Water Quality

The principal water quality problem in the Canadian River Basin is the natural salinity of the Canadian River which adversely affects water stored in Lake Meredith. Water entering the Canadian River from New Mexico contains high levels of dissolved salts. The problem is compounded by the high chloride content contributed by the geologic formations traversed by the Canadian River and its tributaries. In addition, phreatophytes, principally saltcedar, have become established and are spreading in the delta of Lake Meredith and upstream from the lake. During wet periods, saltcedar consume large quantities of water, leaving dissolved chemical constituents as residue. The residue is subsequently redissolved and transported downstream in river flows. Infrequently, high fecal coliform counts occur in some waters of the basin, due in part to large livestock concentrations. Rita Blanca Lake appar-

Table III-1-1. Authorized or Claimed Amount of Water, by Type of Right, Canadian River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	30	179,963
Claims	17	5,900
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	47	185,863

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-1-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Canadian River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	2	10,460	100,000	110,460
Industrial	5	0	51,604	51,604
Irrigation	34	1,215	8,414	9,629
Recreation	6	862	13,308	14,170
Other	1	0	0	0
Total	47[1]	12,537	173,326	183,363

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

ently suffers no bacteriological problems; however, extensive algal blooms have occurred in the lake.

The quality of water from the High Plains Aquifer in the Canadian River Basin is generally good, although fluoride concentrations locally exceed the Environmental Protection Agency Interim Primary Drinking Water Standards.

Flooding and Drainage

Due to the limited urbanization of the Canadian River Basin, flood damages to urban areas have not been significant. With the exception of the floods in 1941, for which damage estimates are not available, no major floods have occurred in the basin. This is primarily the result of construction of Sanford Dam, completed in early 1965, which created Lake Meredith.

Of the 32 communities which have been designated as having special flood hazards, nine cities are participating in the National Flood Insurance Program. All Participants are in the Emergency Phase of the Program. Due to the limited areas which are susceptible to damaging floods, no concentrated effort has been made to establish 100-year flood elevations in the basin with the exception of the City of Amarillo, which presently has a rate study underway.

Flat topography, low permeability of soils, and lack of adequate natural drainage have produced drainage problems in some areas in the High Plains section of the basin. Many of these areas are visible as playa lakes during wet periods.

Recreation Resources

The two reservoirs in the Canadian River Basin have a combined total of 17.0 thousand surface acres of water available for water-oriented recreation activities. Rita Blanca Lake, the smaller of the two reservoirs with 524 surface acres, is used solely for recreational purposes. Lake Meredith, located 10 miles northwest of Borger, has a surface area of 16.5 thousand acres and serves some of the recreational needs of the people in the Panhandle and Southern High Plains areas.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Canadian River Basin is expected to increase 60 percent by the year 2030, from the present 167.5 thousand (1 percent of the State population) to 267.3 thousand (0.8 percent of the State population), as shown in Table III-1-3. A 15 percent increase to 192.8 thousand is forecast from 1980 to the year 2000, and a growth of 39 percent is anticipated for the following 30 years (2000 to 2030).

Population growth in Potter County (part of the Amarillo Standard Metropolitan Statistical Area) is expected to increase 64 percent over the planning period 1980 to 2030. The population of Ochiltree County is expected to increase 19 percent by 2030, from the present 9.6 thousand to 11.4 thousand; and the population in Sherman County should move upward from 3.2 thousand in 1980 to 7.1 thousand by 2030.

Water Requirements

Municipal

Municipal water requirements were projected for two cases of future growth based on both population and per capita water use. Requirements in the Canadian River Basin are projected to increase from the 1980 level of 33.4 thousand acre-feet by 12 to 15 percent by 2000. In the year 2030, water requirements are projected to range from 49.7 to 73.7 thousand acre-feet. Eighty-seven percent of the municipal water requirements in the year 2000 are projected to occur in Zone 2.

Industrial

Manufacturing water requirements in 1980 were 35.0 thousand acre-feet in the Canadian River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Canadian River Basin are projected to increase by at least 147 percent (as compared to the State average of 178 percent) by the year 2030. Over 99 percent of the manufacturing water requirements are, and likely will remain, concentrated in Zone 2, which includes part of the Amarillo Standard Metropolitan Statistical Area.

Table III-1-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Canadian River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			22.7			23.0			24.9			27.0			30.4			34.4
Municipal	4.4	0.0	4.4	6.0	0.0	6.0	6.7	0.0	6.7	7.3	0.0	7.3	8.2	0.0	8.2	7.0	2.3	9.3
Manufacturing	0.1	0.0	0.1	0.1	0.0	0.1	0.2	0.0	0.2	0.2	0.0	0.2	.3	0.0	0.3	0.3	0.0	0.3
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0	5.9	11.7	0.0	11.7	17.6	0.0	17.6
Mining	1.1	0.0	1.1	0.8	0.0	0.8	0.5	0.0	0.5	0.5	0.0	0.5	.4	0.0	0.4	0.3	0.0	0.3
Irrigation	764.6	0.7	765.3	702.3	0.6	702.9	1,384.8	0.6	1,385.4	1,248.9	0.6	1,249.5	1,016.5	0.7	1,017.2	762.1	0.6	762.7
Livestock	4.6	1.0	5.6	5.1	1.6	6.7	5.9	1.8	7.7	5.4	2.3	7.7	4.5	3.2	7.7	3.4	4.3	7.7
Zone Total Water	774.8	1.7	776.5	714.3	2.2	716.5	1,398.1	2.4	1,400.5	1,268.2	2.9	1,271.1	1,041.6	3.9	1,045.5	790.7	7.2	797.9
Zone 2																		
Population			144.8			160.1			167.9			182.4			205.6			232.9
Municipal	17.6	11.4	29.0	25.2	17.7	42.9	28.1	18.0	46.1	31.7	18.6	50.3	37.4	19.4	56.8	43.4	21.0	64.4
Manufacturing	31.6	3.3	34.9	36.9	9.7	46.6	45.8	12.5	58.3	61.1	8.9	70.0	78.4	6.8	85.2	96.2	6.6	102.8
Steam Electric	3.6	10.8	14.4	1.8	17.1	18.9	18.0	17.1	35.1	24.0	17.1	41.1	29.9	17.1	47.0	35.9	17.1	53.0
Mining	5.8	0.1	5.9	4.7	0.5	5.2	4.3	0.1	4.4	4.4	0.1	4.5	4.5	0.1	4.6	4.6	0.2	4.8
Irrigation	983.9	0.3	984.2	972.2	0.3	972.5	1,674.6	0.4	1,675.0	1,611.7	0.4	1,612.1	1,384.7	0.4	1,385.1	980.9	0.4	981.3
Livestock	7.8	2.3	10.1	8.9	3.1	12.0	10.5	3.5	14.0	9.8	4.2	14.0	8.0	6.0	14.0	6.7	7.3	14.0
Zone Total Water	1,050.3	28.2	1,078.5	1,049.7	48.4	1098.1	1,781.3	51.6	1,832.9	1,742.7	49.3	1,792.0	1,542.9	49.8	1,592.7	1,167.7	52.6	1,220.3
BASIN TOTALS																		
Population			167.5			183.1			192.8			209.4			236.0			267.3
Municipal	22.0	11.4	33.4	31.2	17.7	48.9	34.8	18.0	52.8	39.0	18.6	57.6	45.6	19.4	65.0	50.4	23.3	73.7
Manufacturing	31.7	3.3	35.0	37.0	9.7	46.7	46.0	12.5	58.5	61.3	8.9	70.2	78.7	6.8	85.5	96.5	6.6	103.1
Steam Electric	3.6	10.8	14.4	1.8	17.1	18.9	18.0	17.1	35.1	29.9	17.1	47.0	41.6	17.1	58.7	53.5	17.1	70.6
Mining	6.9	0.1	7.0	5.5	0.5	6.0	4.8	0.1	4.9	4.9	0.1	5.0	4.9	0.1	5.0	4.9	0.2	5.1
Irrigation	1,748.5	1.0	1,749.5	1,674.5	0.9	1,675.4	3,059.4	1.0	3,060.4	2,860.6	1.0	2,861.6	2,401.2	1.1	2,402.3	1,743.0	1.0	1,744.0
Livestock	12.4	3.3	15.7	14.0	4.7	18.7	16.4	5.3	21.7	15.2	6.5	21.7	12.5	9.2	21.7	10.1	11.6	21.7
Basin Total Water	1,825.1	29.9	1,855.0	1,764.0	50.6	1,814.6	3,179.4	54.0	3,233.4	3,010.9	52.2	3,063.1	2,584.5	53.7	2,638.2	1,958.4	59.8	2,018.2

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Steam-Electric Power Generation

Water requirements for steam-electric power production in the Canadian River Basin will continue to increase steadily in the future. During the next 20 years, installation of the projected additional generating capacity will occur in Zone 2, so that by the year 2000 total water requirements will exceed 35 thousand acre-feet per year. By the year 2030, total freshwater requirements for steam-electric power production in the basin are projected to increase an additional 54 percent to 101 percent, low and high case, respectively.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Canadian River Basin are projected to increase from the 1980 level of 1.7 million acre-feet by a projected maximum 75 percent by the year 2000 in the high case, declining 3 percent in the low case. In the year 2030, water requirements in the basin are projected to decline to 1.7 million acre-feet annually, in the high case, to irrigate 1.2 million acres.

Zone 1 is projected to account for about 45 percent, and 44 percent of total basin irrigation requirements in 2000 and in 2030 respectively; Zone 2 is projected to account for about 55 and 56 percent of the total in the high case.

A range of 0.7 to 1.4 million acre-feet and 1.0 to 1.7 million acre-feet of irrigation requirements is projected in Zones 1 and 2 by 2000. By 2030, the range is from 0.7 to 0.8 million acre-feet and 1.0 to 1.1 million acre-feet annually in Zones 1 and 2.

Livestock

Livestock water requirements within the basin are projected to increase from 15.7 thousand acre-feet in 1980 to 21.7 thousand acre-feet annually by 2000. In 1980, in Zone 1, livestock used 5.6 thousand acre-feet and 10.1 thousand acre-feet in Zone 2. By2030, approximately 21.7 thousand acre-feet of water will be required to satisfy livestock needs in the basin annually, with an estimated 7.7 thousand acre-feet required in Zone 1 and 14.0 thousand acre-feet needed in Zone 2.

Mining

Mining water use in 1980, primarily oil and gas recovery, totaled 7.0 thousand acre-feet in the Canadian River Basin. These requirements are projected to decrease to 5.1 thousand acre-feet by 2030, due to a decline in quantities of potential oil to produce. The Canadian River Basin proportion of total State mining water use, three percent in 1980, is expected to decline to one percent by 2030.

Navigation

No navigation facilities are planned in the Canadian River Basin.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the Canadian River Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas

Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains Aquifer within the Canadian River Basin from 1990 through 2030 by decade: 1.73 million acre-feet in 1990, 3.13 million acre-feet in 2000, 2.99 million acre-feet in 2010, 2.55 million acre-feet in 2020, and 1.94 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 110 million acre-feet of ground water would be removed from storage, and that of the 99 million acre-feet remaining in recoverable storage in the year 2031 about 32 million acre-feet would remain in the "caprock" (tillable) area and 67 million acre-feet would remain in the "breaks" (nontillable) area of the basin. Within the Canadian River Basin, the High Plains Aquifer receives on an average annual basis about 82.8 thousand acre-feet of recharge. The High Plains Aquifer is the only major fresh to slightly saline water-bearing formation within the Canadian River Basin. Very small, minor amounts of ground water may be available from thin alluvial deposits along the flood plain of the Canadian River and from Mesozoic and Paleozoic rocks in the southwestern portion of the basin where the Ogallala Formation has been removed by erosion in the Canadian River Valley.

The projected annual ground-water use within the Canadian River Basin by decade from 1990 through 2030 is expected to be from 1.76 to 3.15 million acre-feet per year (Table III-1-4). The approximate average annual projected ground-water use within the basin is expected to be about 2.44 million acre-feet per year. Of the 2.44 million acre-feet of average annual projected use, practically all is expected to be from the High Plains (Ogallala) Aquifer.

Surface-Water Availability and Proposed Development

An assessment of the available future water resources in the Canadian River Basin indicates that in all decades beginning in 2000, the basin will experience significant water shortages (Table III-1-4, Figure III-1-2). The surface-water export in Table III-1-4 is for municipal and manufacturing purposes outside of the basin.

Water requirements in Zone 1 of the basin will not exceed available ground- and surface-water resources until after 2030 (Table III-1-5, Figure III-1-3). Shortages amounting to 30.8 thousand acre-feet and 143.8 thousand acre-feet per year (Table III-1-6, Figure III-1-4) are projected to occur in Zone 2 in 2000 and 2030, respectively. The water use category expected to experience these shortages is irrigated agriculture. Water shortages in the basin occur primarily due to the decline in available ground-water resources beginning around the year 1990. Total water shortages in the basin for irrigation increase from 6.2 thousand acre-feet in year 1990 to 147.0 thousand acre-feet in the year 2030.

The continued suitability of water from Lake Meredith for municipal and manufacturing purposes is potentially threatened by increasing salinity of the water in the lake. Salt concentrations in Lake Meredith have, during drought periods, reached levels considered undesirable for drinking water by the U.S. Public Health Service and the Environmental Protection Agency. The U.S. Bureau of Reclamation is studying the feasibility of the development of a pumping and surface storage system to control the flow of brine from artesian aquifers which contribute saline inflows to the Canadian River upstream of Lake Meredith. Such a control system is needed now to protect the water quality of Lake Meredith from further deterioration.

The arid nature of the Canadian River Basin limits the future surface-water resources that can be developed. Because of local interest in developing a supplemental surface-water supply in the area, considerable study has been given to a potential reservoir on Palo Duro Creek, a principal tributary of the North Canadian River. Following creation of the Palo Duro Water Authority by the 56th Legislature, the Authority conducted feasibility studies of potential reservoir sites on Palo Duro Creek. Subsequently, in 1974 the Authority obtained a permit from the Texas Water Rights Commission for construction of a 60.9 thousand acre-feet capacity reservoir on Palo Duro Creek several miles north of Spearman in Hansford County. The reservoir would provide municipal supplies, serve recreational needs of the area, and provide some flood-control benefits along Palo Duro Creek below the dam. The project would have a dependable yield of approximately 10.5 thousand acre-feet annually. Construction of Palo Duro Reservoir will depend upon final decisions of local interests and development of financing arrangements. Project sponsors are currently planning the reservoir and expect to have it constructed by 1990.

Water Quality Protection

A water quality management plan for the Canadian River Basin has been developed pursuant to the requirements of the federal and State Clean Water legislation. The purpose of the plan is to provide information for use in protecting and improving water quality. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Table III-1-4. Water Resources of the Canadian River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1757.8	—	—	—	1757.8	1764.0	—	—	1764.0	.0	(6.2)	(6.2)
Surface Water	103.0	—	18.0	.0	121.0	44.5	—	66.2	110.7	10.3	.0	10.3
Total	1860.8	—	18.0	.0	1878.8	1808.5	—	66.2	1874.7	10.3	(6.2)	4.1
2000												
Ground Water	3146.7	—	—	—	3146.7	3179.5	—	—	3179.5	.0	(32.8)	(32.8)
Surface Water	103.0	—	18.3	.0	121.3	47.6	—	71.7	119.3	2.0	.0	2.0
Total	3249.7	—	18.3	.0	3268.0	3227.1	—	71.7	3298.8	2.0	(32.8)	(30.8)
2010												
Ground Water	2975.1	—	—	—	2975.1	3010.0	—	—	3010.0	.0	(35.9)	(35.9)
Surface Water	103.0	—	18.6	.0	121.6	44.6	—	74.2	118.8	2.8	.0	2.8
Total	3078.1	—	18.6	.0	3096.7	3055.6	—	74.2	3129.8	2.8	(35.9)	(33.1)
2020												
Ground Water	2493.1	—	—	—	2493.1	2584.5	—	—	2584.5	.0	(91.4)	(91.4)
Surface Water	103.0	—	19.1	.0	122.1	43.3	—	74.5	117.8	4.3	.0	4.3
Total	2596.1	—	19.1	.0	2615.2	2627.8	—	74.5	2702.3	4.3	(91.4)	(87.1)
2030												
Ground Water	1811.4	—	—	—	1811.4	1958.4	—	—	1958.4	.0	(147.0)	(147.0)
Surface Water	113.6	—	19.6	.0	133.2	47.0	—	74.7	121.7	11.4	.0	11.4
Total	1925.0	—	19.6	.0	1944.6	2005.4	—	74.7	2080.1	11.4	(147.0)	(135.6)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

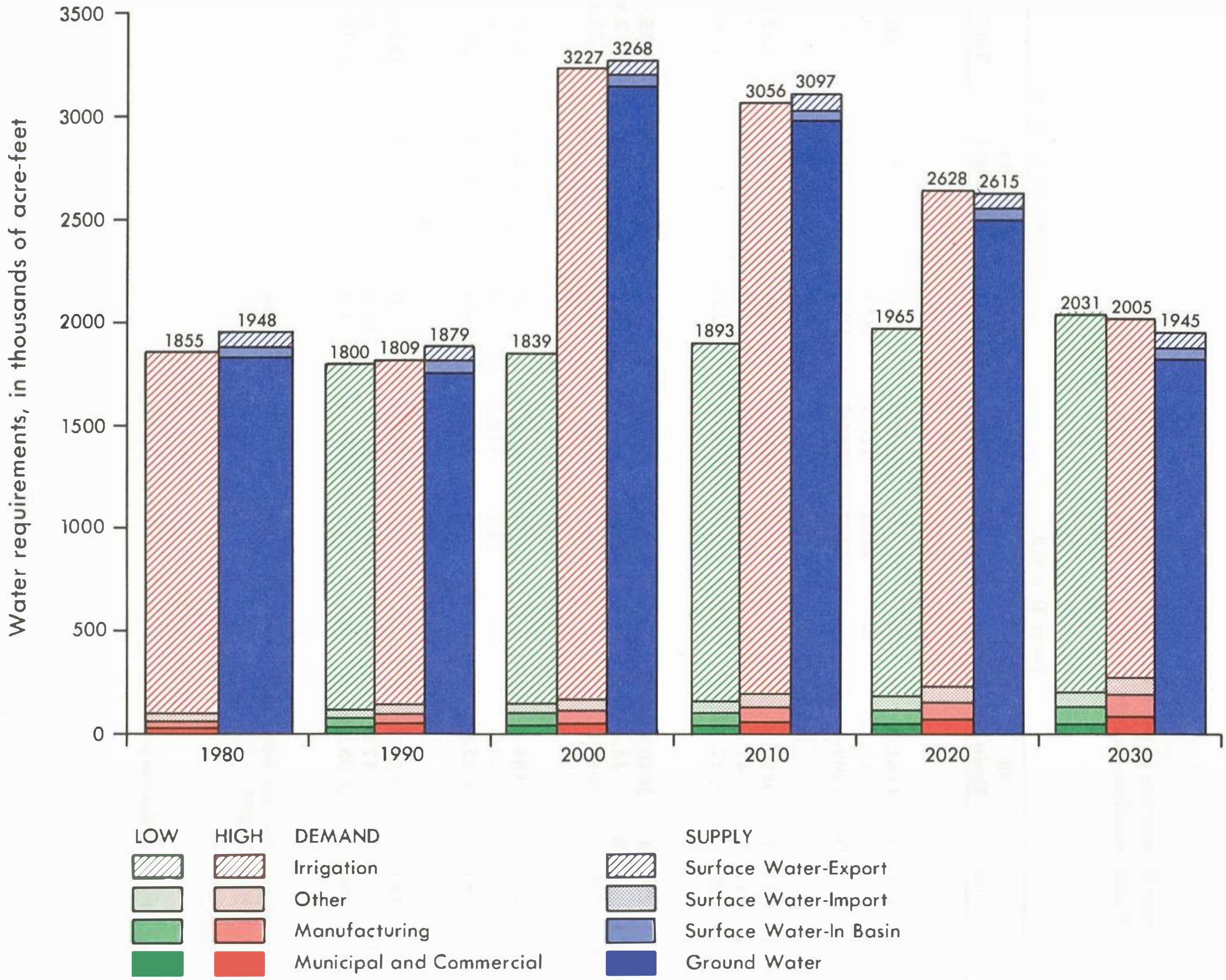

Figure III-1-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, 1980-2030

Construction costs associated with municipal wastewater collection treatment facilities needs have been estimated to be approximately $37.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Canadian River Basin with approximately $34.6 million required in Zone 2, while approximately $3 million is projected for Zone 1. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of oil and gas, agricultural, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Lake Meredith is the only major flood-control reservoir in the Canadian River Basin. The reservoir has 543.2 thousand acre-feet of flood-control storage. The U.S. Army Corps of Engineers is currently studying the basin to evaluate water-resource problems and needs. The objective of the study is to develop a comprehensive integrated

Table III-1-5. Water Resources of the Canadian River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	714.3	—	—	—	714.3	714.3	—	—	714.3	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	714.3	.0	.0	.0	714.3	714.3	.0	.0	714.3	.0	.0	.0
2000												
Ground Water	1398.1	—	—	—	1398.1	1398.1	—	—	1398.1	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1398.1	.0	.0	.0	1398.1	1398.1	.0	.0	1398.1	.0	.0	.0
2010												
Ground Water	1268.2	—	—	—	1268.2	1268.2	—	—	1268.2	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1268.2	.0	.0	.0	1268.2	1268.2	.0	.0	1268.2	.0	.0	.0
2020												
Ground Water	1041.6	—	—	—	1041.6	1041.6	—	—	1041.6	.0	.0	.0
Surface Water	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total	1041.6	.0	.0	.0	1041.6	1041.6	.0	.0	1041.6	.0	.0	.0
2030												
Ground Water	790.7	—	—	—	790.7	790.7	—	—	790.7	.0	.0	.0
Surface Water	10.6	.0	.0	.0	10.6	2.2	.0	.0	2.2	8.4	.0	8.4
Total	801.3	.0	.0	.0	801.3	793.0	.0	.0	793.0	8.4	.0	8.4

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

plan of improvement for the Canadian River Basin. An interim report on the feasibility of a multipurpose project on Palo Duro Creek in Hansford County, near Spearman, Texas has been completed and is under review by the Corps' Southwestern Division. The project would provide standard project flood protection.

In the Canadian River Basin, 20 floodwater-retarding structures are planned for construction in Zone 2 under the U.S. Department of Agriculture—Soil Conservation Service Watershed Management Program. None are planned in Zone 1. There were no such structures in the basin as of October 1980.

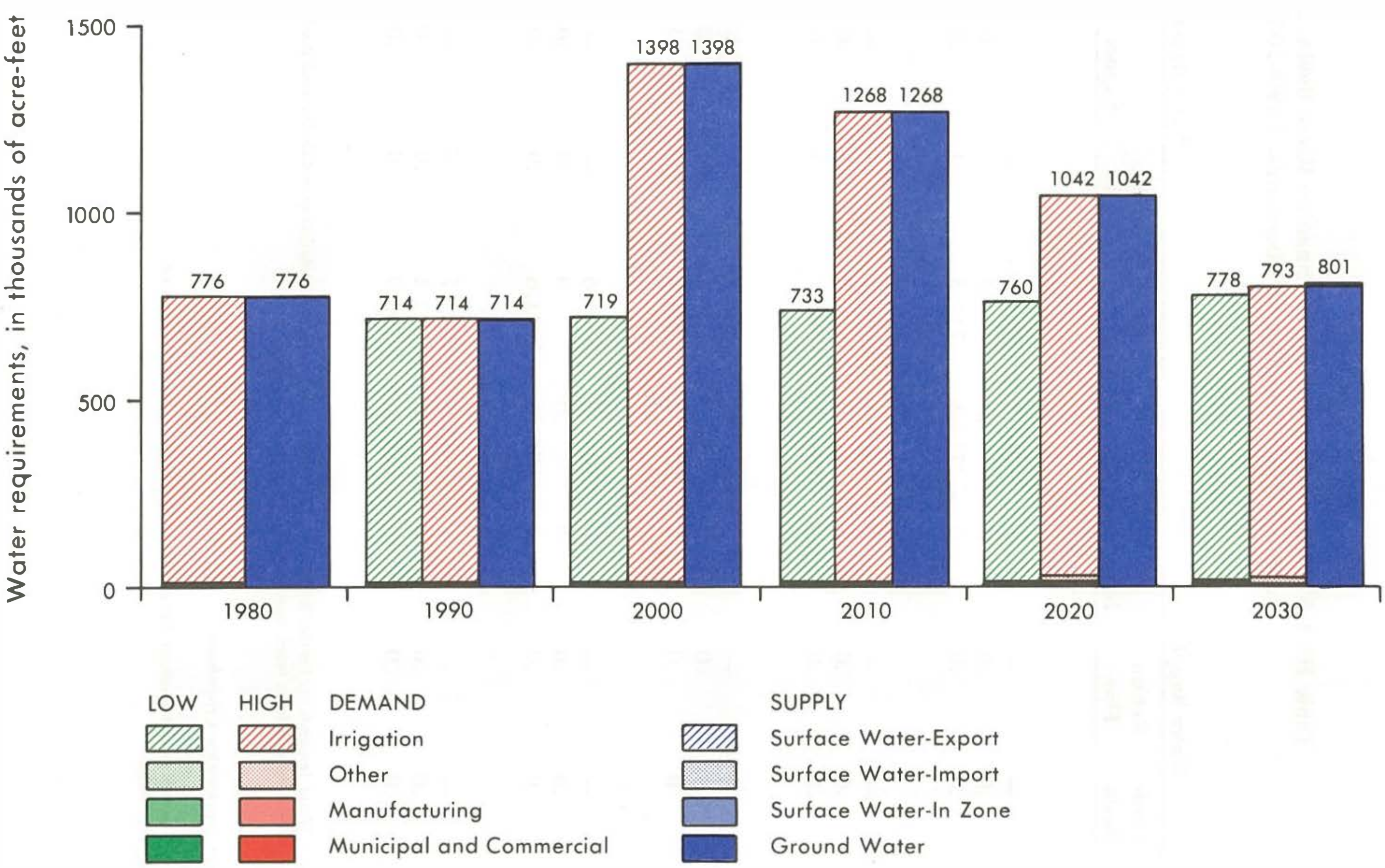

Figure III-1-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, Zone 1, 1980-2030

Table III-1-6. Water Resources of the Canadian River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1043.5	—	—	—	1043.5	1049.7	—	—	1049.7	.0	(6.2)	(6.2)
Surface Water	103.0	.0	18.0	.0	121.0	44.5	.0	66.2	110.7	10.3	.0	10.3
Total	1146.5	.0	18.0	.0	1164.5	1094.2	.0	66.2	1160.4	10.3	(6.2)	4.1
2000												
Ground Water	1748.6	—	—	—	1748.6	1781.4	—	—	1781.4	.0	(32.8)	(32.8)
Surface Water	103.0	.0	18.3	.0	121.3	47.6	.0	71.7	119.3	2.0	.0	2.0
Total	1851.6	.0	18.3	.0	1869.9	1829.0	.0	71.7	1900.7	2.0	(32.8)	(30.8)
2010												
Ground Water	1706.9	—	—	—	1706.9	1742.8	—	—	1742.8	.0	(35.9)	(35.9)
Surface Water	103.0	.0	18.6	.0	121.6	44.6	.0	74.2	118.8	2.8	.0	2.8
Total	1809.9	.0	18.6	.0	1828.5	1787.4	.0	74.2	1861.6	2.8	(35.9)	(33.1)
2020												
Ground Water	1451.5	—	—	—	1451.5	1542.9	—	—	1542.9	.0	(91.4)	(91.4)
Surface Water	103.0	.0	19.1	.0	122.1	43.3	.0	74.5	117.8	4.3	.0	4.3
Total	1554.5	.0	19.1	.0	1573.6	1586.2	.0	74.5	1660.7	4.3	(91.4)	(87.1)
2030												
Ground Water	1020.7	—	—	—	1020.7	1167.7	—	—	1167.7	.0	(147.0)	(147.0)
Surface Water	103.0	.0	19.6	.0	122.6	44.7	.0	74.7	119.4	3.2	.0	3.2
Total	1123.7	.0	19.6	.0	1143.3	1212.4	.0	74.7	1287.1	3.2	(147.0)	(143.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
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Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

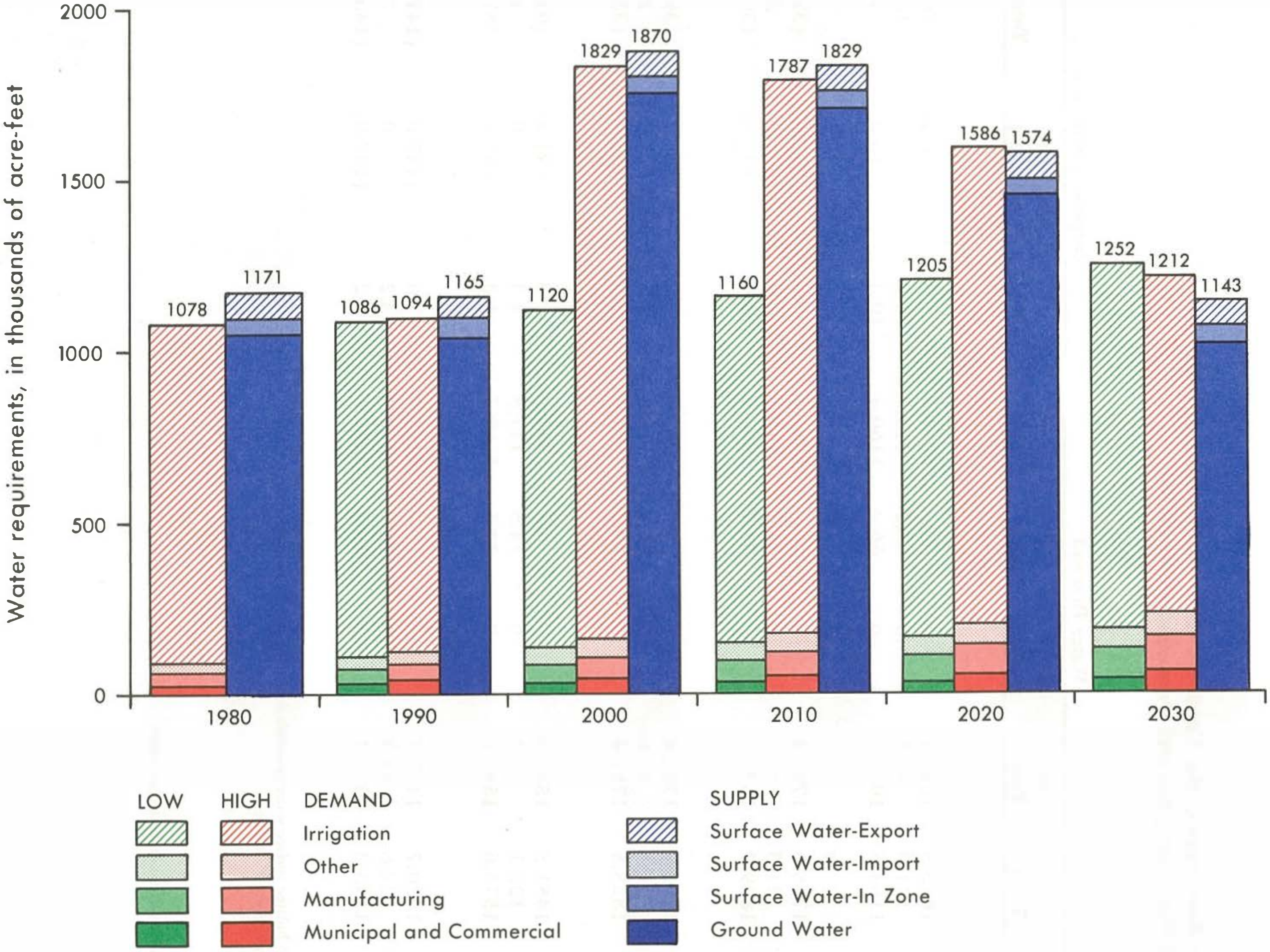

Figure III-1-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Canadian River Basin, Zone 2, 1980-2030

2. RED RIVER BASIN

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2. RED RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Red River Basin is bounded on the north by the Canadian River Basin and on the south by the Brazos, Trinity, and Sulphur River Basins. Beginning in the High Plains of eastern New Mexico at an elevation of about 4,800 feet, the Red River flows eastward and forms the northern boundary of Texas east of the Panhandle. The river leaves Texas near Texarkana where the elevation of the streambed is about 250 feet. Total basin drainage area is 48,030 square miles, of which 24,463 square miles is in Texas. The North Fork of the Red River forms near Pampa and the Salt Fork of the Red River forms about 26 miles east of Amarillo. Both forks exit Texas into Oklahoma and join the Red River, individually, about 17 miles north of Vernon, Texas. Palo Duro Creek forms near Canyon, Texas and becomes Prairie Dog Town Fork to the east, which in turn becomes the Red River at the 100th meridian. The Red River Basin has been divided into three zones for planning purposes (Figure III-2-1).

Surface Water

The average annual runoff in the basin from 1941 through 1970 was about 203 acre-feet per square mile of contributing drainage area. The lowest flows occurred during the period 1952-56 and 1963-67. From 1952 through 1956, the average annual runoff was 110 acre-feet per square mile, while from 1963 through 1967 the average annual runoff was 95 acre-feet per square mile.

Major flooding occurs infrequently on the upper branches and primary tributaries of the Red River in the drier High Plains region. However, localized "flash" flooding, characterized by rapidly rising and falling peak discharges and high flow velocities, occurs within the region. Progressing eastward through the Red River Basin, flood characteristics change as annual rainfall increases and wide, shallow stream channels become more wooded. Floods rise for several hours after intense rainfall and usually remain out of the banks for several hours.

Extreme variations in chemical quality occur in streams in the Red River Basin in Texas. In the eastern, high-rainfall part of the basin, tributaries carry water containing less than 100 milligrams per liter (mg/l) total dissolved solids, while in the western part of the basin many streams are highly saline and the water is unsuitable for most beneficial uses.

Under low-flow conditions, waters of the lower reaches of the Prairie Dog Town Fork Red River, Pease River, and Wichita River are highly saline, frequently exceeding 25,000 mg/l total dissolved solids, 3,000 mg/l sulfate, and 10,000 mg/l chloride. These high salt loads are derived principally from salt springs and seeps. The average dissolved-solids concentration of water in Lake Kemp is about 3,000 mg/l, of which 700 mg/l is sulfate and 1,200 mg/l is chloride. Beaver and Buffalo Creeks, tributaries of the Wichita River, are periodically affected by drainage from oil fields, but otherwise contribute water of good quality. Despite dilution by floodwaters, the water of the Wichita River averages more than 2,000 mg/l total dissolved solids at the mouth. Water of the Little Wichita River is of excellent quality. The average dissolved-solids concentration is about 400 mg/l.

The quality of the main stem of the Red River gradually improves downstream, but near Gainesville the concentration of dissolved solids between 1977 and 1980 ranged from 850 to 4,000 mg/l, with an average of 2,500 mg/l. Lake Texoma, on the main stem, receives good quality inflows from the Washita River in Oklahoma. The resulting dilution reduces the average concentration of total dissolved solids in water discharged from the lake to about 1,000 mg/l.

Below Lake Texoma, waters of all tributaries of the Red River are low in dissolved solids, thus improving the quality of the main stem. At De Kalb, Texas, the average concentration of dissolved solids in the Red River is about 900 mg/l.

Ground Water

The High Plains (Ogallala) Aquifer underlies most of the upper Red River Basin. The Ogallala Formation is the most productive water-bearing unit of the High Plains Aquifer in Texas. In 1980, the saturated thickness of the High Plains Aquifer within the basin ranged from about 20 feet to 420 feet. Yields of large-capacity wells average about 500 gallons per minute (gpm); although locally wells produce up to 1,100 gpm. Generally, the water has less than 1,000 mg/l total dissolved solids. However, in some areas of the basin, water of the High Plains Aquifer has fluoride concentrations which exceed Environmental Protection Agency—Texas Department of Health primary standards for fluoride.

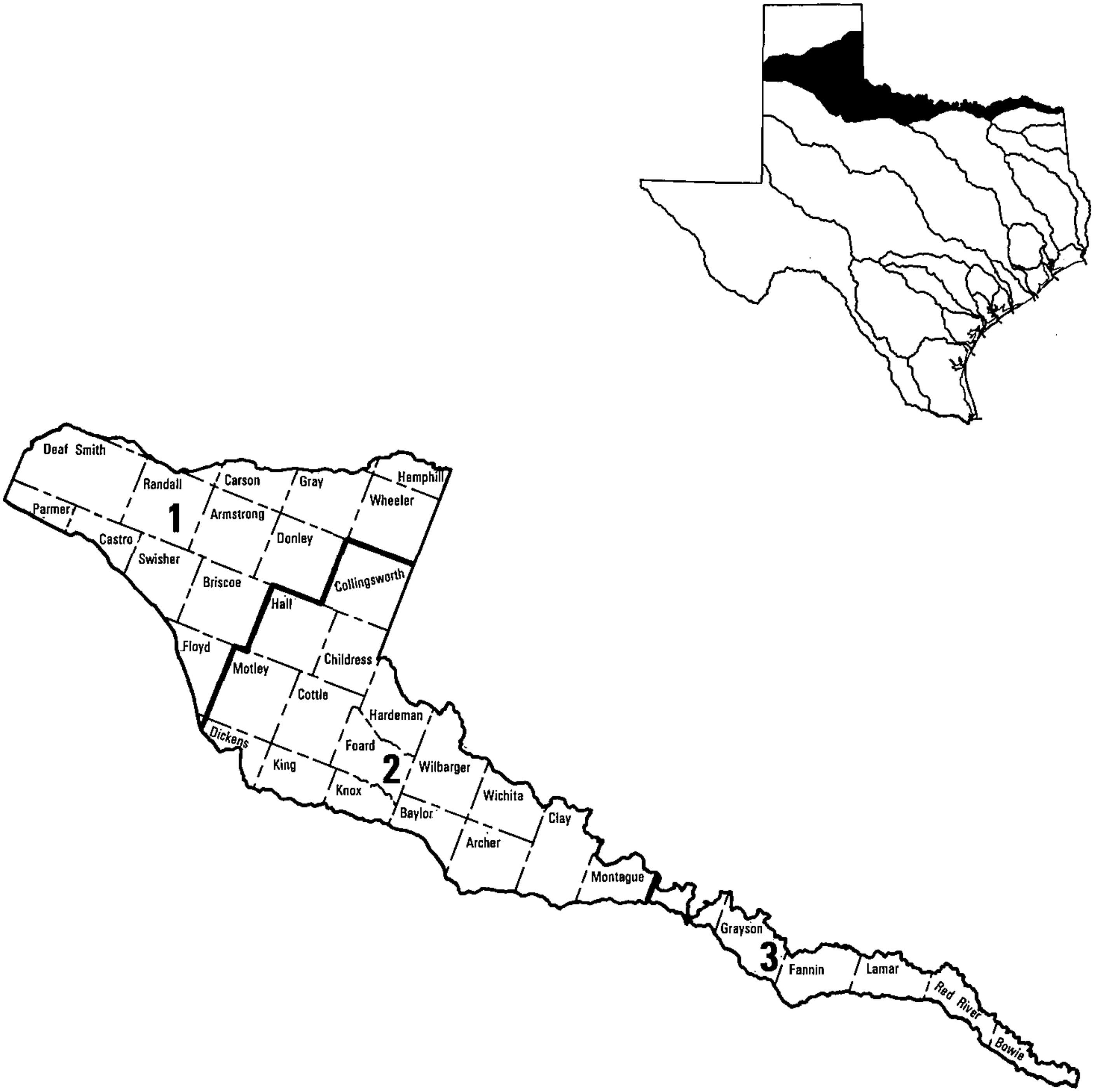

Figure III-2-1. Red River Basin and Zones

The Alluvium Aquifer produces water in local areas in the central part of the Red River Basin. Generally, total thickness is 100 feetorless, but locally it ranges up to about 360 feet. Saturated thickness is commonly less than 50 feet, with a maximum of about 150 feet. Yields of high-capacity wells average 300 gpm, but locally wells produce up to 1,300 gpm. Water in the aquifer is fresh over most of the area, but in some locations is slightly saline.

The Trinity Group Aquifer extends over the eastern and east-central parts of the basin. Total thickness ranges from approximately 400 feet to more than 1,000 feet. Yields of large-capacity wells average 325 gpm; locally wells produce up to 700 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip and toward the east.

The Blaine Gypsum Aquifer occurs in the west-central part of the Red River Basin. Total thickness ranges up to about 250 feet. Yields of high-capacity wells average 400 gpm but locally wells produce up to 1,500 gpm. Water in the aquifer is of relatively poor quality, generally ranging from 2,000 to more than 5,000 mg/l total dissolved solids.

The Woodbine Aquifer occurs in the eastern part of the basin. Total thickness ranges from about 400 to 600 feet. Yields of large-capacity wells average 175 gpm; locally, wells produce up to about 700 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip.

The Blossom Sand Aquifer also extends through the eastern part of the basin. Total thickness ranges up to approximately 400 feet. Yields of high-capacity wells range up to about 650 gpm, but average well yields are significantly lower. Water in the aquifer generally contains from about 500 to more than 2,000 mg/l total dissolved solids.

The Nacatoch Sand Aquifer occurs in Bowie County in the far eastern part of the basin. Total thickness ranges from 350 feet to 500 feet. The aquifer produces usable-quality water to a depth of about 800 feet. Well yields range up to a maximum of about 500 gpm. Water in the aquifer generally contains from 400 to 1,000 mg/l total dissolved solids, with salinity increasing downdip.

Highly mineralized ground waters occur locally in the upper half of the Red River Basin. In these areas, depletion of storage within these aquifers will cause highly mineralized ground waters to invade the depleted fresh to slightly saline ground waters.

Population and Economic Development

The population of the Red River Basin was reported to be 506.0 thousand in 1980. Amarillo is the largest city in the basin with an in-basin population of over 95.9 thousand. It is followed in size by Wichita Falls, which has a population of 94.2 thousand; Sherman, Denison, Hereford, and Vernon all have populations of 12 thousand or more.

The economy of the area is based on oil and gas production, agriculture and agribusiness, manufacturing, retail trade, and tourism. In the western portion of the basin, there is extensive crop irrigation. Wichita Falls serves as a retail trading center and the Sherman-Denison area is a leading manufacturing and trade center serving the north Texas and southern Oklahoma region.

Water Use

Municipal water use in the Red River Basin totaled 98.4 thousand acre-feet in 1980. Zone 1 accounted for 38 percent, Zone 2 consumed 39 percent, and Zone 3 used 23 percent of the basin total.

Cities using significant quantities of municipal water in Zone 1 in 1980 were Hereford, Friona, Amarillo (58 percent of Zone 1 total), and Tulia; Wichita Falls was the largest user in Zone 2 (45 percent of the zone total), and the Cities of Denison, Sherman, and Paris accounted for over 61 percent of municipal water use in Zone 3. Over the basin, 19 percent of the total municipal water use (18.4 thousand acre-feet) was used by rural population or by cities of less than one thousand population.

Manufacturing industries in the Red River Basin used 17.2 thousand acre-feet of freshwater during 1980. Fifty-five percent of this amount originated in Zone 1, while 16 and 29 percent of the total was used in Zone 2 and Zone 3, respectively. Food and kindred products was the major water-using industrial category in Zone 1. Manufacturing freshwater use in Zone 2, however, occurred predominantly in Wichita County where a relatively large variety of manufacutring industries used moderate quanitites of freshwater. In Zone 3, almost the entire use (5.0 thousand acre-feet) occurred in Grayson County, whose major industries were the manufacture of food products, electrical machinery, and scientific instruments.

In 1980, there was 1,144 megawatts of steam-electric power generating capacity in the Red River Basin.

All plants used surface water for cooling, and together they consumed about 9.2 thousand acre-feet of water. This included 6.3 thousand acre-feet of estimated net natural evaporation from cooling reservoirs. In addition, 136 acre-feet of ground water was used for power plant operations.

Irrigation development in the Red River Basin in Texas is largely in the High Plains area (Zone 1). About 1.2 million acres was irrigated in the basin during 1980 using 1.4 million acre-feet of water. About 87 percent of the irrigated acreage was located in Zone 1. Of the approximately 1.2 million acre-feet of irrigation water used in Zone 1 during 1980, all except 2.4 thousand acre-feet was supplied by the High Plains (Ogallala) Aquifer.

In the North-Central Texas area (Zone 2), about 111.0 thousand acres was irrigated in 1980 using 143.6 thousand acre-feet of water. The Alluvium Aquifer and the Blaine Gypsum Aquifer supplied 86.7 thousand acre-feet of this total. Surface water supplied 56.9 thousand acre-feet of on-farm use, most of which was supplied from Lake Kemp and Lake Diversion on the Wichita River.

About 38.3 thousand acre-feet of water was used for irrigation in Zone 3 in 1980. Approximately 92 percent of the Zone 3 irrigation use was from surface-water sources.

Petroleum and natural gas production in the Red River Basin accounted for approximately 87 percent of the 1980 estimated total mining freshwater use of 2.7 thousand acre-feet. The largest freshwater withdrawals for fuel production occurred in Zone 1, with 1.1 thousand acre-feet. Major areas of mining water use are concentrated in Gray County, which accounts for approximately 29 percent of the total basin mining water use.

Livestock water use in 1980 in the basin totaled 33.4 thousand acre-feet. About 20.0 thousand acre-feet was used in Zone 1, 9.1 thousand in Zone 2, and the remainder was used in Zone 3.

There is 70 megawatts of installed hydroelectric power generating capacity at Denison Dam.

Return Flows

In 1980, municipal and manufacturing return flows in the Red River Basin totaled 43.0 thousand acre-feet.

In Zone 1 of the Red River Basin, irrigation return flows are negligible. Any excess irrigation water applied is generally either reused as tailwater or percolates into the soil.

In Zone 2, the areas irrigated from ground-water supplies contribute negligible amounts of irrigation return flows. An estimated 10.5 thousand acre-feet of return flows (35 percent of surface-water use) originated in Zone 2 in 1980. In-stream losses by seepage and evapotranspiration deplete most of these return flows above Lake Texoma.

In 1980, about 2.6 thousand acre-feet of return flows was estimated to originate in Zone 3 of the basin.

Current Ground-Water Development

In 1980, approximately 1,347.0 thousand acre-feet of ground water was used in the Red River Basin. Of this amount, 1,226.7 thousand acre-feet was used in Zone 1, 99.4 thousand acre-feet in Zone 2, and 20.9 thousand acre-feet in Zone 3 of the basin. Practically all of the ground water used in 1980 in Zone 1 of the basin was withdrawn from the High Plains (Ogallala) Aquifer. In Zone 2, most of the ground water used in 1980 was from the Seymour Alluvial Aquifer. Most of the ground water used in Zone 3 was from the Woodbine and Trinity Group Aquifers.

Of the 1,347.0 thousand acre-feet of ground water used in the basin approximately 1,264.3 thousand acre-feet or 94 percent was used for irrigation and about 61.6 thousand acre-feet or about 4 percent was used for municipal and manufacturing purposes.

Withdrawals of ground water in 1980 in Zone 1 from the High Plains Aquifer are estimated at about 22 times the aquifer's annual natural recharge. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage which has caused significant water-level declines.

In 1980 within Zone 2, small overdrafts of ground water from the Seymour Alluvial Aquifer for irrigation purposes occurred in Collingsworth, Foard, and Wilbarger Counties.

Within Zone 3 of the basin, overdrafts of ground water for mainly municipal purposes occurred in the Trinity Group Aquifer in Cooke and Grayson Counties, in the Woodbine Aquifer in Grayson County, in the Nacatoch Aquifer in Bowie County, and in the Blossom Aquifer in Fannin, Lamar, and Red River Counties.

Current Surface-Water Development

Since December 1980, Texas use of water in the Red River Basin has been subject to the Red River Compact.

There are 23 major reservoirs in the Red River Basin of Texas. Of this total, 4 projects are located in Zone 1, 11 in Zone 2, and 8 in Zone 3.

Zone 1 of the Red River Basin is served principally from ground-water sources; however, important surface-water projects have been developed locally. Mackenzie Reservoir, located on Tule Creek in Briscoe County, is owned by the Mackenzie Municipal Water Authority. Member cities include Floydada and Lockney in the Brazos River Basin and the Cities of Silverton and Tulia in the Red River Basin. No diversions were made from the project in 1980 because water conveyance and treatment facilities had not been constructed. It is anticipated that all future water needs of the member cities will be supplied through the facilities of the Authority.

Greenbelt Reservoir, located in Donley County, is owned by the Greenbelt Municipal and Industrial Water Authority. Member cities include Clarendon and Hedley in Zone 1, and Childress, Crowell, Memphis, Quanah, and Wellington in Zone 2. Total diversions from Greenbelt Reservoir in 1980 totaled slightly over 4.4 thousand acre-feet, of which about 715 acre-feet was used in Zone 1 and the remainder delivered to cities in Zone 2.

Bivins Lake, owned by the City of Amarillo, is used for aquifer recharge, Buffalo Lake, owned by the U.S. Fish and Wildlife Service is no longer in use because of inadequacy of the dam structure.

The City of Amarillo, part of which is located in the Red River Basin, is a member of the Canadian River Municipal Water Authority which delivered 20.83 thousand acre-feet of water to the city in 1980 through its aqueduct system from Lake Meredith in the Canadian River Basin.

Existing major reservoirs in Zone 2 are Baylor Creek, Electra, Kemp, Diversion, Santa Rosa, North Fork Buffalo Creek, Lake Wichita, Lake Kickapoo, Arrowhead, and Farmers Creek. The City of Wichita Falls owns and operates Lakes Wichita, Kickapoo, and Arrowhead, and is co-owner of Lakes Kemp and Diversion with the Wichita County Water Improvement District No. 2. These projects serve the needs of the City of Wichita Falls and provide municipal and manufacturing supplies for much of Wichita, Archer, and Clay Counties. Lake Wichita is not currently being used because of the inadequacy of the dam structure. Lakes Kickapoo and Arrowhead are the principal sources of surface-water supply for the Wichita Falls area. Lakes Kemp and Diversion supplied 55.5 thousand acre-feet of water for irrigation purposes in 1980. Other reservoirs in Zone 2 supply local needs. Baylor Creek Reservoir was constructed by the City of Childress for a municipal water supply; however, no water was used from this source in 1980. North Fork Buffalo Creek Reservoir is owned by the Wichita County Water Control and Improvement District No. 3 and supplies most of the municipal water used by the City of Iowa Park. Electra Reservoir is owned by the City of Electra and supplements the city's ground-water supply. Santa Rosa Reservoir is owned by the W.T. Waggoner Estate and is used for livestock watering and oil and gas secondary recovery operations. Farmers Creek Reservoir, owned and operated by the North Montague County Water Supply District, supplies the City of Nocona and other areas of Montague County.

One element of the Arkansas-Red Basins Chloride Control Project, Truscott Brine Reservoir located in Knox County on the South Fork of the Wichita River, has been completed by the U.S. Army Corps of Engineers.

Major reservoirs in Zone 3 are Moss, Texoma, Randell, Bonham, Coffee Mill Creek, Pat Mayse, Crook, and Valley. Hubert H. Moss Lake is owned and operated by the City of Gainesville in the Trinity River Basin. No water has been used from the project; however, it is anticipated that future requirements of the Gainsville area will be served from the project. Lake Bonham is owned by the Bonham Municipal Water Authority. In 1980, 1.4 thousand acre-feet of water was diverted from the project for municipal and manufacturing purposes for the City of Bonham. Pat Mayse Reservoir is a multiple-purpose project constructed by the U.S. Army Corps of Engineers for flood control and water supply. The City of Paris, located partially in the Sulphur River Basin, has purchased the conservation storage space in the reservoir to augment the city's supply from Lake Crook. In 1980, 12.7 thousand acre-feet was diverted from the two projects for municipal and manufacturing purposes in the City of Paris as well as other areas of Lamar County in both the Red and Sulphur River Basins.

Lake Texoma, located on the main stem of the Red River, was constructed by the Corps of Engineers as a multiple-purpose project to include flood control, hydroelectric power generation, water supply, and recreation. The City of Denison, Texas Power and Light Company, Atlantic Richfield Co., Texaco, Inc., and the Red River Authority have contracts with the Corps of Engineers for conservation storage capacity. In addition, the City of Sherman has the authority under P.L. 85-146 to contract for water-supply storage, although no contract has yet been consummated. Lake Randell, owned by the City of Denison for a municipal water supply, is also used for regulating diversions from Lake Texoma. In 1980, about 6.1 thousand acre-feet of water was diverted from Lake Randell for municipal and manufacturing uses in the City of Denison and other areas of Grayson County. Valley Lake, owned and operated by Texas Power and Light Company, is also supplemented by diversions from Lake Texoma to maintain a constant operating level for steam-electric power plant operation. The remaining major reservoir in Zone 3 of the Red River Basin, Coffee Mill Creek Lake, is owned by the U.S. Department of Agriculture and is used for recreation.

Surface water utilized for municipal and manufacturing purposes in the lower reach of Zone 3 of the Red River Basin is supplied largely from Lake Wright Patman in the Sulphur River Basin.

Water Rights

The total quantity of surface water authorized or claimed for diversion and use in the Red River Basin was 678,825 acre-feet as of December 31, 1983 (Table III-2-1). Municipal use totaled 312,923 acre-feet, or 46.1 percent of the basin total (Table III-2-2). Zone 2 has the largest quantity of authorized and claimed water in the basin with 418,791 acre-feet, or 61.7 percent of the total amount of water authorized and/or claimed in the basin (Table III-2-2).

Water Quality

A general water quality problem in the Red River Basin is the excessive dissolved-solids concentrations prevalent in most of the streams. These high concentrations are caused in large part by the presence of salt water springs and outcrops of gypsum. Salt water springs are located in the western portion of the basin in the upper reaches of the Wichita River, the North and South Forks of the Pease River, and on the Little Red River which is a tributary to the Prairie Dog Town Fork of the Red River. Gypsum outcrops are found in the area ranging westward from Wichita County to the High Plains caprock escarpment. The water from these areas is usually very high in dissolved solids and occasionally contains chemical concentrations comparable to those found in sea water.

The lower portion of the Wichita River and McKinney Bayou experience occasional low dissolved oxygen and elevated fecal coliform levels. These conditions are primarily due to the discharge of treated wastewater and, in the case of McKinney Bayou, are complicated by the naturally low reaeration capacity of the stream.

Flooding, Drainage, and Subsidence

Reliable estimates of monetary damages due to historical flooding in the basin are generally unavailable. Most of the damages from floods occur in localized areas, for which flood damages estimates have not been made. However, the Corps of Engineers has compiled flood histories for several federal projects within the basin. Floods in 1954, 1955, and 1957 on the Wichita River caused an estimated $4 million in damages. During the period 1950-71, six floods caused an estimated $395 thousand in damages on Big Pine Creek, and during the period 1950-62 floods caused an estimated $313 thousand in damages on Sanders Creek.

Table III-2-1. Authorized or Claimed Amount of Water, by Type of Right, Red River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	245	571,009
Claims	161	22,407
Certified Filings	4	85,409
Certificates of Adjudication	0	0
Total Authorizations and Claims	410	678,825

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-2-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Red River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Total
Municipal	45	19,620	206,443	86,860	312,923
Industrial	17	2,721	51,081	53,157	106,959
Irrigation	309	14,575	142,159	32,059	188,793
Mining	10	1,045	4,771	100	5,916
Recreation	46	32,818	6,277	17,079	56,174
Other	4	0	8,060	0	8,060
Total	410[1]	70,779	418,791	189,255	678,825

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

In recent years, floods in Amarillo in 1978, 1979, and 1981; Wichita Falls in 1979 and 1980; and Sherman in 1981 along with other minor floods throughout the basin produced 201 flood insurance claims for flood damages amounting to approximately $1.6 million. Flooding in October 1981 also brought a Presidential disaster declaration to Grayson County resulting in expenditures of approximately $642 thousand by various federal agencies to offset flood damages in the Red River Basin.

To date, 57 incorporated cities have been designated as having one or more flood hazard areas within their boundaries. Maps have been prepared which identify the areas subject to inundation by the 100-year flood. Thirty-one of the designated cities have adopted minimum flood plain management standards in compliance with the National Flood Insurance Program. In the Cities of Sherman and Wichita Falls, detailed flood insurance studies have been completed. Detailed studies are also underway in the Cities of Canyon, Lake Tanglewood, Burkburnett, Iowa Park, and Pleasant Valley. Completion of these studies will make additional layers of flood insurance coverage available to local residents and will also provide 100-year flood elevation data to the cities for use in future planning and growth.

Drainage problems exist throughout the entire Red River Basin. In the High Plains region, numerous depressions in the generally flat terrain collect storm runoff and form the playa lakes. Playa lake areas pose problems to lands under cultivation. In the lower part of the basin below Lake Texoma, drainage problems occur in alluvium-filled bottomlands.

Land subsidence caused by withdrawals of ground water from the various aquifers is not a problem within the Red River Basin. However, the potential for locally significant subsidence exists within the basin in the area of the Blaine Gypsum Aquifer.

Recreation Resources

There are 22 reservoirs in the Red River Basin with capacities of 5 thousand acre-feet or more. These 22 reservoirs provide over 159 thousand surface acres of water for recreational purposes. Zone 3 of the basin, contains over 101 thousand of the surface acres, with Lake Texoma accounting for 88 percent of the zone total. Lake Texoma, located in Texas and Oklahoma, offers numerous water-oriented recreation opportunities as indicated by the recorded recreation use ofthe reservoir which totaled more than 12.0 million visits by recreationists during 1980. An additional 1.0 million visits were recorded in 1980 at Pat Mayse Reservoir, located in Zone 3.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Red River Basin is projected to increase 82 percent by the year 2030, from 506.0 thousand in 1980 to 919.7 thousand in 2030. A 23 percent growth, to over 624 thousand is anticipated from 1980 to the year 2000, and a gain of 47 percent is forecasted for the remainder of the planning period (2000 to 2030). In comparison, state population is projected to increase 49 percent and 62 percent, respectively, over the same time period (Table III-2-3).

In 1980, Zone 2 population was 38 percent of the total basin population, and this figure is not expected to change by 2030. In contrast, Zone 1 percentage of the basin population increases from 35 percent in 1980 to 36 percent in 2030. Over the projection period, the population in Zone 3 of the basin grows at a slower rate than the basin average (70 percent compared to 79 percent), and its share of basin population declines from 27 percent to 25 percent.

The growth in Zone 1 of the Red River Basin is attributable largely to expected expansion of economic activity in Randall (part of the Amarillo Standard Metropolitan Statistical Area) and Deaf Smith (which includes the City of Hereford) Counties.

Almost all of Zone 2's population growth occurs in Wichita County (part of the Wichita Falls SMSA).

Of the six counties partially in Zone 3 of the Red River Basin, Cooke and Lamar Counties are expected to grow faster than the basin average (95 and 90 percent respectively, from 1980 to 2030 compared to 79 percent). Grayson County accounts for a large portion of the total projected population increase in this zone (an increase of 52 thousand people out of a total zone gain of 95 thousand).

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Red River Basin are projected to increase from the 1980 level of98.4 thousand acre-feet by a projected maximum of 59 percent by theyear 2000. In the year 2030, water requirements are

Table III-2-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Red River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			178.8			206.3			228.2			254.7			289.4			332.3
Municipal	25.7	11.3	37.0	32.0	23.2	55.2	35.0	26.7	61.7	41.4	27.5	68.9	51.0	27.6	78.6	63.0	27.5	90.5
Manufacturing	8.6	0.8	9.4	13.0	0.1	13.1	17.8	0.1	17.9	23.0	0.0	23.0	28.1	1.2	29.3	36.0	0.8	36.8
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	2.3	4.5	0.0	4.5	6.8	0.0	6.8
Mining	1.2	0.3	1.5	0.8	0.4	1.2	0.4	0.5	0.9	0.3	0.5	0.8	0.2	0.6	0.8	0.1	0.7	0.8
Irrigation	1,174.7	2.4	1,177.1	1,034.3	2.3	1,036.6	2,060.5	2.3	2,062.8	2,003.8	2.3	2,006.1	2,692.7	2.4	2,695.1	2,695.2	2.4	2,697.6
Livestock	16.5	3.5	20.0	19.5	4.3	23.8	23.2	4.4	27.6	20.3	7.3	27.6	13.4	14.2	27.6	8.8	18.8	27.6
Zone Total Water	1,226.7	18.3	1,245.0	1,099.6	30.3	1,129.9	2,136.9	34.0	2,170.9	2,091.1	37.6	2,128.7	2,789.9	46.0	2,835.9	2,809.9	50.2	2,860.1
Zone 2																		
Population			192.3			198.5			233.9			268.0			310.7			359.5
Municipal	10.0	28.7	38.7	11.9	35.6	47.5	12.5	44.6	57.1	2.9	52.5	65.4	13.8	61.9	75.7	14.6	72.9	87.5
Manufacturing	0.8	2.0	2.8	1.4	3.0	4.4	1.9	4.4	6.3	2.5	6.0	8.5	3.2	7.9	11.1	4.0	10.3	14.3
Steam Electric	0.0	3.2	3.2	0.0	9.6	9.6	0.0	16.0	16.0	0.0	15.7	15.7	0.0	15.3	15.3	0.0	15.0	15.0
Mining	0.6	0.2	0.8	0.5	0.1	0.6	0.4	0.1	0.5	0.3	0.0	0.3	0.2	0.0	0.2	0.1	0.0	0.1
Irrigation	86.7	56.9	143.6	95.7	36.1	131.8	185.0	95.2	280.2	201.8	250.9	452.7	247.0	194.9	441.9	221.9	252.0	473.9
Livestock	1.3	7.8	9.1	2.2	8.6	10.8	2.2	10.3	12.5	2.2	10.3	12.5	2.2	10.3	12.5	1.8	10.7	12.5
Zone Total Water	99.4	98.8	198.2	111.7	93.0	204.7	202.0	170.6	372.6	219.7	335.4	555.1	266.4	290.3	556.7	242.4	360.9	603.3
Zone 3																		
Population			134.9			150.2			162.1			179.4			200.8			227.9
Municipal	13.2	9.5	22.7	4.0	29.8	33.8	4.0	33.2	37.2	4.1	37.1	41.2	4.3	41.7	46.0	4.3	48.0	52.3
Manufacturing	3.3	1.7	5.0	0.2	7.7	7.9	0.2	11.3	11.5	0.2	15.1	15.3	0.2	19.7	19.9	0.2	25.2	25.4
Steam Electric	0.1	5.9	6.0	0.1	5.9	6.0	0.1	10.4	10.5	0.1	17.0	17.1	0.1	23.5	23.6	0.1	30.1	30.2
Mining	0.4	0.0	0.4	0.3	0.0	0.3	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0
Irrigation	2.9	35.4	38.3	2.1	36.5	38.6	2.1	39.8	41.9	2.1	43.2	45.3	2.1	43.2	45.3	2.1	43.2	45.3
Livestock	1.0	3.3	4.3	1.7	3.4	5.1	2.4	3.5	5.9	2.4	3.5	5.9	2.3	3.6	5.9	2.4	3.5	5.9
Zone Total Water	20.9	55.8	76.7	8.4	83.3	91.7	8.9	98.2	107.1	9.0	115.9	124.9	9.1	131.7	140.8	9.1	150.0	159.1
BASIN TOTALS																		
Population			506.0			555.0			624.2			702.1			800.9			919.7
Municipal	48.9	49.5	98.4	47.9	88.6	136.5	51.5	104.5	156.0	58.4	117.1	175.5	69.1	131.2	200.3	81.9	148.4	230.3
Manufacturing	12.7	4.5	17.2	14.6	10.8	25.4	19.9	15.8	35.7	25.7	21.1	46.8	31.5	28.8	60.3	40.2	36.3	76.5
Steam Electric	0.1	9.1	9.2	0.1	15.5	15.6	0.1	26.4	26.5	2.4	32.7	35.1	4.6	38.8	43.4	6.9	45.1	52.0
Mining	2.2	0.5	2.7	1.6	0.5	2.1	0.9	0.6	1.5	0.7	0.5	1.2	0.5	0.6	1.1	0.2	.7	.9
Irrigation	1,264.3	94.7	1,359.0	1,132.1	74.9	1,207.0	2,247.6	137.3	2,384.9	2,207.7	296.4	2,504.1	2,941.8	240.5	3,182.3	2,919.2	297.6	3,216.8
Livestock	18.8	14.6	33.4	23.4	16.3	39.7	27.8	18.2	46.0	24.9	21.1	46.0	17.9	28.1	46.0	13.0	33.0	46.0
Basin Total Water	1,347.0	172.9	1,519.9	1,219.7	206.6	1,426.3	2,347.8	302.8	2,650.6	2,319.8	488.9	2,808.7	3,065.4	468.0	3,533.4	3,061.4	561.1	3,622.5

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

projected to range from 148.5 to 230.3 thousand acre-feet. Zone 1 is projected to account for 40 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 39 percent of the total.

A range of 39.8 to 57.1 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000, most in Wichita County. Total municipal water requirements in Zone 3 are projected to range from 26 to 37 thousand acre-feet in the year 2000, of which Grayson County accounts for the greatest portion. By 2030, Zone 3 is projected to account for 22 to 23 percent of the total basin municipal water requirements.

Industrial

Manufacturing water requirements in 1980 were 17.2 thousand acre-feet in the Red River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Red River Basin are projected to increase more than two times by the year 2030, to a potential high of 76.5 thousand acre-feet by 2030.

Steam-Electric Power Generation

Provided announced changes in installed capacity by the electric power companies operating in Texas materialize, most of the growth in steam-electric power generating capacity will occur in Zones 2 and 3 of the Red River Basin. Based on these projections, water consumption requirements in the basin will increase 22 to 26.4 thousand acre-feet annually by 2000 and 36.4 to 52 thousand acre-feet annually by 2030.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Red River Basin are projected to increase from the 1980 level of 1.4 million acre-feet by a projected maximum 75 percent by the year 2000 in the high case. In the year 2030, water requirements in the Basin are projected to range from 1.5 to 3.2 million acre-feet annually, low and high case, respectively, to irrigate from 1.2 to 2.5 million acres.

Zone 1 is projected to account for about 86 percent of total basin irrigation requirements in 2000; in 2030, Zone 1 is projected to account for about 84 percent of the total in the high case.

A range of 108.2 to 280.2 thousand acre-feet of irrigation requirements is projected in Zone 2 by 2000. By 2030, the range for this Zone is from 122.5 to 473.9 thousand acre-feet annually. Irrigation water requirements in Zone 3 are small by comparison with the other two zones, at a range of 31.1 to 41.9 thousand acre-feet annually for year 2000; in 2030, the range in irrigation requirements is from 31.1 to 45.3 thousand acre-feet per year in Zone 3.

Livestock

Livestock water requirements within the basin are projected to increase from 33.4 thousand acre-feet in 1980 to 46.0 thousand acre-feet by 2000. Livestock water use in 2000 is expected to be 27.6 thousand acre-feet in Zone 1, about 12.5 thousand acre-feet in Zone 2, and 5.9 thousand acre-feet in Zone 3. By 2030, it is estimated that 46.0 thousand acre-feet of water will be required annually to satisfy livestock needs in the basin.

Mining

Mining water requirements in the Red River Basin are projected to decline from 2.7 thousand acre-feet in 1980 to 0.9 thousand acre-feet in 2030. The estimated decline in the basin's mining water requirements will result from technological advances and greater water-use efficiency in the recovery of crude petroleum and natural gas. Increasing water requirements by nonmetal mining firms should correspond to expected increases in demand for construction-related raw materials.

Navigation

As part of the authorized Red River Waterway project, the Corps of Engineers has released a feasibility report of the economics of navigation. If this project becomes economically favorable, no additional freshwater requirement is anticipated for the Red River Basin.

Hydroelectric Power

There are currently no plans to expand hydroelectric power generating capacity in the Red River Basin beyond the existing 70 megawatts of installed capacity at Denison Dam.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains Aquifer within the Red River Basin from 1990 through 2030 by decade: 1.02 million acre-feet in 1990, 1.58 million acre-feet in 2000, 1.48 million acre-feet in 2010, 0.93 million acre-feet in 2020, and 0.69 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 43 million acre-feet of ground water would be removed from storage, and that of the 29 million acre-feet remaining in storage in the year 2031 about 7 million acre-feet would remain in the "caprock" (tillable) area and 22 million acre-feet would remain in the "breaks" (nontillable) area of the basin. Within the Red River Basin, the High Plains (Ogallala) Aquifer receives on an average annual basis about 57.4 thousand acre-feet of recharge.

The approximate annual ground-water yield to the year 2030 within the remaining portion of the Red River Basin is 321.3 thousand acre-feet with the following amounts annually available by aquifer: 159.8 thousand acre-feet from the Seymour Alluvial Aquifer, 142.6 thousand acre-feet from the Blaine Aquifer, 14.0 thousand acre-feet from the Woodbine Aquifer, 4.4 thousand acre-feet from the Trinity Group Aquifer, 0.3 thousand acre-feet from the Blossom Aquifer, and 0.2 thousand acre-feet from the Nacatoch Aquifer. The quality of the ground water from the Blaine Aquifer is such that it can only be used for irrigation purposes. In the year 2030, the yields of the Seymour Alluvial Aquifer and the Trinity Group Aquifer within the basin would be reduced to their average annual recharge rates of 119.8 and 3.7 thousand acre-feet per year, respectively. These reductions decrease the total ground-water availability within the basin in 2030 to 280.6 thousand acre-feet (High Plains Aquifer not included).

The projected annual ground-water use within the Red River Basin by decade from 1990 through 2030 is expected to be from 0.91 to 1.73 million acre-feet per year (Table III-2-4). The approximate average annual projected ground-water use within the basin is expected to be about 1.31 million acre-feet per year. Of the 1.31 million acre-feet of average annual projected use about 86 percent is expected to be from the High Plains (Ogallala) Aquifer, about 9 percent from the Seymour Alluvial Aquifers, and about 2 percent from the Blaine Aquifer.

Surface-Water Availability and Proposed Development

Projected surface-water needs in the Red River Basin are estimated to exceed total basin existing and proposed surface-water resources beginning about 2000 and continuing through 2030 (Table III-2-4, Figure III-2-2). However, water shortages are projected to occur in irrigated agriculture by 1990. Projected surface-water needs for municipal and manufacturing purposes in the Red River Basin may be met from existing reservoirs in the basin and imports from adjacent basins until the year 2030 except in Zone 2.

Zone 1

By the year 2000, approximately 566 thousand acre-feet per year of irrigation water need is estimated to be unsatisfied in Zone 1 of the basin (Table III-2-5, Figure

Table III-2-4. Water Resources of the Red River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1133.4	—	—	—	1133.4	1219.6	—	—	1219.6	.0	(86.2)	(86.2)
Surface Water	507.1	—	32.9	22.2	562.2	151.7	—	114.4	266.1	306.5	(10.5)	296.0
Total	1640.5	—	32.9	22.2	1695.6	1371.3	—	114.4	1485.7	306.5	(96.7)	209.8
2000												
Ground Water	1731.2	—	—	—	1731.2	2347.7	—	—	2347.7	.0	(616.5)	(616.5)
Surface Water	498.1	—	41.4	25.4	564.9	245.6	—	125.1	370.7	269.2	(75.1)	194.1
Total	2229.3	—	41.4	25.4	2296.1	2593.3	—	125.1	2718.4	269.2	(691.6)	(422.4)
2010												
Ground Water	1657.4	—	—	—	1657.4	2319.8	—	—	2319.8	.0	(662.4)	(662.4)
Surface Water	495.3	—	48.7	26.2	570.2	428.7	—	132.6	561.3	243.0	(234.1)	8.9
Total	2152.7	—	48.7	26.2	2227.6	2748.5	—	132.6	2881.1	243.0	(896.5)	(653.5)
2020												
Ground Water	1125.7	—	—	—	1125.7	3065.4	—	—	3065.4	.0	(1939.7)	(1939.7)
Surface Water	492.4	—	57.5	26.6	576.5	403.4	—	137.6	541.0	213.5	(178.1)	35.4
Total	1618.1	—	57.5	26.6	1702.2	3468.8	—	137.6	3606.4	213.5	(2117.8)	(1904.3)
2030												
Ground Water	907.4	—	—	—	907.4	3061.4	—	—	3061.4	.0	(2154.0)	(2154.0)
Surface Water	551.6	—	67.7	27.3	646.6	491.0	—	145.8	636.8	244.9	(235.1)	9.8
Total	1459.0	—	67.7	27.3	1554.0	3552.4	—	145.8	3698.2	244.9	(2389.1)	(2144.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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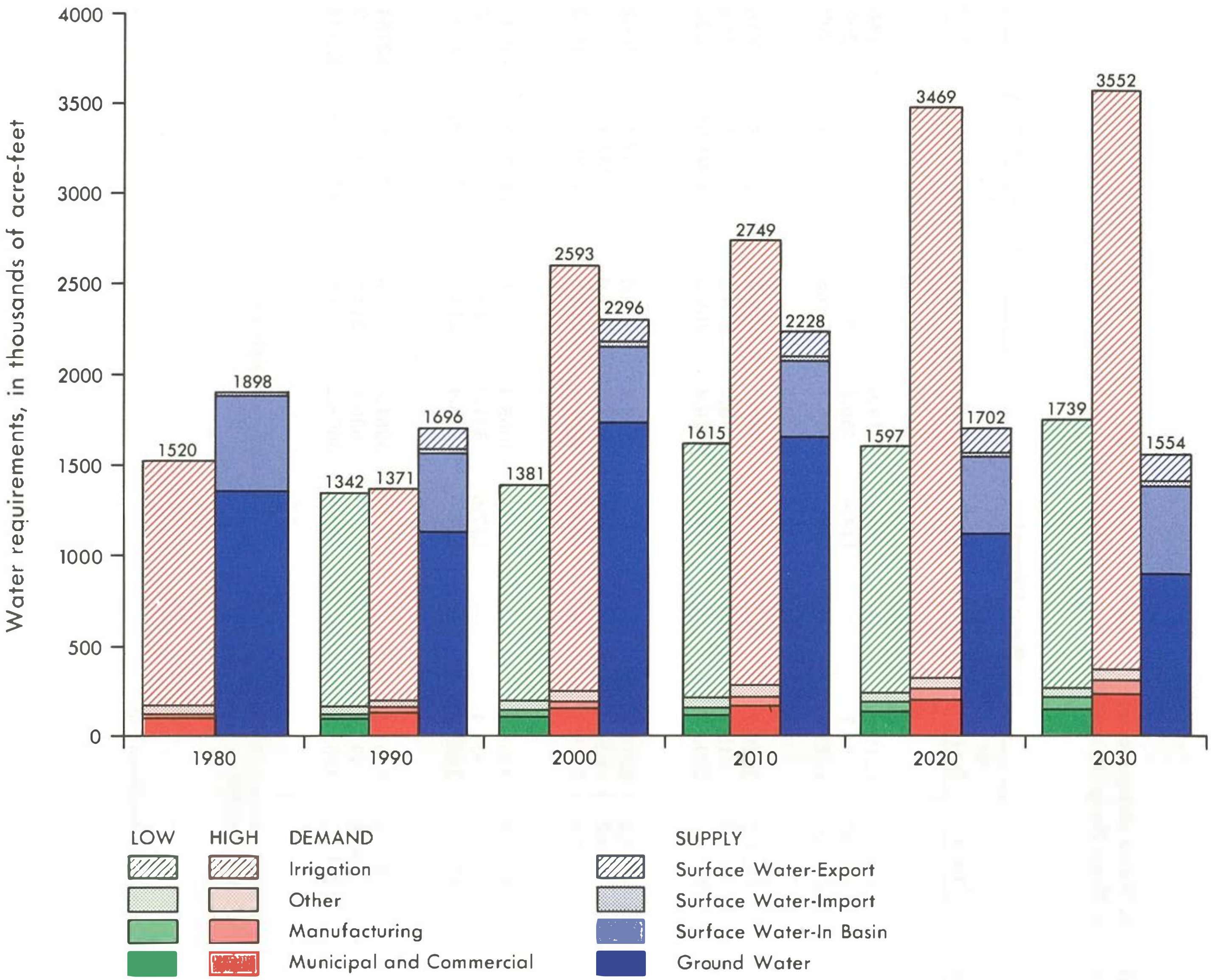

Figure III-2-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, 1980-2030

III-2-3). This shortage is projected to increase to about 2.0 million acre-feet per year in 2030. The shortages projected for this zone occur as a consequence of the decline of available ground-water resources in the area, primarily from the High Plains (Ogallala) Aquifer. Shortages for irrigation water use are estimated to begin by the year 1990, with an acceleration in the volume of shortage around the year 2010.

Sweetwater Creek Reservoir site is located on Sweetwater Creek in Wheeler County. Studies performed by the Red River Authority indicate that a reservoir at this site with a capacity of 65.8 thousand acre-feet would have a dependable annual yield of 5.2 thousand acre-feet of water for municipal, industrial, and recreational purposes. In 1982, the Red River Authority reactivated a water use permit application for Sweetwater Creek Reservoir previously submitted to the Department of Water Resources. Based upon local interest and diminishing ground-water resources in the area, the reservoir is proposed for operation by 1990. Continuing administrative and potential legal actions will most likely delay completion past 1990.

Should additional water needs develop in Zone 1 of the basin beyond the year 2000, potential reservoirs which could be constructed to meet such needs include Lower

Table III-2-5. Water Resources of the Red River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1013.3	—	—	—	1013.3	1099.5	—	—	1099.5	.0	(86.2)	(86.2)
Surface Water	22.7	.0	.0	19.8	42.5	23.3	3.7	.7	27.7	14.8	.0	14.8
Total	1036.0	.0	.0	19.8	1055.8	1122.8	3.7	.7	1127.2	14.8	(86.2)	(71.4)
2000												
Ground Water	1570.6	—	—	—	1570.6	2136.8	—	—	2136.8	.0	(566.2)	(566.2)
Surface Water	22.1	.0	.0	22.6	44.7	26.7	4.0	1.1	31.8	12.8	.0	12.8
Total	1592.7	.0	.0	22.6	1615.3	2163.6	4.0	1.1	2168.7	12.8	(566.2)	(553.4)
2010												
Ground Water	1470.6	—	—	—	1470.6	2091.1	—	—	2091.1	.0	(620.5)	(620.5)
Surface Water	21.7	.0	.0	23.1	44.8	27.3	4.4	1.3	33.0	11.8	.0	11.8
Total	1492.3	.0	.0	23.1	1515.4	2118.4	4.4	1.3	2124.1	11.8	(620.5)	(608.7)
2020												
Ground Water	948.2	—	—	—	948.2	2789.9	—	—	2789.9	.0	(1841.7)	(1841.7)
Surface Water	21.2	.0	.0	23.1	44.3	28.8	5.0	2.5	36.3	8.0	.0	8.0
Total	969.4	.0	.0	23.1	992.5	2818.7	5.0	2.5	2826.2	8.0	(1841.7)	(1833.7)
2030												
Ground Water	765.1	—	—	—	765.1	2809.9	—	—	2809.9	.0	(2044.8)	(2044.8)
Surface Water	20.8	.0	.0	23.2	44.0	28.3	5.8	3.3	37.4	6.6	.0	6.6
Total	785.9	.0	.0	23.2	809.1	2838.2	5.8	3.3	2847.3	6.6	(2044.8)	(2038.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
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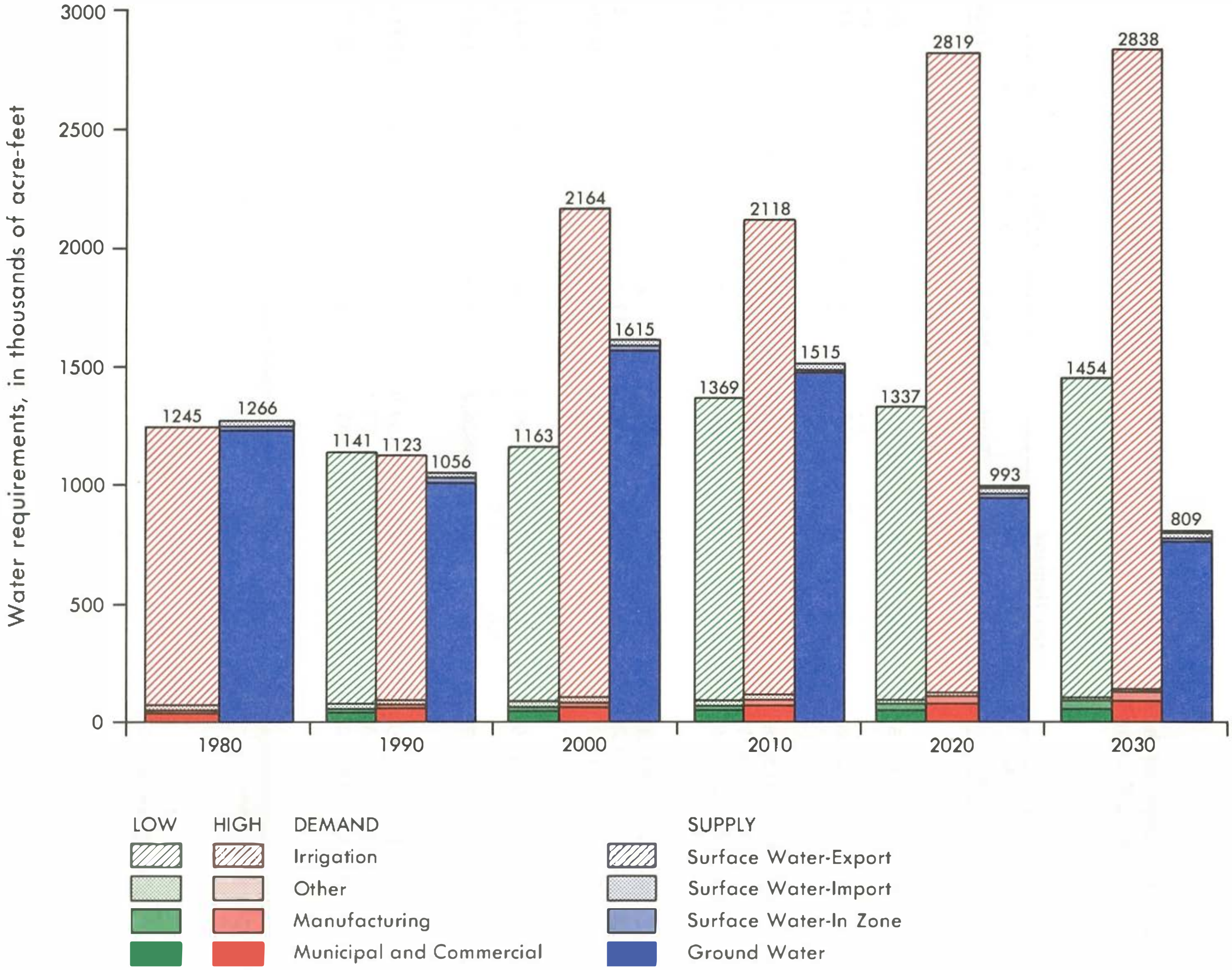

Figure III-2-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 1, 1980-2030

McClellan Creek Reservoir and Lelia Lake Creek Reservoir.

The Lower McClellan Creek Reservoir site is located in Gray County on McClellan Creek near its confluence with the North Fork of the Red River. This potential reservoir would also provide municipal and industrial water supply and serve recreation needs. The Lelia Lake Creek Reservoir site, located in Donley County, could supplement the Greenbelt Reservoir system should needs for additional water supply arise. The reservoir would have a capacity of about 17.2 thousand acre-feet and would also provide recreational benefits to the area.

Zone 2

Water requirements are projected to exceed water resources by 15.5 thousand acre-feet and 208.0 thousand acre-feet per year in Zone 2 by 2000 and 2030, respectively (Table III-2-6, Figure III-2-4). The year 2030 shortage includes a projected shortfall of 332.1 thousand acre-feet per year for irrigation and an annual surplus of 124.1 thousand acre-feet for municipal and industrial uses. This water surplus occurs as a consequence of existing and proposed surface-water development to be used exclusively for municipal and industrial purposes. Surface water is estimated to supply 250.2 thousand acre-feet

Table III-2-6. Water Resources of the Red River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	111.7	—	—	—	111.7	111.7	—	—	111.7	.0	.0	.0
Surface Water	193.0	3.7	.7	.0	197.4	79.4	.0	1.5	80.9	121.4	(4.9)	116.5
Total	304.7	3.7	.7	.0	309.1	191.1	.0	1.5	192.6	121.4	(4.9)	116.5
2000												
Ground Water	151.7	—	—	—	151.7	202.0	—	—	202.7	.0	(50.3)	(50.3)
Surface Water	186.7	4.0	.8	.0	191.5	155.1	.0	1.6	156.7	101.0	(66.2)	34.8
Total	338.4	4.0	.8	.0	343.2	357.1	.0	1.6	358.7	101.0	(116.5)	(15.5)
2010												
Ground Water	177.8	—	—	—	177.8	229.7	—	—	229.7	.0	(41.9)	(41.9)
Surface Water	184.8	4.4	.9	.0	190.1	320.0	.0	1.7	321.7	90.3	(221.9)	(131.6)
Total	362.6	4.4	.9	.0	367.9	539.7	.0	1.7	541.4	90.3	(263.8)	(173.5)
2020												
Ground Water	168.4	—	—	—	168.4	266.4	—	—	266.4	.0	(98.0)	(98.0)
Surface Water	182.9	5.0	1.1	.0	189.0	277.5	.0	1.8	279.3	75.5	(165.9)	(90.4)
Total	351.3	5.0	1.1	.0	357.4	543.9	.0	1.8	545.7	75.5	(263.9)	(188.4)
2030												
Ground Water	133.2	—	—	—	133.2	242.4	—	—	242.4	.0	(109.2)	(109.2)
Surface Water	243.1	5.8	1.3	.0	250.2	347.2	.0	1.8	349.0	124.1	(222.9)	(98.8)
Total	376.3	5.8	1.3	.0	383.4	589.6	.0	1.8	591.4	124.1	(332.1)	(208.0)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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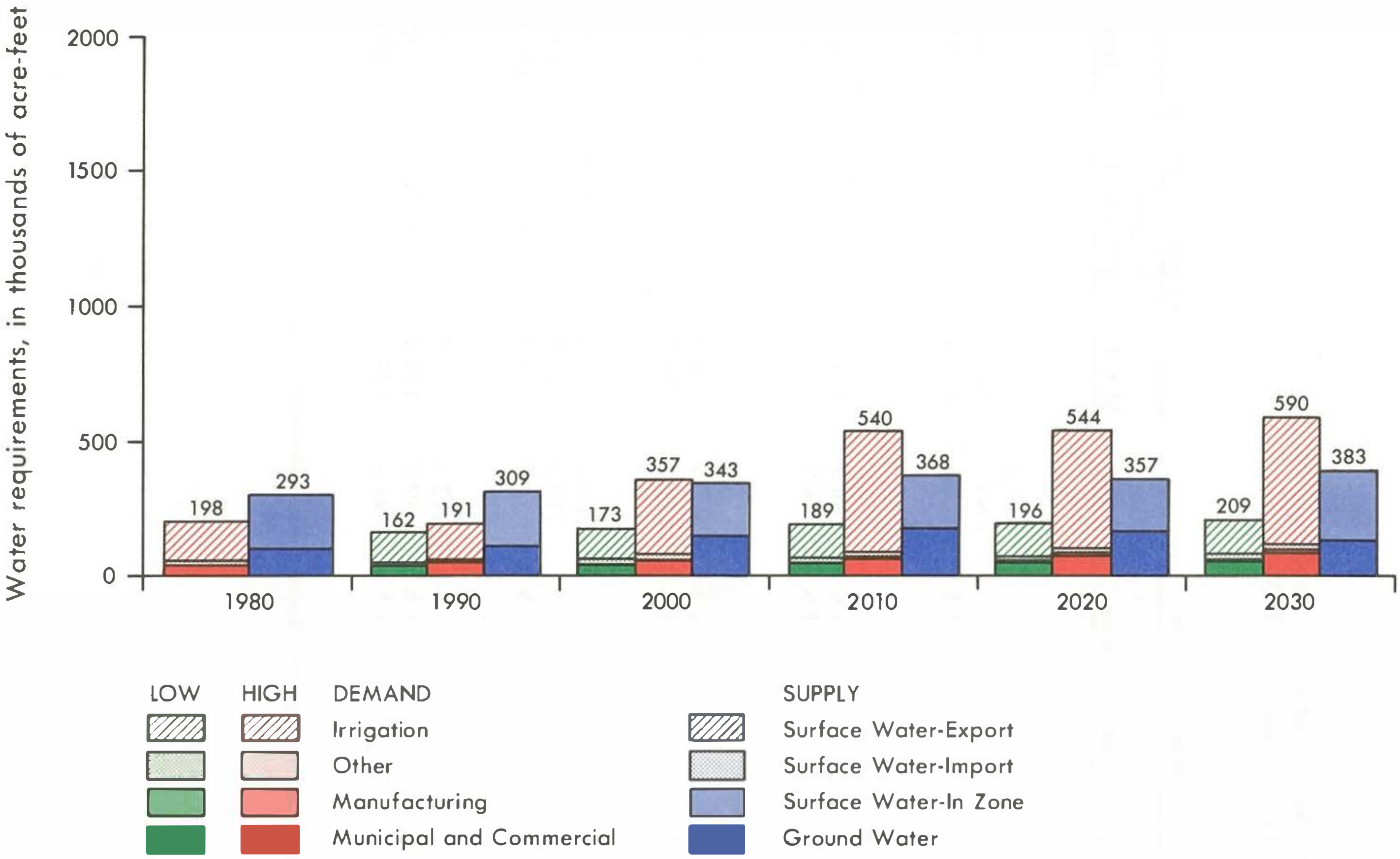

Figure III-2-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 2, 1980-2030

annually in 2030, with 1.8 thousand acre-feet exported for use outside of the basin. The irrigation water shortage occurs due to the limitation on available ground-water resources.

Shortly after the year 2020, additional supplies are projected to be needed in Zone 2 for municipal and manufacturing purposes for the City of Wichita Falls and adjacent Wichita County. The potential Ringgold Reservoir on the Little Wichita River is proposed as the source of the additional water needed in this area until well after the year 2030. Further studies will be needed by State and local interests to determine the economic feasibility of this project.

In Zones 2 and 3 of the basin, surface-water needs to the year 2000 and through 2030 can be met from existing major reservoirs and small local systems provided measures for alleviating natural salinity are implemented and are successful. Construction of all elements of the Arkansas-Red Basins Chloride Control Project will substantially improve the quality of surface-water supplies in Zone 2 and Zone 3. Construction of Canal Creek Brine Reservoir, Little Red River Brine Reservoir, Dry Salt Creek Brine Reservoir, and Truscott Brine Reservoir and the appurtenant low-flowdams, pipelines, and pumping facilities is essential. Natural salt-control facilities on the South Fork Wichita River is the only project which has received construction funding to date. Construction of all authorized salinity-control measures will improve the water quality in Lake Kemp, Lake Diversion, and Lake Texoma. The quality of the Red River below Denison Dam will also be significantly improved for beneficial uses by several states.

Studies are currently underway to determine feasibility of desalting water from the Lake Kemp and Lake Diversion system for use in the Wichita Falls area. Preliminary indications are that Lake Kemp-Lake Diversion water, to which the City of Wichita Falls has a permit for 31.0 thousand acre-feet, can be desalted by reverse osmosis and delivered to the city for substantially less than water from the potential Lake Ringgold. Other studies to determine the feasibility of desalting slightly to moderately saline ground-and surface-water in Zone 2 are also being conducted.

Zone 3

An excess in total surface-water supplies for all purposes other than irrigation is projected to occur in each decade through 2030 in Zone 3 of the basin (Table III-2-7, Figure III-2-5). However, shortages of 12.2 thousand acre-feet occur for irrigation needs as a consequence of limited ground-water resources. Surface-water supplies in year 2030 are estimated at 358.2 thousand acre-feet, with 140.7 thousand acre-feet of this supply exported to other basins. Approximately 114.2 thousand acre-feet of surface water is surplus for municipal and industrial purposes in year 2030.

Future availability of surface water in Zone 3 will be influenced by the Red River Compact which was ratified in December 1980. The Compact governs use of the waters of the Red River Basin (and the Sulphur River and Cypress Creek Basins in Texas) by the States of Texas, Oklahoma, Arkansas, and Louisiana. The Red River Compact provides that 400 thousand acre-feet of water in Lake Texoma be allocated to conservation storage. This conservation storage would be equally divided between Texas and Oklahoma. Therefore, for planning purposes it has been assumed that the water supply available to Texas from Lake Texoma in the future for municipal and industrial uses will be 200 thousand acre-feet annually.

Zone 3 of the Red River Basin may supply future surface-water needs in the adjacent Trinity River Basin. The North Texas Municipal Water District (NTMWD) is negotiating with the principals involved in Lake Texoma for up to 150.0 thousand acre-feet per year of water supply from that lake. Legislation has been introduced in Congress to authorize a reallocation of this same amount from hydroelectric power generation purposes to water supply use in Texas from Lake Texoma. Part of this annual reallocation could be used to meet the water needs of the Sherman and Denison areas in the Red River Basin. For planning purposes, it was assumed that 100.0 thousand acre-feet of annual water supply would be available to NTMWD. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

The projected surplus water supplies in Zone 3 to the year 2030 are based on a comparison of water availability and currently projected water demands. Should additional water needs develop, several major reservoirs could be constructed in Zone 3; these projects could also serve other needs such as flood protection, recreation, fish and wildlife purposes, and irrigation. There are four potential, and one federally authorized, major reservoir projects which could be constructed in Zone 3.

Big Pine Lake is an authorized Corps of Engineers reservoir project located on Big Pine Creek in Red River and Lamar Counties. Big Pine Lake would provide flood protection along Big Pine Creek, water-supply storage for regional municipal and manufacturing purposes, recreation, and fishing and hunting.

Four potential reservoir projects in Zone 3 are Bonham, Pecan Bayou, Liberty Hill, and Barkman Creek. Bonham C. of E. (Corps of Engineers) Reservoir is one element of a combined plan for the Bois d' Arc Creek Basin, in Texas. The reservoir would lie in Fannin County on Bois d' Arc Creek and would provide flood control and a dependable water supply of about 27 thousand acre-feet per year. The reservoir is currently under study by NTMWD as an alternative water supply to the District's proposed Red River Diversion. The Pecan Bayou Reservoir site is located on Pecan Bayou near Clarksville in Red River County. The reservoir would provide a dependable annual firm yield of about 30 thousand acre-feet. Liberty Hill damsite is located on Mud Creek near New Boston in Bowie County. This reservoir would provide a dependable annual water supply of about 33.6 thousand acre-feet. Barkman Creek Reservoir is a potential industrial water-supply project located in Bowie County near Texarkana.

Water Quality Protection

A water quality management plan for the Red River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Texarkana metropolitan area. The purpose of these plans is to provide information for use in making water quality management decisions. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $112.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Red River Basin with approximately $52.8 million required for Zone 3, $36.9 million for Zone 2, and $22.9 million for Zone 1. All costs are in January 1980 dollars

Table III-2-7. Water Resources of the Red River Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply: In Zone	Intra-Basin	Return Flow	Import	Total	Water Demand: In Zone	Intra-Basin	Export	Total	Surplus or Shortage: M & I	Irrigation (Shortage)	Total
1990												
Ground Water	8.4	—	—	—	8.4	8.4	—	—	8.4	.0	.0	.0
Surface Water	291.4	.0	32.2	2.4	326.0	49.1	.0	112.2	161.3	170.3	(5.6)	164.7
Total	299.8	.0	32.2	2.4	334.4	57.5	.0	112.2	169.7	170.3	(5.6)	164.7
2000												
Ground Water	8.9	—	—	—	8.9	8.9	—	—	8.9	.0	.0	.0
Surface Water	289.3	.0	40.6	2.8	332.7	63.8	.0	122.4	186.2	155.4	(8.9)	146.5
Total	298.2	.0	40.6	2.8	341.6	72.7	.0	122.4	195.1	155.4	(8.9)	146.5
2010												
Ground Water	9.0	—	—	—	9.0	9.0	—	—	9.0	.0	.0	.0
Surface Water	288.8	.0	47.8	3.1	339.7	81.4	.0	129.6	211.0	140.9	(12.2)	128.7
Total	297.8	.0	47.8	3.1	348.7	90.4	.0	129.6	220.0	140.9	(12.2)	128.7
2020												
Ground Water	9.1	—	—	—	9.1	9.1	—	—	9.1	.0	.0	.0
Surface Water	288.3	.0	56.4	3.5	348.2	97.1	.0	133.3	230.4	130.0	(12.2)	117.8
Total	297.4	.0	56.4	3.5	357.3	106.2	.0	133.3	239.5	130.0	(12.2)	117.8
2030												
Ground Water	9.1	—	—	—	9.1	9.1	—	—	9.1	.0	.0	.0
Surface Water	287.7	.0	66.4	4.1	358.2	115.5	.0	140.7	256.2	114.2	(12.2)	102.0
Total	296.8	.0	66.4	4.1	367.3	124.6	.0	140.7	265.3	114.2	(12.2)	102.0

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

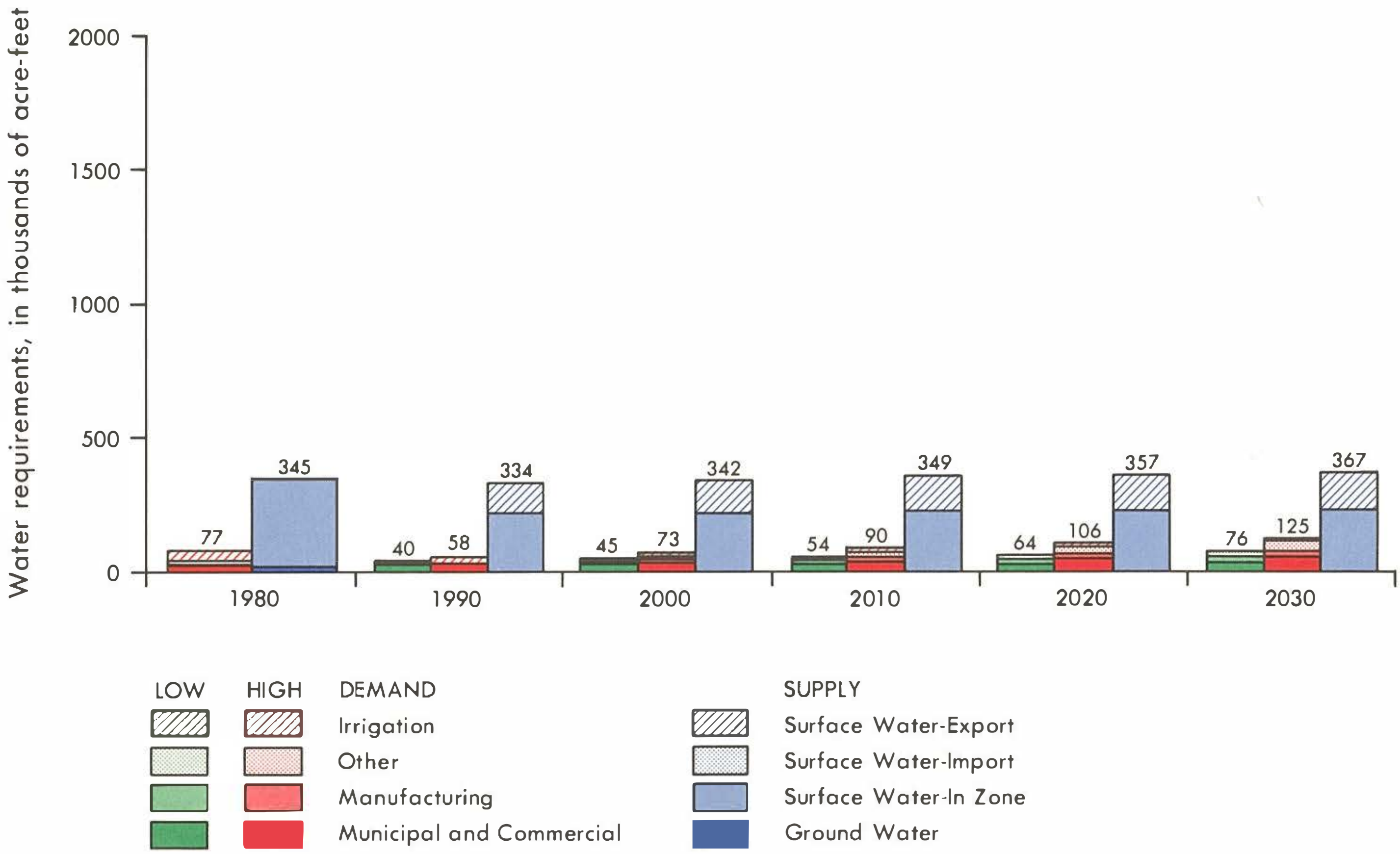

Figure III-2-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Red River Basin, Zone 3, 1980-2030

and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989 at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

The three major reservoirs in the Red River Basin which provide flood control as a project purpose are Lakes Kemp, Texoma, and Pat Mayse. These three reservoirs have a combined flood-control storage capacity of 2.9 million acre-feet.

The Corps of Engineers is currently studying the basin above Denison Dam to evaluate water-resource problems and needs. The study report is scheduled for completion in December 1990. The Corps has planning and engineering studies on Lake Wichita, Holliday Creek at Wichita Falls, Texas. The proposed plan of improvement includes the replacement of the existing Lake Wichita Dam and 9.3 miles of channel improvement below the dam. Feasibility studies are also underway on McGrath Creek as part of the continuation of planning and engineering for Lake Wichita-Holiday Creek. These projects when completed will provide protection for the 100-year flood.

The Corps has completed preconstruction planning work on Big Pine Lake in Red River County and the project is awaiting funding to initiate construction. This project would provide 74,450 acre-feet of storage for flood control.

There is about 584 square miles of drainage area above 90 existing floodwater-retarding structures constructed under the U.S. Department of Agriculture—Soil Conservation Service Watershed Management Program within the Red River Basin. As of October 1980, an additional 41 structures with a combined drainage area of 279 square miles were planned for construction. Existing and planned structures are distributed evenly throughout all three zones of the basin.

3. SULPHUR RIVER BASIN

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BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Sulphur River Basin in Texas is bounded on the north by the Red River Basin, on the west by the Trinity River Basin, on the south by the Sabine and Cypress Creek Basins, and on the east by the Texas-Arkansas boundary. The Sulphur River joins the Red River in Arkansas. Originating in southeastern Fannin County, the North Sulphur River flows eastward, joining the South Sulphur River at a streambed elevation of about 330 feet. From an elevation of about 600 feet in south-central Fannin County, the South Sulphur River flows southeast past Commerce, then eastward, joining the Middle Sulphur River at a streambed elevation of about 420 feet. The Sulphur River exits Texas in Bowie County above the confluence with the Red River in Arkansas. Total basin drainage area in Texas is 3,558 square miles. For planning purposes, the Sulphur River Basin is treated as a single hydrologic unit (Figure III-3-1).

Surface Water

Average annual runoff for the Sulphur River Basin in Texas during the 1941-70 period varied from approximately 600 acre-feet per square mile in the western part to 1,000 acre-feet per square mile in the easternmost part of the basin. Lowest flows in consecutive years for the 1941-56 period occurred during 1955 and 1956, when average annual runoff was 230 and 162 acre-feet per square mile, respectively. Runoff rates in the western part of the basin were 146 and 124 acre-feet per square mile in 1955 and 1956, respectively.

Due to channel rectification of the North Sulphur River, floods in this stream differ greatly from those in the South Sulphur River. Floods in the North Sulphur River characteristically rise and fall rapidly, rarely go beyond bankfull, and have high flow velocities.

The South Sulphur River and its tributaries have small main channels and wide, timbered floodplains. Consequently, floodwaters have lower velocities and extend beyond bankfull levels for long periods of time.

The surface-water resources of the Sulphur River Basin are generally of good quality. Treated municipal and industrial waste discharges are small, particularly in the western part of the basin where the North Sulphur, Middle Sulphur, and South Sulphur Rivers originate. The Sulphur River also receives flow from White Oak Bayou before reaching Lake Wright Patman and then crossing into Arkansas.

Concentrations of dissolved solids average about 250 milligrams per liter (mg/l) in the North Sulphur River and about 150 mg/l in the South Sulphur. White Oak Bayou contains good quality water above the Talco oil field; however, the quality is impaired in the lower reach of the stream. Flood runoff in this area has been sufficient, however, to dilute saline inflows. The concentration of total dissolved solids in Lake Wright Patman on the main stream of the Sulphur River generally ranges between 100 and 150 mg/l.

Ground Water

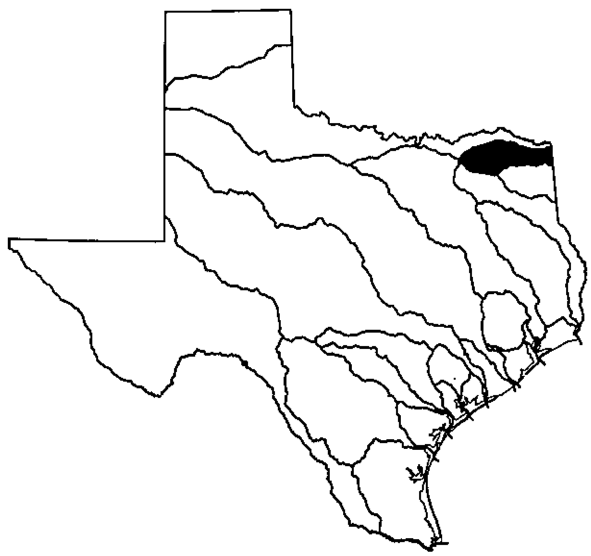
The Trinity Group Aquifer occurs in the western part of the Sulphur River Basin. Total thickness ranges to approximately 1,000 feet. Yields of large-capacity wells completed in the aquifer in adjacent basins average about 430 gallons per minute (gpm). The quality of water in the aquifer ranges from about 1,000 to 3,000 mg/l total dissolved solids.

The Carrizo-Wilcox Aquifer occurs in the south and eastern parts of the basin. Thickness ranges from about 500 to 900 feet. Yields of large-capacity wells average about 275 gpm, but locally wells produce up to 700 gpm. Ground water in the aquifer generally contains less than 500 mg/l total dissolved solids.

The Woodbine Aquifer occurs in a small area in the western part of the basin. Total thickness ranges from 400 to 600 feet. Yields of large-capacity wells completed in the aquifer in nearby basins average about 150 gpm. The quality of water in the aquifer generally exceeds 1,000 mg/l total dissolved solids.

The Blossom Sand Aquifer occurs in a narrow band across the northern edge of the basin. Maximum thickness is about 400 feet. Yields of high-capacity wells range upward to a maximum of about 500 gpm, but the average yield of most wells is much lower. The quality of water in the aquifer ranges from less than 1,000 to 3,000 mg/l total dissolved solids.

The Nacatoch Sand Aquifer occurs in a narrow band across the western part of the basin. Total thickness ranges from 350 to 500 feet. It produces usable-quality water in most places to a depth of about 800 feet. Maximum yields of large-capacity wells reach 500 gpm, but average consid-



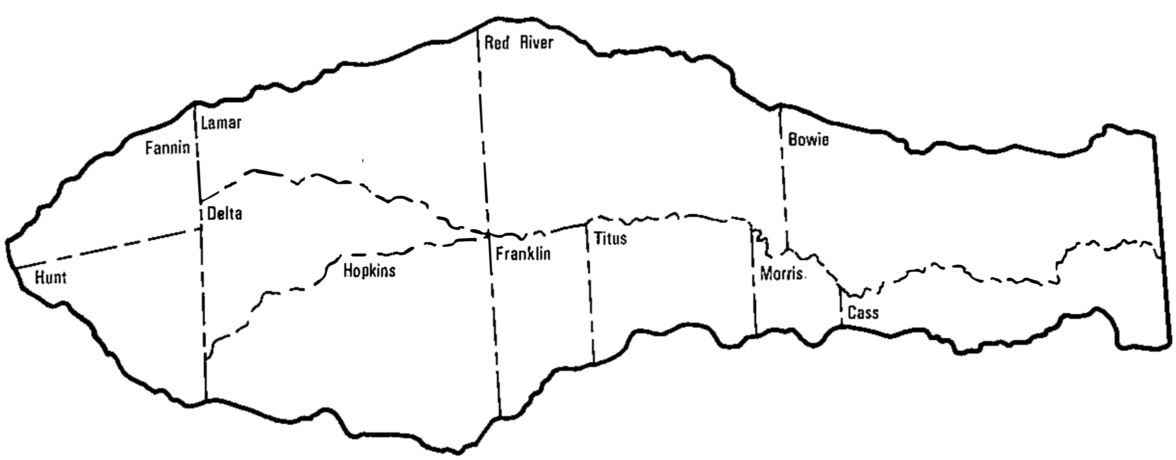


Figure III-3-1. Sulphur River Basin

erably less. The water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases with depth.

The Queen City Aquifer occurs in the southeastern part of the basin. The aquifer ranges to about 500 feet in total thickness. Well yields are generally less than 250 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids; salinity increases with depth.

Saline-water encroachment is a potential problem within the basin due to local heavy withdrawals of ground waters from the Woodbine, Nacatoch, and Blossom Aquifers.

Water in the Carrizo-Wilcox and Queen City Aquifers in the Sulphur River Basin is generally suitable for most purposes; however, both aquifers produce water with relatively high iron concentrations throughout much of the basin. Water in the Queen City Aquifer is generally corrosive, as is water in the Carrizo-Wilcox Aquifer. Locally, the concentration of fluoride in the Woodbine, Nacatoch, and Blossom Aquifers exceeds the Interim Primary Drinking Water Standards promulgated by the Environmental Protection Agency—Texas Department of Health primary standards for fluoride.

Population and Economic Development

The population of the Sulphur River Basin was reported at 154.0 thousand in 1980. Texarkana, the largest city in the basin, had a 1980 in-basin population of 31.0 thousand. The economy of the area is based primarily on agriculture, agribusiness, and to a lesser extent on manufacturing, government employment, and tourism. Hopkins County, located within the basin, is the leading dairy county in Texas. Mineral activities in the basin are principally confined to oil, gas, and clay production.

Water Use

Municipal water use in the Sulphur River Basin totaled 28.1 thousand acre-feet in 1980. Bowie County accounted for 15.2 thousand acre-feet or 54 percent of basin municipal use. The city using the most significant quantity of water was Texarkana, 40 percent, of the total, including that portion of the city in Arkansas. Almost 99 percent of the 45.1 thousand acre-feet of freshwater use for manufacturing occurs in Bowie, Cass, and Lamar Counties. Major industries using significant quantities of water include food and related products, fabricated metal products, and paper and allied products.

In 1980, there was 110 megawatts of steam-electric power generating capacity in the Sulphur River Basin. The plant has an annual forced evaporation of about 150 acre-feet of surface water. In addition, estimated net natural evaporation from the cooling reservoir exceeds 1,600 acre-feet per year. Thus, total surface-water consumption was 1,750 acre-feet per year. An additional 187 acre-feet of ground water was also used.

In 1980, there were only about 1.8 thousand acre-feet of water used for irrigation in the basin.

Estimated mining water use in 1980 in the basin totaled 1.3 thousand acre-feet of freshwater of which 736 acre-feet was utilized for the mining of nonmetals. The remaining 591 acre-feet was used for fuel production.

Livestock water use in the Sulphur River Basin during 1980 totaled 6.5 thousand acre-feet, with an estimated 2.6 thousand acre-feet from ground water and 3.9 thousand acre-feet from surface water.

Return Flows

In 1980, municipal and manufacturing return flows totaled 15.8 thousand acre-feet in the Sulphur River Basin.

Current Ground-Water Development

Approximately 11.2 thousand acre-feet of ground water was used in 1980 in the Sulphur River Basin. The most developed aquifers within the basin are the Carrizo-Wilcox, Nacatoch, and Blossom. Over 50 percent of the ground water used in the basin in 1980 was from the Carrizo-Wilcox Aquifer.

Of the 11.2 thousand acre-feet of ground water used in the basin, about 7.1 thousand acre-feet or 64 percent was for municipal purposes.

Overdrafts of ground water for mainly municipal purposes occurred in the Carrizo-Wilcox Aquifer in Bowie, Cass, Franklin, and Morris Counties; in the Nacatoch Aquifer in Hunt County; and in the Blossom Aquifer in Red River County.

Current Surface-Water Development

Since December 1980 Texas use of water in the Sulphur River Basin has been subject to the Red River Compact.

Lake Wright Patman was constructed and is operated by the U.S. Army Corps of Engineers for flood-control purposes. In 1958, the Cities of Texarkana, Texas and Texarkana, Arkansas contracted with the federal government to reserve part of the storage capacity of the reservoir for water-supply purposes. In 1968, the City of Texarkana, Texas contracted with the federal government to make available, on an interim basis, an additional supply of water for municipal and industrial purposes through modification of the reservoir operating rules. Total use from Lake Wright Patman in 1980 was about 51.8 thousand acre-feet, with the Cities of Texarkana, Texas and Texarkana, Arkansas using about 13.6 thousand acre-feet. About three thousand acre-feet of this total was delivered to the Cities of Wake Village, Hooks, New Boston, Maud, DeKalb, Avery, Annona, Atlanta, and Oak Grove. In addition, International Paper Company has contracted with the City of Texarkana, Texas to purchase raw water, in an amount up to 118 thousand acre-feet annually, for operation of its paper mill which is located near the Sulphur River downstream from Lake Wright Patman Dam. This includes process water and water required for operation of the plant's waste treatment facilities in accordance with the current State-Federal National Pollutant Discharge Elimination System permit provisions and present stream-quality standards for the Sulphur River.

Lake Sulphur Springs, located on White Oak Creek, is owned and operated by the City of Sulphur Springs. It provides municipal water supplies for the city and rural areas and various manufacturing plants served by the city in Hopkins County. The City of Sulphur Springs also supplies water to the City of Cooper and rural areas in Delta County. Approximately 2.9 thousand acre-feet of water was diverted from the reservoir in 1980.

The Cooper Lake and Channels Project, on the South Sulphur River, is a multipurpose federal project which was under construction by the Corps of Engineers when halted by an order of the U.S. District Court in 1971 pursuant to litigation filed under provisions of the National Environmental Policy Act of 1969. In July 1984, the 5th U.S. Circuit Court of Appeals overturned the construction injuction by the U.S. District Court. Appeal of this latest decision is a possibility, thereby continuing litigation on this project. The Sulphur River Municipal Water District holds water rights to 26.282 percent of the 273.0 thousand acre-feet of conservation storage which the project will develop, when completed, as well as the right to divert its proportional share of the yield for use by the District's customers. Upon completion of Cooper Lake, 120.0 thousand acre-feet of flood-control storage in Lake Wright Patman will be transferred to Cooper Reservoir, thus increasing the water-supply storage in Lake Wright Patman.

River Crest Reservoir, the remaining major reservoir in the basin, is an off-channel storage facility which provides water for steam-electric power plant cooling. Under permit provisions, up to 10.0 thousand acre-feet of water can be diverted annually from the Sulphur River, under specified river-flow conditions, into River Crest Reservoir to maintain a constant operating level.

The City of Commerce, although supplied partially by ground water pumped from the Nacatoch Aquifer, obtained about 900 acre-feet of surface-water supplies in 1980 from Lake Tawakoni in the Sabine River Basin through agreements with the Sabine River Authority. Pumping and pipeline facilities for the City of Commerce have the capability of delivering up to 10.0 thousand acre-feet of water annually from Lake Tawakoni to the city.

The City of Paris, part of which lies within the Sulphur River Basin, and domestic and manufacturing users which the city serves are supplied from Lake Creek and Lake Pat Mayse, both located in the Red River Basin.

Water Rights

A total of 367,292 acre-feet of surface water was authorized or claimed for diversion and use in the Sulphur River Basin as of December 31, 1983 (Table III-3-1). Municipal use accounted for 50.2 percent of the total amount of water authorized and/or claimed in the basin (Table III-3-2).

Water Quality

The Sulphur River above Lake Wright Patman and Days Creek in the Texarkana area frequently experience low dissolved oxygen and elevated nutrient and fecal coliform levels. These conditions are primarily due to the discharge of treated wastewater. Upon completion of Cooper Reservoir, a minimum water release will be maintained and should alleviate some of these water quality problems in the Sulphur River.

Flooding and Drainage

Since 1953, the Sulphur River Basin has experienced damaging floods 11 times. Basinwide, historic damages tabulated by the Corps of Engineers total in excess of $9.3 million. Completion of Lake Wright Patman in 1956 has greatly reduced flood potential for the extreme eastern part of the basin. Completion of the Cooper Lake and Channels Project will provide significant additional flood protection for the basin.

Table III-3-1. Authorized or Claimed Amount of Water, by Type of Right, Sulphur River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	36	365,552
Claims	43	1,730
Certified Filings	2	10
Certificates of Adjudication	0	0
Total Authorizations and Claims	81	367,292

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-3-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Sulphur River Basin

Type of Use	Number of Rights	Basin Total
Municipal	16	184,223
Industrial	11	166,412
Irrigation	46	10,143
Recreation	12	6,514
Total	81[1]	367,292

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

The Federal Emergency Management Agency, has designated 27 communities within the Sulphur River Basin as having one or more potential flood-hazard areas. Sixteen of these cities are participants in the National Flood Insurance Program. Nine participants are eligible for the sale of insurance at subsidized rates and seven cities are eligible for actuarial rates under the regular program. Studies to determine 100-year flood elevations within the Cities of Texarkana and Commerce have been completed.

In the Sulphur River Basin, drainage problems occur in alluvial river bottoms and terraces. If additional timbered areas are cleared for cultivation, on-farm drainage systems must be expanded for good crop production. Channels have been enlarged and levees constructed in local areas to enhance drainage capability of natural outlets and streams. Some of this work was accomplished by the Corps of Engineers in association with the Cooper Lake and Channels Project. At least one-half of the area which is feasible for drainage improvements will need to be provided with lateral ditches to connect farm drainage systems to major outlets and improved stream channels.

Recreation Resources

Lake Wright Patman, with over 20.0 thousand surface acres, accounted for 91 percent of the total surface area of lakes in the Sulphur River Basin available for flat-water recreation. This reservoir, operated by the Corps of Engineers, had a recorded recreation use of more than 4.5 million visits by recreationists during 1980. The Sulphur River, plus Lake Sulphur Springs with 1.3 thousand surface acres and River Crest Lake with 600 surface acres, provides additional water-oriented recreation opportunities.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Sulphur River Basin is projected to increase 81 percent by the year 2030, from the present 154.0 thousand (1.1 percent of the State population) to 279.0 thousand (0.8 percent of the State population). A 23 percent increase, to 189.3 thousand, is forecasted from 1980 to the year 2000, and a growth of 47 percent is anticipated for the ensuing 30 years (Table III-3-3). These rates of change are lower than the projected statewide trends of 49 percent and 62 percent, respectively.

The Sulphur River Basin includes the City of Texarkana, in Bowie County, which is one of the fastest growing counties in the basin. Population of Bowie County is projected to increase by 83 percent from 1980 to 2030. The percentage of basin population in Bowie County is expected to increase from 41.6 percent to 42.3 percent.

Table III-3-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Sulphur River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Sulphur Basin																		
Population			154.0			171.8			189.3			211.6			242.1			279.0
Municipal	7.1	21.0	28.1	2.9	39.8	42.7	1.9	46.4	48.3	2.0	52.0	54.0	2.1	59.7	61.8	1.8	69.7	71.5
Manufacturing	0.1	45.0	45.1	0.0	51.4	51.4	0.0	59.1	59.1	0.0	81.1	81.1	0.0	106.8	106.8	0.0	122.6	122.6
Steam Electric	0.2	1.7	1.9	0.0	1.9	1.9	0.0	14.7	14.7	0.0	21.6	21.6	0.0	28.4	28.4	0.0	38.3	35.3
Mining	1.2	0.1	1.3	1.3	0.2	1.5	1.4	0.2	1.6	1.5	0.2	1.7	1.5	0.3	1.8	1.6	0.2	1.8
Irrigation	0.0	1.8	1.8	1.0	4.3	5.3	1.0	6.1	7.1	1.0	8.0	9.0	1.0	8.0	9.0	1.0	8.0	9.0
Livestock	2.6	3.9	6.5	0.9	6.7	7.6	0.9	7.9	8.8	0.9	7.9	8.8	0.9	7.9	8.8	0.9	7.9	8.8
Basin Total Water	11.2	73.5	84.7	6.1	104.3	110.4	5.2	134.4	139.6	5.4	170.8	176.2	5.5	211.1	216.6	5.3	243.7	249.0

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

Water Requirements

Municipal

Municipal water requirements were projected for two cases of future growth based on both population and per capita water use. From 1980 to 2000, municipal water requirements in the Sulphur River Basin are projected to increase 52 percent (high set). From 1980 to 2030, an almost threefold increase is projected, with the majority of the growth occurring in Bowie County.

Industrial

Manufacturing water requirements in 1980 were 45.1 thousand acre-feet in the Sulphur River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Basin water requirements will increase to 57.4 thousand acre-feet or 59.1 thousand acre-feet by 2000, low and high cases, respectively. From 2000 to 2030, water demands are projected to increase an additional 56 percent (low set) to 107 percent (high set).

Steam-Electric Power Generation

Although the Sulphur River Basin consumes less than 2000 acre-feet of surface water per year for steam-electric power generation, available near-surface lignite reserves will result in growth. By 2000, water consumption for power-plant cooling is projected to exceed 14 thousand acre-feet per year and, by 2030 be more than 35 thousand acre-feet annually (high case).

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Sulphur River Basin are projected to increase from the 1980 level of 1.8 thousand acre-feet by a projected threefold increase to the year 2000 in the high case, and declining 38 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 1.1 to 9.0 thousand acre-feet annually, low and high case, respectively, to irrigate from 1.3 thousand acres to 10.2 thousand acres.

Livestock

A slight increase in cattle production is expected to increase livestock water use to more than 8.8 thousand acre-feet by 2000. In 1980, livestock water use was 6.5 thousand acre-feet. By 2030, water use is projected to increase 35 percent over the 1980 use.

Mining

Nonmetal mining water use in 1980 (737 acre-feet) is projected to more than double by 2030, however, water used in the recovery of crude petroleum and natural gas is not expected to exceed 300 acre-feet by the end of the planning period. By 2030, mining water use is projected to increase by 38 percent, 1.8 thousand acre-feet.

Navigation

No navigation facilities are planned in the Sulphur River Basin.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the Sulphur River Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Sulphur River Basin to the year 2030 is 14.0 thousand acre-feet with the following amounts annually available by aquifer; 4.0 thousand acre-feet from the Carrizo-Wilcox, 1.3 thousand acre-feet from the Trinity Group, 1.3 thousand acre-feet from the Nacatoch, 0.4 thousand acre-feet from the Blossom, and 7.0 thousand acre-feet from the Queen City. Since the ground water available from the Queen City Aquifer within the basin has high concentrations of iron and high acidity (low pH), it should not be considered a suitable source of water for municipal and most manufacturing purposes. However, Queen City ground water is suitable for irrigation, steam-electric power generation (cooling), mining and livestock watering purposes. At the end of the year 2029, the annual yield of the Trinity Group Aquifer within the basin would be reduced from 1.3 thousand acre-feet to zero, because all of the ground water in recoverable artesian storage would be removed. Since the artesian portion of the Trinity Group Aquifer within the basin does not receive any effective recharge, the yield of the aquifer in the year 2030 is zero. This reduction decreases the total ground-water availability within the basin in 2030 to 12.7 thousand acre-feet.

The projected annual ground-water use within the Sulphur River Basin by decade from 1990 through 2030 is expected to be from 5.2 to 6.1 thousand acre-feet per year (Table III-3-4). The approximate average annual projected ground-water use within the basin is expected to be about 5.5 thousand acre-feet per year. Of the 5.5 thousand acre-feet of average annual projected use, about 51 percent is expected to be from the Carrizo-Wilcox Aquifer, and about 24 percent is expected to be from the Queen City Aquifer.

Surface-Water Availability and Proposed Development

Projected surface-water requirements can be fully satisfied by existing and proposed surface-water projects in the Sulphur Basin through the year 2030 (Table III-3-4, Figure III-3-2). An excess of 244.5 thousand acre-feet of annual surface-water supply is projected to occur in the river basin by 2030. A slight shortage of 6.8 thousand acre-feet for irrigation is estimated to occur due to locally limiting ground-water supplies. The total surface-water supply in the basin is anticipated to be 963.1 thousand acre-feet in year 2030, with imports accounting for 40.4 thousand acre-feet and exports totaling 485.0 thousand acre-feet.

The Sulphur River Basin surface-water needs may be met from existing reservoirs in the basin and imports from adjacent basins through the year 2030. However, major surface-water storage and conveyance facilities will be needed in the Sulphur River Basin to supply water to adjacent river basins, particularly the Trinity River Basin. Water demand and supply analyses indicate that Cooper Reservoir, in the upper basin, would be needed by the year 2000 to meet anticipated increases in the water requirements for municipal and manufacturing use for the City of Irving and the service area for the North Texas Municipal Water District (NTMWD) in the Trinity River Basin. Pipelines connecting Cooper Reservoir to Lake Lavon and the City of Irving would be needed upon completion of the reservoir project. Upon completion of the Cooper Lake and Channels Project, 120.0 thousand acre-feet of flood-control storage will be reallocated from Lake Wright Patman to Cooper Lake, thus increasing the water supply storage capacity in Wright Patman by 120.0 thousand acre-feet.

By the year 2010, the increased needs for the cities serviced by NTMWD are projected to exceed available supplies even with Cooper Reservoir. An alternative for additional surface-water resources is the development of Stage I of George Parkhouse Reservoir, located downstream of Cooper Reservoir.

Increases in water needs for municipal and manufacturing purposes in the upper Trinity River Basin are anticipated to exceed available supplies by the year 2020. These shortages could be met from the development of Stage II of George Parkhouse Reservoir on the North Sulphur River. Water from this project, in addition to waters provided by Cooper and Parkhouse Stage I Reservoirs could be used to meet the year 2020 needs in the Trinity River Basin for the Tarrant County Water Control and Improvement District No. 1 (TCWCID-1) and NTMWD.

Cooper and Parkhouse Reservoirs could supply the increased water needs for NTMWD through the year 2030. However, TCWCID-1 and the City of Dallas are projected to need additional surface-water resources to meet water demands. Stage I of the Marvin C. Nichols Reservoir project downstream of Parkhouse Reservoir could provide this water supply. Conveyance facilities consisting of pipelines and/or open channels would have to be constructed to move available water from Nichols Reservoir to the upper Trinity River Basin.

Table III-3-4. Water Resources of the Sulphur River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	6.1	—	—	—	6.1	6.1	—	—	6.1	.0	.0	.0
Surface Water	129.3	—	21.2	19.1	169.6	96.0	—	4.9	100.9	71.8	(3.1)	68.7
Total	135.4	—	21.2	19.1	175.7	102.1	—	4.9	107.0	71.8	(3.1)	68.7
2000												
Ground Water	5.2	—	—	—	5.2	5.2	—	—	5.2	.0	.0	.0
Surface Water	320.6	—	26.4	23.3	370.3	124.5	—	72.6	197.1	178.2	(5.0)	173.2
Total	325.8	—	26.4	23.3	375.5	129.7	—	72.6	202.3	178.2	(5.0)	173.2
2010												
Ground Water	5.4	—	—	—	5.4	5.4	—	—	5.4	.0	.0	.0
Surface Water	446.6	—	32.0	28.0	506.6	160.9	—	115.2	276.1	237.3	(6.8)	230.5
Total	452.0	—	32.0	28.0	512.0	166.3	—	115.2	281.5	237.3	(6.8)	230.5
2020												
Ground Water	5.5	—	—	—	5.5	5.5	—	—	5.5	.0	.0	.0
Surface Water	584.5	—	39.1	33.7	657.3	201.1	—	232.4	433.5	230.6	(6.8)	223.8
Total	590.0	—	39.1	33.7	662.8	206.6	—	232.4	439.0	230.6	(6.8)	223.8
2030												
Ground Water	5.3	—	—	—	5.3	5.3	—	—	5.3	.0	.0	.0
Surface Water	875.3	—	47.4	40.4	963.1	233.6	—	485.0	718.6	251.3	(6.8)	244.5
Total	880.6	—	47.4	40.4	968.4	238.9	—	485.0	723.9	251.3	(6.8)	244.5

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

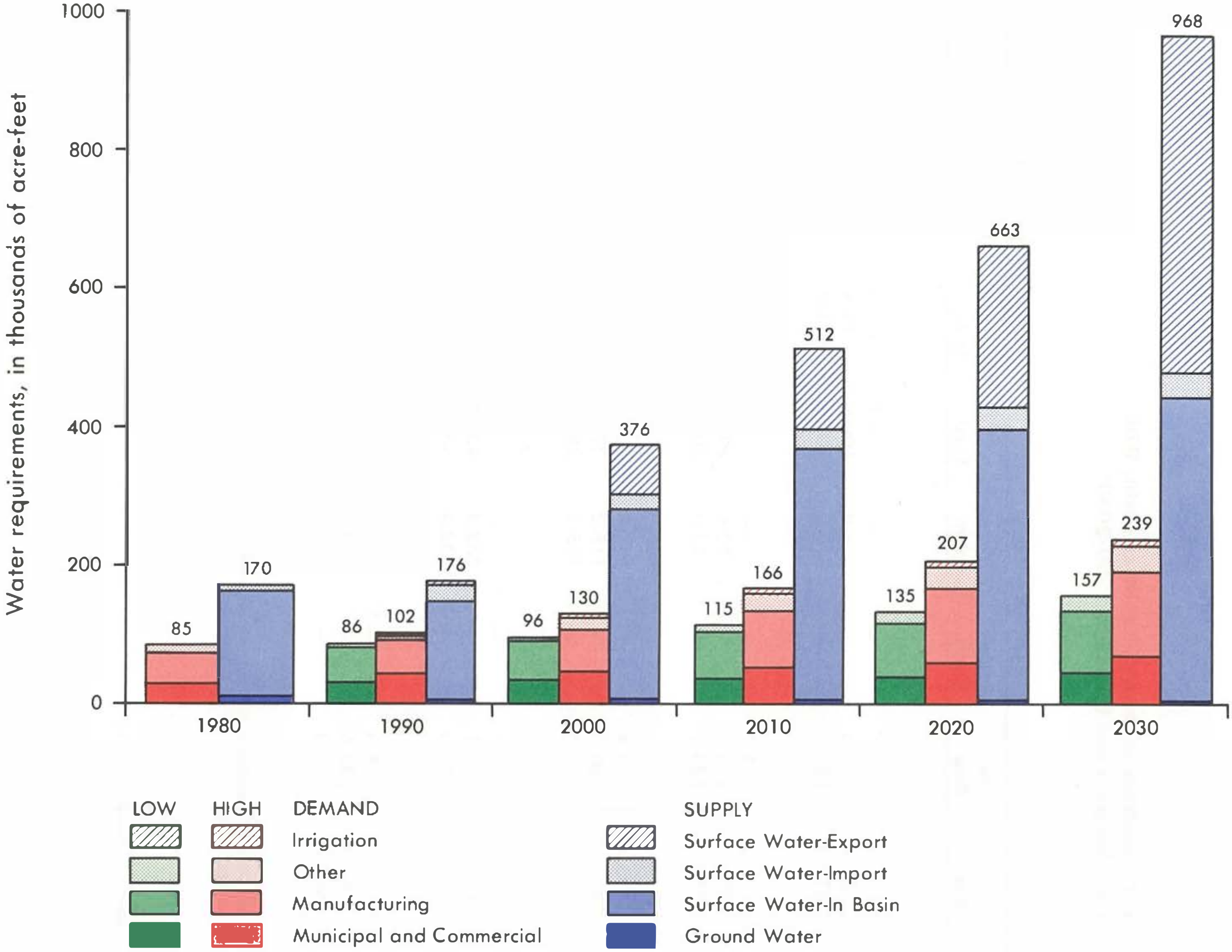


Figure III-3-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Sulphur River Basin, 1980-2030

Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such major interbasin transfers of water as proposed above.

Water Quality Protection

A water quality management plan for the Sulphur River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Texarkana metropolitan area. The purpose of these plans is to provide information for use in making water quality management decisions. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $65.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Sulphur River Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of industrial, agricultural, and oil and gas pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Wright Patman Reservoir is presently the only reservoir in the basin with flood-control storage capacity, which totals 2.5 million acre-feet; however, it is planned to reallocate part of the flood-control storage to Cooper Lake, as previously described.

Construction of floodwater-retarding structures in the basin by the U.S. Department of Agriculture, Soil Conservation Service includes 40 square miles of drainage area above 25 existing floodwater-retarding structures. As of October 1980 there were no additional structures planned for construction.

4. CYPRESS CREEK BASIN

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4. CYPRESS CREEK BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Cypress Creek Basin is bounded on the north by the Sulphur River Basin, on the west and south by the Sabine River Basin, and on the east by the Texas-Arkansas and Texas-Louisiana state boundaries. The headwaters of Big Cypress Creek form in southeastern Hopkins County at a streambed elevation of 445 feet. Big Cypress Creek is joined from the north by Boggy Creek near Lone Star and becomes Big Cypress Bayou in Marion County. Lily Creek and Carney Creek join to form Little Cypress Creek near Gilmer, becoming Little Cypress Bayou in Harrison County. Big Cypress Bayou and Little Cypress Bayou join at the boundary of Marion and Harrison Counties at a streambed elevation of about 170 feet. The Cypress Creek Basin empties into the Red River near Shreveport, Louisiana. Total basin drainage area in Texas is 2,812 square miles. For planning purposes, the basin is treated as a single hydrologic unit (Figure III-4-1).

Surface Water

The average runoff in the Cypress Creek Basin in Texas during the period 1941 through 1958 was 696 acre-feet per square mile. The lowest consecutive runoff rates during the 1941-58 period occurred in 1954, 1955, and 1956, when runoff rates averaged 256, 248, and 122 acre-feet per square mile, respectively.

Floods frequently occur in the Cypress Creek Basin. Floods generally rise and fall slowly and have relatively low flow velocities. Heavily timbered flood plains retard surface runoff and create natural obstructions to flood flows, causing additional backwater problems.

Principal streams of the Cypress Creek Basin flow through dense, undeveloped forested areas. The quality of water in these streams and existing reservoirs is generally good. Dissolved-solids concentrations average between 50 to 200 milligrams per liter (mg/l) in the principal streams, and about 100 mg/l in Lake O' the Pines on Big Cypress Creek.

Ground Water

The Carrizo-Wilcox Aquifer occurs over the entire Cypress Creek Basin. Yields of high-capacity wells average 200 gallons per minute (gpm), but locally wells produce up to 900 gpm. The water generally contains less than 500 mg/l total dissolved solids.

The Queen City Aquifer occurs in a wide band across the central part of the basin. Total thickness ranges up to about 500 feet. Well yields are generally low, but locally wells produce as much as 200 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids.

Ground waters contained in the shallow water-bearing sands of the Carrizo-Wilcox and Queen City Aquifers within the basin usually have excessive concentrations of iron and low pH (high acidity) values. Also, due to excessive pumpage, saline-water encroachment may occur from saline water-bearing sands laterally adjacent to or beneath the fresh water-bearing sands of the aquifers.

Population and Economic Development

The population of the Cypress Creek Basin was reported at 118.2 thousand in 1980. Mount Pleasant is the largest population center in the basin. The economy of the Cypress Creek Basin is based on agriculture, agribusiness, manufacturing, paper and wood products, and steel production. Oil and gas processing and tourism round out the basin economy. Mineral activities in the basin include lignite mining and the production of gas, oil, iron ore, sand, gravel, and clay.

Water Use

Municipal water use in the Cypress Creek Basin in 1980 totaled 15.6 thousand acre-feet. The City of Mount Pleasant, in Titus County, used 10 percent of the total basin municipal water in 1980; 51 percent of the total basin use was in rural areas or in cities and communities of less than one thousand population.

Manufacturing industries in the Cypress Creek Basin used 198.4 thousand acre-feet of freshwater in 1980. Most of the water use was concentrated in Harrison, Morris, and Titus Counties where food and kindred products, chemicals, petroleum, and primary metals establishments are the major water-using industries.

In 1980, there was 3,885 megawatts of steam-electric power generating capacity in the Cypress Creek Basin. Surface-water consumption (including net evaporation) for power generation was 29.6 thousand acre-feet

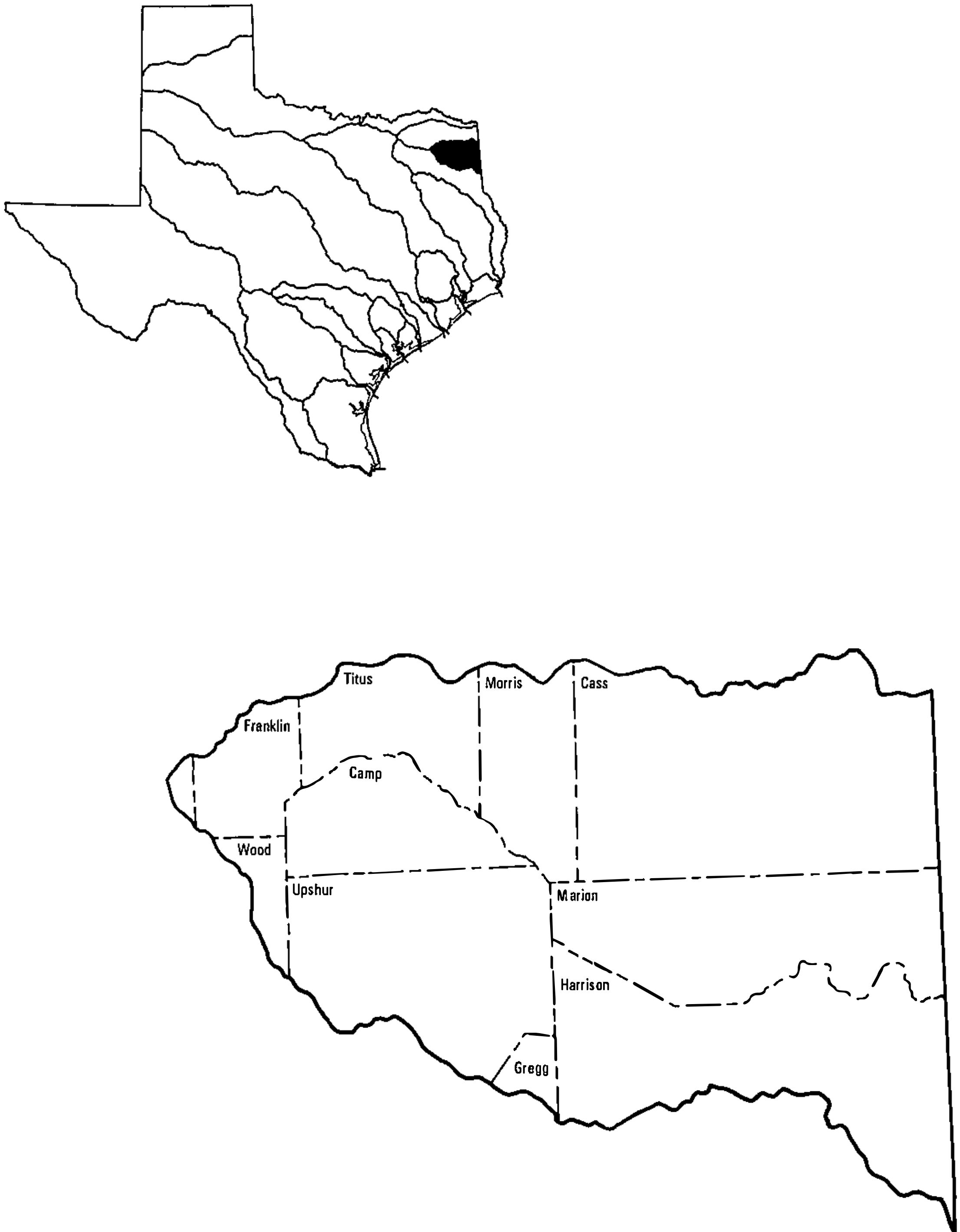

Figure III-4-1. Cypress Creek Basin

during 1980 while ground-water consumption totaled 62 acre-feet. Net evaporation from power plant cooling reservoirs was estimated at 9.5 thousand acre-feet in 1980.

In 1980, irrigation use was only 0.5 thousand acre-feet in the Cypress Creek Basin. Although small acreages have been irrigated periodically with ground water, none was used in 1980. Irrigation is not expected to become widespread in the basin, as rainfall is generally adequate for the production of grazing and feed crops grown in the area.

Estimated freshwater withdrawals associated with nonmetal production (primarily sulfur) accounted for approximately 25 percent of the total mining water use (1.9 thousand acre-feet) in the Cypress Creek Basin in 1980. The largest mining water use was in Harrison County, where 243 acre-feet of fresh water was used for petroleum production.

Livestock water use in 1980, principally for cattle production, totaled about 3.4 thousand acre-feet in the basin. Of this 1.8 thousand acre-feet was surface water.

Return Flows

In 1980, reported municipal and manufacturing return flows totaled 108.5 thousand acre-feet in the Cypress Creek Basin. Steel production in Morris County accounted for most of this return flow.

In the Cypress Creek Basin, irrigation is expected to continue with water diverted directly from streams, small impoundments, farm ponds, or pumped from wells. This small amount of scattered irrigation is not anticipated to produce any significant volumes of return flows.

Current Ground-Water Development

Approximately 14.7 thousand acre-feet of ground water was used in 1980 in the Cypress Creek Basin. The Carrizo-Wilcox and Queen City Aquifers are the only fresh to slightly saline water-bearing formations occurring within the basin. In 1980, about 75 percent ofthe ground water used in the basin was from the Carrizo-Wilcox Aquifer.

Of the 14.7 thousand acre-feet of ground water used in the basin, about 10.7 thousand acre-feet or 73 percent was for municipal purposes.

Overdrafts of ground water for municipal purposes occurred in Upshur County from the Carrizo-Wilcox Aquifer.

Current Surface-Water Development

There are eight major reservoirs in the Cypress Creek Basin: Cypress Springs, Bob Sandlin, Lake O' the Pines, Monticello, Welsh, Ellison Creek, Johnson Creek, and Caddo. Caddo Lake lies partly within Texas and partly in Louisiana, with Caddo Dam located in Louisiana. Since December 1980, Texas use of water in the Cypress Creek Basin has been subject to the Red River Compact.

Lake Cypress Springs, located near the headwaters of Big Cypress Creek, is owned by the Franklin County Water District. The District currently supplies raw water to the City of Mount Vernon, located in the Sulphur River Basin, and has commitments to serve rural areas in the Franklin County area through the South Franklin Water Supply Corporation. Also, up to 3.8 thousand acre-feet annually is committed to Texas Utilities Generating Company for steam-electric power plant cooling. Lake Bob Sandlin, owned and operated by the Titus County Fresh Water Supply District No. 1 just downstream from Lake Cypress Springs, supplies the municipal and manufacturing water needs of the City of Mount Pleasant, and supplies up to 38.5 thousand acre-feet of water annually to Texas Utilities Generating Company for steam-electric power plant cooling.

Lake O' the Pines, located downstream from Lake Bob Sandlin, was constructed and is operated by the U.S. Army Corps of Engineers for flood control and water-supply purposes. The Northeast Texas Municipal Water District owns the 251 thousand acre-feet of conservation storage in the reservoir and presently supplies municipal and manufacturing water to the Cities of Daingerfield, Lone Star, and Hughes Springs as well as industrial use described below.

Monticello, Ellison Creek, Welsh, and Johnson Creek Reservoirs are located on tributaries of Big Cypress Creek and all serve manufacturing and steam-electric power plant cooling water needs. Monticello Reservoir, located on Blundell Creek, was constructed by Dallas Power and Light Co. and others, to supply cooling water and other water required for operation of steam-electric power plants near the reservoir. In order to maintain a constant operating level necessary for power plant operation, make-up water is diverted to Monticello Reservoir from Lake Bob Sandlin, as necessary, pursuant to water supply contracts with Titus County Fresh Water Supply District No. 1, Franklin County Fresh Water Supply District, and Dallas Power and Light Co. Welsh Reservoir, located on Swauano Creek, is owned by Southwestern Electric Power Company and provides cooling water and other water requirements for operation of the steam-electric power plant located at the reservoir. The reservoir is maintained at constant operating level by supplemental diversions, as necessary, from Lake O' the Pines through a contractual agreement with the Northeast Texas Municipal Water District. Ellison Creek Reservoir, owned by Lone Star Steel Co., supplies water for its steel mill located near Daingerfield. Through prior water rights held by the company to the flows of Cypress Creek, supplemental water is diverted from Cypress Creek into Ellison Creek Reservoir. In 1980, a total of 195.6 thousand acre-feet of water was diverted from the combined Cypress Creek-Ellison Creek Reservoir supply system for industrial use. Johnson Creek Reservoir, located on Johnson Creek, is owned by Southwestern Electric Power Company. The reservoir supplies cooling water and other water needs associated with operation of the company's steam-electric power plant located at the reservoir and is maintained at a constant operating level by diversions, as necessary, from Lake O' the Pines.

Caddo Lake, on the Louisiana border, is created by Caddo Dam on Big Cypress Bayou in Caddo Parish, Louisiana. The lake is owned and operated by the Caddo Lake Levee District. The original dam, constructed in 1914 by the federal government for local navigation purposes, was reconstructed by the Corps of Engineers in 1971. The City of Marshall diverts water from Big Cypress Bayou. In 1980, the city diverted about 7.1 thousand acre-feet of water from Cypress Creek. Oil City and Mooringsport, Louisiana currently withdraw municipal supplies from Caddo Lake. Cooling water is also withdrawn from the lake by a steam-electric power plant located near Mooringsport. The Red River Compact provides that each state shall have unrestricted right to use 50 percent of the conservation storage capacity, subject to the provision that supplies for existing uses of water from the lake on date of Compact, are not reduced.

Owing to the complexities arising from the appropriation of waters of the Cypress Creek Basin, and the rapid development and use of the basin supplies, extensive hydrologic studies of the basin have been performed which led to the development of an operating agreement between the Franklin County Water District, the Titus County Fresh Water Supply District No. 1, the Northeast Texas Municipal Water District, the Texas Water Development Board, and Lone Star Steel Company. The agreement, approved by the participants in 1972 includes rules for the operation of reservoirs owned by various entities and provisions for accounting for the waters held in storage. In 1973, the Texas Water Rights Commission adopted an order approving the operating agreement. Basically, the agreement provides that Lakes Cypress Springs and Bob Sandlin can impound and store water previously appropriated to downstream entities (specifically Lake O' the Pines and Lone Star Steel Company) subject to call for releases from upstream storage to satisfy downstream requirements as needed. The agreement establishes storage accounts in the main stem reservoirs and Ellison Creek Reservoir such that the basin waters are appropriately divided, in accordance with existing water rights, through exchange of storage.

Water Rights

A total of 422,013 acre-feet of surface water was authorized or claimed for diversion and use in the Cypress Creek Basin as of December 31, 1983 (Table III-4-1). Municipal use accounted for 22.7 percent of the total amount of water authorized and/or claimed in the basin (Table III-4-2).

Water Quality

Some streams in the Cypress Creek Basin periodically exhibit low dissolved-oxygen concentrations. This problem is caused by the discharge of treated sewage and is compounded by low stream discharge rates and low reaeration rates characteristic of streams in the area. Cypress Creek above Lake O' the Pines experiences periodic low dissolved-oxygen concentrations under low-flow conditions. Black Bayou occasionally experiences low dissolved-oxygen concentrations, as the result of the discharge of

Table III-4-1. Authorized or Claimed Amount of Water, by Type of Right, Cypress Creek Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	54	417,485
Claims	97	4,528
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	151	422,013

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-4-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Cypress Creek Basin

Type of Use	Number of Rights	Basin Total
Municipal	13	95,729
Industrial	16	310,824
Irrigation	108	7,056
Mining	1	282
Recreation	23	8,122
Total	151[1]	422,013

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

treated wastewaters in the Atlanta area. James (Jim's) Bayou also has low dissolved-oxygen concentrations. This condition results also from the discharge of treated sewage, low stream discharge rates and low reaeration rates.

Flooding and Drainage

Very few estimates of dollar losses due to flooding are available for the Cypress Creek Basin. Floods in April and June of 1957 caused an estimated $420 thousand in damages to agriculture and nonagricultural properties. It has been estimated that the May 1958 flood in Atlanta and vicinity caused damages in excess of $1 million to highways and bridges. Minor flooding in Jefferson in 1979 and Mount Pleasant in 1981 produced three flood insurance claims for slightly over $11 thousand in flood damages.

Within the Cypress Creek Basin, 18 cities have one or more flood-hazard areas within their corporate limits. Maps identifying areas inundated by the 100-year flood have been prepared for these cities, and work is underway to identify flood plains within unincorporated areas of the basin. Presently, nine of the 18 designated cities have adopted flood plain management standards in compliance with the National Flood Insurance Program.

The most critical drainage problems in the basin occur in the alluvial bottoms and terraces along the major streams. Changes in land use may preclude the necessity for improving drainage, as cultivated lands in the area between Lake O' the Pines and Caddo Lake are being progressively coverted to improved pasture land.

Recreation Resources

The seven reservoirs in the Cypress Creek Basin with capacities of 5.0 thousand acre-feet or more provide over 64.0 thousand surface acres of water available for flat-water recreation. Caddo Lake, which extends into Louisiana, accounts for over 41 percent of this surface area. Caddo Lake State Park, located adjacent to the shoreline of Caddo Lake, provides additional recreation facilities with a recorded 138.0 thousand visits by recreationists during 1980. Lake O'the Pines, with 18.7 thousand surface acres, provides 29 percent of the water surface area available for flat-water recreation in the basin. Almost 4.0 million visits were made to this reservoir by water-oriented recreationists during 1980.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Cypress Creek Basin is expected to increase about 99 percent by 2030, from a level of 118.2 thousand in 1980 to over 235 thousand. A 37 percent growth, to almost 162 thousand, is predicted from 1980 to 2000, and an increase of 45 percent is forecast for the period 2000 to 2030 (Table III-4-3).

Cass County, the most populous county with 22 percent of the 1980 basin population, is expected to experience a population growth of 82 percent from 1980 to 2030, when it is expected to account for 20 percent of the 2030 basin population.

Water Requirements

Municipal

Municipal water requirements in the Cypress Creek Basin were 15.6 thousand acre-feet in 1980. Municipal water requirements were projected for two cases of future growth based on population changes, and per capita water use. From the 1980 level, both the high and low projections estimate a near doubling of water use by 2030. By 2000, municipal water use is projected to increase by 32 percent, 20.6 thousand acre-feet (low set), and increase another 35 to 45 percent by 2030. The proportionate share of use among the counties in the basin is projected to remain fairly constant.

Table III-4-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Cypress Creek Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Cypress Basin																		
Population			118.2			142.4			161.9			181.5			205.8			235.4
Municipal	10.7	4.9	15.6	8.5	18.8	27.3	9.0	23.0	32.0	9.4	26.4	35.8	9.9	30.7	40.6	10.0	36.5	46.5
Manufacturing	0.9	197.5	198.4	0.3	235.3	235.6	0.3	222.8	223.1	0.3	228.3	228.6	0.3	234.6	234.9	0.3	242.4	242.7
Steam Electric	0.1	29.6	29.7	0.0	38.7	38.7	12.0	46.1	58.1	12.0	63.0	75.0	12.0	80.0	92.0	12.0	97.0	109.0
Mining	1.4	0.5	1.9	1.0	0.7	1.7	0.6	1.0	1.6	3.8	1.1	4.9	7.0	1.2	8.2	10.2	1.3	11.5
Irrigation	0.0	0.5	0.5	0.2	0.3	0.5	0.2	0.4	.6	0.3	0.3	0.6	0.3	0.3	0.6	0.2	0.4	0.6
Livestock	1.6	1.8	3.4	1.2	2.8	4.0	1.4	3.3	4.7	1.2	3.5	4.7	1.2	3.5	4.7	1.0	3.7	4.7
Basin Total Water	14.7	234.8	249.5	11.2	296.6	307.8	23.5	296.6	320.1	27.0	322.6	349.6	30.7	350.3	381.0	33.7	381.3	415.0

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Industrial

Manufacturing water needs in 1980 were 198.4 thousand acre-feet in the Cypress Creek Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

In the low case projection, manufacturing water use is projected to decline 16 percent by 2000, then increase gradually back to near the 1980 level by 2030. The predicted decline in water requirements for manufacturing does not result from an anticipated reduction in economic activity, but from projected major technological improvements in water use efficiency.

The anticipated reduction in industrial water requirements occurs primarily in Morris County. Almost all of the projected reduction in Morris County manufacturing water requirements results from anticipated greater water use efficiency in the production of steel and related primary metals products.

Steam-Electric Power Generation

Rapid development of the vast, near-surface lignite reserves in the Cypress Creek Basin, in conjunction with available water supplies, is projected to spur future growth of steam-electric generating capacity in the basin.

In 1980, 29.7 thousand acre-feet of water was consumed in steam-electric power generation. Future growth in this industry was projected for two electricity demand levels. By 2000, water requirements for power generation are projected to range from 38.7 to 58.1 thousand acre-feet. Water requirements are projected to increase from 2000-2030 by 88 to 99 percent.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Cypress Creek Basin are projected to increase from the 1980 level of 0.5 thousand acre-feet to 0.6 thousand acre-feet by the year 2000 in the high case, declining 37 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 0.3 to 0.6 thousand acre-feet annually, low and high case, respectively, to irrigate from 0.3 thousand acres to 0.7 thousand acres.

Livestock

Some increase in cattle production is projected for the Cypress Creek Basin. Livestock water requirements by 2000 are estimated to be 4.7 thousand acre-feet annually. Livestock water requirements are projected to increase 38 percent from 1980 to 2030.

Mining

Mining water use in the Cypress Creek Basin, which totaled 1.9 thousand acre-feet in 1980, is projected to decrease 14 percent by 2000. This slight decrease is the result of a decline in quantities of oil and gas available for production in the Cypress Creek Basin. Nonmetal mining water requirements are projected to increase from 465 acre-feet in 1980 to 1,180 acre-feet in 2030. Total mining water use estimates are projected to increase to 11.5 thousand acre-feet by 2030 mostly due to the production of synfuels.

Navigation

As part of the authorized Red River Waterway project, the Corps of Engineers has released a feasiblity report of the economics of navigation between Louisiana and Morris County. If this project becomes economically favorable, availability of lockage water requirements will be studied. At present, no supplemental diversions are anticipated.

Hydroelectric Power

No hydroelectric power generating facilities are planned for the Cypress Creek Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Cypress Creek Basin to the year 2030 is 250.3 thousand acre-feet with the following amounts annually available by aquifer: 15.8 thousand acre-feet from the Carrizo-Wilcox Aquifer, and 234.5 thousand acre-feet from the Queen City Aquifer. Since the ground water available from the Queen City Aquifer within the basin has high concentrations of iron and high acidity (low pH), it should not be considered a suitable source of water for municipal and most manufacturing purposes. However, Queen City ground water is suitable for irrigation, steam-electric power generation (cooling), mining, and livestock watering purposes. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual effective recharge of 15.0 thousand acre-feet per year. This reduction decreases the total ground water available within the basin in 2030 to 249.5 thousand acre-feet.

The annual ground-water use within the Cypress Creek Basin by decade from 1990 through 2030 is projected to increase from 11.2 to 33.7 thousand acre-feet per year (Table III-4-3). The approximate average annual projected ground-water use within the basin is expected to be about 25.2 thousand acre-feet per year. Of the 25.2 thousand acre-feet of average annual projected use, about 58 percent is expected to be from the Queen City Aquifer, and about 42 percent is expected to be from the Carrizo-Wilcox Aquifer.

Surface-Water Availability and Proposed Development

The Cypress Creek Basin has projected surface-water resources from proposed and existing reservoirs in excess of forecasted water requirements through the year 2030 (Table III-4-4, Figure III-4-2). Approximately 104.8 thousand acre-feet annually is available as surplus in the year 2030 for meeting additional basin municipal and manufacturing demands and for export to adjacent river basins. Surface-water supplies in the basin are projected at 493.8 thousand acre-feet per year in 2030, with 13.1 thousand acre-feet annually proposed for export to other basins.

Projected surface-water needs in the Cypress Creek Basin may be satisfied from existing sources with the exception that anticipated municipal and manufacturing water needs for the City of Marshall and adjacent area are projected to exceed available supplies by the year 1990. An anticipated supply source for additional surface water is the Big Sandy Reservoir project on the Big Sandy Creek tributary of the Sabine River. This project would provide the basin with sufficient quantities of surface water to meet projected needs through the year 2020. The project is needed by 1990.

Between 2020 and 2030, additional surface water will be needed in the Marshall area. Water pumped by pipeline from Toledo Bend Reservoir in the Sabine River Basin is proposed to meet the needs. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a interbasin transfer of water.

An alternative additional surface-water supply for the basin is the proposed Little Cypress Reservoir in Harrison County. Feasibility-level studies of construction of the project have been performed by federal, State and local agencies. A project with a water conservation storage capacity of 782.3 thousand acre-feet would yield 284.1 thousand acre-feet of annual water supply during the critical drought period.

The Black Cypress Reservoir project offers potential for the development of additional firm supplies in the basin for use in water-short areas of the State. Reconnaissance-level studies performed by the Department indicate a project could be constructed on Black Cypress Bayou with a total storage capacity of 824.4 thousand acre-feet.

Water Quality Protection

A water quality management plan for the Cypress Creek Basin has been developed pursuant to the requirements of federal and State Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permit-

Table III-4-4. Water Resources of the Cypress Creek Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	11.2	—	—	—	11.2	11.2	—	—	11.2	.0	.0	.0
Surface Water	254.9	—	221.0	2.4	478.3	292.7	—	15.0	307.7	170.6	.0	170.6
Total	266.1	—	221.0	2.4	489.5	303.9	—	15.0	318.9	170.6	.0	170.6
2000												
Ground Water	23.5	—	—	—	23.5	23.5	—	—	23.5	.0	.0	.0
Surface Water	254.9	—	211.0	2.9	468.8	292.0	—	14.3	306.3	162.5	.0	162.5
Total	278.4	—	211.0	2.9	492.3	315.5	—	14.3	329.8	162.5	.0	162.5
2010												
Ground Water	27.0	—	—	—	27.0	27.0	—	—	27.0	.0	.0	.0
Surface Water	254.9	—	217.2	3.3	475.4	317.7	—	13.6	331.3	144.1	.0	144.1
Total	281.9	—	217.2	3.3	502.4	344.7	—	13.6	358.3	144.1	.0	144.1
2020												
Ground Water	30.7	—	—	—	30.7	30.7	—	—	30.7	.0	.0	.0
Surface Water	254.9	—	224.5	3.7	483.1	345.2	—	13.0	358.2	124.9	.0	124.9
Total	285.6	—	224.5	3.7	513.8	375.9	—	13.0	388.9	124.9	.0	124.9
2030												
Ground Water	33.7	—	—	—	33.7	33.7	—	—	33.7	.0	.0	.0
Surface Water	254.9	—	233.5	5.4	493.8	375.9	—	13.1	389.0	104.9	(.1)	104.8
Total	288.6	—	233.5	5.4	527.5	409.6	—	13.1	422.7	104.9	(.1)	104.8

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-face supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

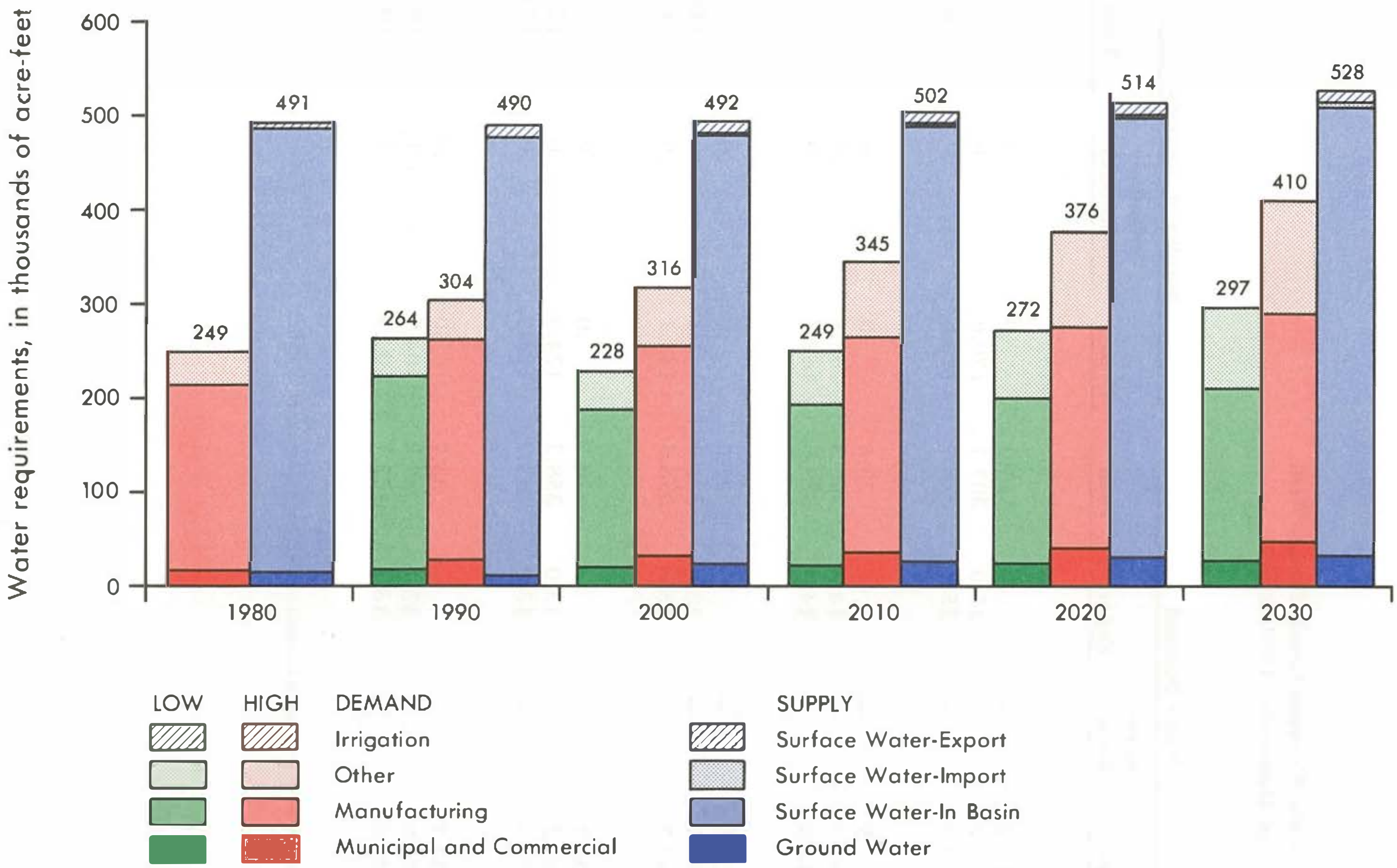

Figure III-4-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Cypress Creek Basin, 1980-2030

ting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $31.2 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Cypress Creek Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Lake O' the Pines is the only reservoir in the Cypress Creek Basin which has flood-control storage as a project purpose. The amount of flood-control storage capacity available is 587.2 thousand acre-feet. No reservoirs are planned by the year 2000 that would provide additional flood-control storage.

The Corps of Engineers has a study underway to determine the feasibility of federal participation in flood-control improvements within the Cypress Creek Basin. This study is scheduled for completion in fiscal year 1985.

5. SABINE RIVER BASIN

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5. SABINE RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Sabine River Basin is bounded on the north by the Sulphur River and Cypress Creek Basins, on the west by the Trinity and Neches River Basins, and on the east by the Red and Calcasieu River Basins. Headwaters of the Sabine River originate in northwest Hunt County at an elevation of about 650 feet. Flowing eastward, the Sabine River is joined by the South Fork at the intersection of Hunt, Van Zandt, and Rains Counties. The Sabine River flows southward from the southeast corner of Panola County, becomes the Texas-Louisiana boundary near Logansport, Louisiana, and continues southward to Sabine Lake on the Gulf Coast. The total basin drainage area is 9,756 square miles, of which 7,426 square miles is in Texas. The Sabine River Basin has been divided into two zones for planning purposes (Figure III-5-1).

Surface Water

Average runoff within about 97 percent of the Sabine River Basin during the 1941-67 period was about 640 acre-feet per square mile. In the southernmost part of the basin near Buna, average runoff in the 1953-70 period was about 687 acre-feet per square mile. The westernmost part of the basin near Quinlan had an average runoff of about 508 acre-feet per square mile during the 1960-70 period. Average runoff for drainage areas west of Logansport, Louisiana was about 530 acre-feet per square mile during the 1941-67 period.

During the 1941-67 period, lowest flows occurred during the 1954-56 and 1963-64 periods when the average runoff was 334 and 229 acre-feet per square mile, respectively. The lowest runoff in the earlier period was 269 acre-feet per square mile (1956) and 210 acre-feet per square mile (1963) in the later period. Low flows of the main stem at Logansport, Louisiana occurred during the same intervals; the average runoff was 226 acre-feet per square mile in the earlier period and 104 acre-feet per square mile in the later period. In 1956 and 1964, the runoff rates were 152 and 82 acre-feet per square mile, respectively.

The Sabine River Basin is characterized by flat slopes and wide, timbered flood plains. Floods generally rise and fall slowly and have low flow velocities, although flash flooding occasionally occurs in the basin. The extreme southern portion of the Sabine River Basin is subject to hurricane flooding.

The main stem of the Sabine River and the majority of its tributaries exhibit good inorganic quality, with discharge-weighted average concentrations of dissolved solids ranging from 100 to 250 milligrams per liter (mg/l). Salinity problems occur locally in the basin in Dry, Lake Fork, Socagee, Rabbit, and Grand Saline Creeks. Mineralization in Grand Saline Creek is a result of natural salt contributions from the Grand Saline Salt Dome, while salinity problems in the other streams result principally from oil-field drainage. Water stored in major reservoirs in the basin generally contains less than 150 mg/l of dissolved solids, and the Sabine River near Ruliff in southern Newton County seldom exceeds 150 mg/l of dissolved solids. Chloride and sulfate concentrations of the basin's surface waters generally fall below 80 and 35 mg/l, respectively.

Ground Water

The Gulf Coast Aquifer occurs throughout the southern part of the Sabine River Basin. This system extends to depths of more than 3,000 feet. Yields of large-capacity wells average about 1,800 gallons per minute (gpm), with some producing 3,500 gpm. Water pumped from the aquifer is generally suitable for most uses. Total dissolved-solids concentrations are commonly less than 500 mg/l.

The Carrizo-Wilcox Aquifer crops out at the surface in the central part and underlies much of the basin. Thickness ranges from zero to 1,600 feet for the entire Carrizo-Wilcox Aquifer. Yields from large-capacity wells average about 275 gpm, but locally wells produce as much as 700 gpm. Water throughout the aquifer generally contains less than 1,000 mg/l total dissolved solids and is suitable for most purposes.

In the extreme upper part of the Sabine River Basin, the Trinity Group Aquifer contains usable-quality water near its downdip limits. Thickness ranges from 100 to 300 feet. Productive portions of the aquifer occur northwest of the Mexia-Talco fault zone at depths of about 2,700 to 4,000 feet near the fault zone. No wells are known to be producing from this portion of the aquifer. Total dissolved-solids concentrations in ground water in the aquifer in this area range from about 1,000 to 3,000 mg/l. Excessive depth and unknown water quality characteristics may limit development of the aquifer in the Sabine River Basin.

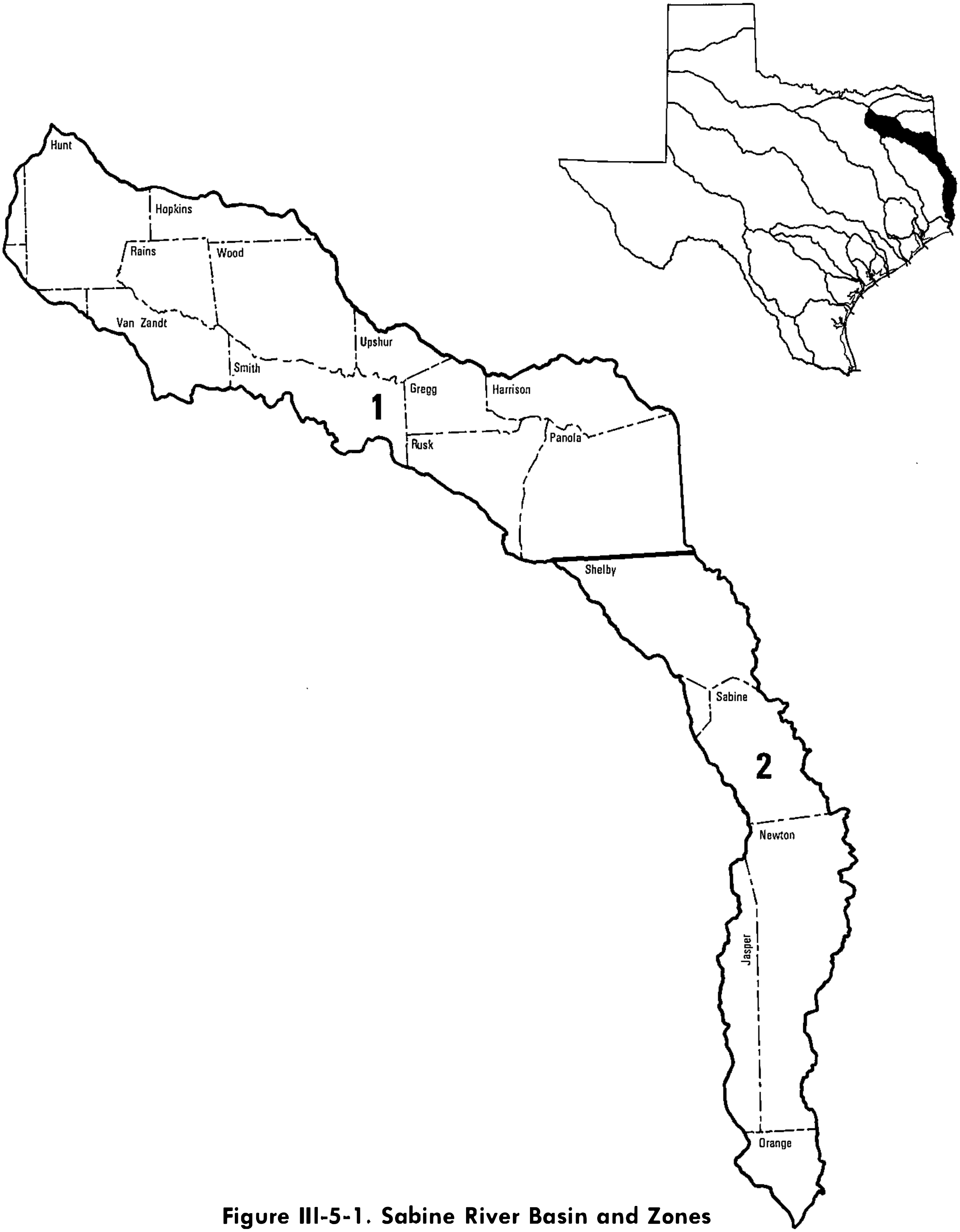

Figure III-5-1. Sabine River Basin and Zones

The Sparta Aquifer occurs in the south-central part of the Sabine River Basin. Limited data suggest that the thickness of the aquifer ranges from 200 to 260 feet. Data on yields of wells in the basin are unavailable; however, in the adjacent Neches River Basin well yields are estimated to average about 200 gpm, but locally wells produce up to 500 gpm. Generally, water produced from the Sparta Aquifer contains less than 500 mg/l total dissolved solids in its outcrop area, but water quality deteriorates rapidly with depth.

The Queen City Aquifer is present in the north-central part of the Sabine River Basin. Thickness ranges from zero to 600 feet. Water-bearing sand comprises 25 to 75 percent of the total thickness of the aquifer. Water in the aquifer is generally under water-table conditions. Well yields range up to 400 gpm. Water produced from the Queen City Aquifer is usually of good quality, having total dissolved-solids concentrations ranging from less than 100 to 300 mg/l.

The Nacatoch Sand Aquifer occurs in the upper part of the Sabine River Basin. Generally, the water-bearing zone occurs in the top 30 to 40 feet of the aquifer; however, its thickness ranges up to 100 to 150 feet downdip from the outcrop. Well yields generally average between 20 to 45 gpm, but may reach 200 gpm. Quality of water produced from the Nacatoch Sand Aquifer ranges from about 800 to 1,350 mg/l total dissolved solids, increasing with depth.

The Woodbine Aquifer occurs in the extreme upper part of the Sabine River Basin. Depths of the aquifer range from 1,600 to 1,800 feet below land surface, and its thickness varies between 550 and 650 feet.

Ground waters contained in the shallow water-bearing sands of the Carrizo-Wilcox and Queen City Aquifers within the basin usually have excessive concentrations of iron and low pH (high acidity) values. Also, due to excessive pumpage, saline-water encroachment may occur from saline water-bearing sands laterally adjacent to or beneath the fresh water-bearing sands of the aquifers.

Population and Economic Development

Population of the Sabine River Basin was reported at 407.3 thousand in 1980. Longview is the largest city in the basin, having a 1980 population of 62,762. It is followed by Marshall, Orange, and Greenville. The economy of the basin is diversified but is based principally on mineral production, agriculture, agribusiness, manufacturing, and recreation and tourism. The Port of Orange serves as a distribution and shipping center for many basin products.

Water Use

Municipal water use in the Sabine River Basin totaled 61.8 thousand acre-feet in 1980. Zone 1 used about 73 percent of total basin municipal water and Zone 2 utilized about 27 percent. Major municipal water- using counties in Zone 1 were Gregg, Harrison, and Hunt. The City of Longview (Gregg County) used 18 percent of total Zone 1 use. In Zone 2, Orange County used over 52 percent of the Zone total.

Water use by manufacturing industries in the Sabine River Basin totaled 84.3 thousand acre-feet in 1980. Upper basin areas (Zone 1) used 45 percent of the total manufacturing requirement, and the lower basin (Zone 2) used 55 percent. Zone 1 water use originated almost entirely in Gregg and Harrison Counties. In Zone 2, water use was concentrated principally in Orange County where large water-using industries of paper and allied products and chemicals are located. These industries used approximately 95 percent, or 43.9 thousand acre-feet, of the total water used in Zone 2 in 1980.

In 1980, there was 4,810 megawatts of steam-electric power generating capacity in the Sabine River Basin. Sixty percent of this capacity was in Zone 1 and used fresh surface water. The remaining 40 percent was located in Zone 2, and used fresh and saline water for cooling. A total of 1.5 thousand acre-feet of ground water was withdrawn for power production purposes. In addition, 23.0 thousand acre-feet of fresh surface water was consumed (including 11.5 thousand acre-feet of estimated net evaporation from cooling reservoirs).

In Zone 1, approximately 600 acre-feet of irrigation water was used in 1980. Irrigable lands in the upper basin are typically located in small, scattered tracts. Generally adequate and evenly distributed rainfall makes irrigation unnecessary most of the time, although supplemental water use is occasionally beneficial on improved pasture, hay, peanuts, some vegetables, and nursery stock. In the rice-growing area of the lower basin (Zone 2), about 8.4 thousand acre-feet of water was used in 1980. Of the total basin irrigation water use of 9.0 thousand acre-feet in 1980, ground water provided negligible amounts.

Mining water use in the Sabine River Basin was estimated at 6.8 thousand acre-feet of freshwater in 1980. Water use was concentrated in Zone 1. Petroleum and natural gas production used 5.2 thousand acre-feet, with the remaining water use being for nonmetals (sulfur and salt).

Livestock water use in 1980 totaled 8.7 thousand acre-feet in the Sabine River Basin. About 7.2 thousand acre-feet was used in Zone 1; Zone 2 used 1.5 thousand acre-feet.

Navigation facilities in the Sabine River Basin include portions of the Sabine-Neches Waterway, the Sabine Pass Channel, the Sabine-Neches Canal, the Sabine River to Orange, the Gulf Intracoastal Waterway, Adams Bayou Channel, and Cow Bayou Channel. These marine navigation facilities have no regulated freshwater requirements.

There is 85 megawatts of hydroelectric power generating capacity in the Sabine River Basin at Toledo Bend Dam, with a design rate of 16,000 cubic feet per second.

Return Flows

In 1980, municipal and manufacturing return flows in the Sabine River Basin totaled 67.0 thousand acre-feet. Zone 2 accounted for 44 percent of total basin return flows (29.5 thousand acre-feet) and the Zone 1 total was 37.5 thousand acre-feet.

Return flows from irrigation in Zone 1 were insignificant in 1980. Return flows from irrigated rice farms totaled about 1.3 thousand acre-feet in Zone 2 in 1980. These return flows enter the river at a point below all diversions and are therefore not reused.

Current Ground-Water Development

In 1980, approximately 54.6 thousand acre-feet of ground water was used in the Sabine River Basin. Of this amount, 30.3 thousand acre-feet was used in Zone 1, and 24.3 thousand acre-feet in Zone 2. In Zone 1 in 1980, about 81 percent of the ground water used was from the Carrizo-Wilcox Aquifer, and about 15 percent was from the Queen City Aquifer. In Zone 2, about 87 percent was used from the Gulf Coast Aquifer, and about 11 percent from the Carrizo-Wilcox Aquifer.

Of the 54.6 thousand acre-feet of ground water used in the basin approximately 42.7 thousand acre-feet or 80 percent was used for municipal and manufacturing purposes.

In 1980 within Zone 2, significant overdraft of ground water from the Carrizo-Wilcox Aquifer for municipal purposes occurred in Smith County. In Zone 2, significant overdrafts of ground water occurred in Orange County from the Gulf Coast Aquifer for municipal and manufacturing purposes, and in Shelby County, from the Carrizo-Wilcox Aquifer for municipal purposes.

Current Surface-Water Development

Since 1954, Texas use of Sabine River Basin water has been subject to the Sabine River Compact.

There are 12 major reservoirs in the Sabine River Basin, 11 of which are located in Zone 1 and one in Zone 2. Existing major reservoirs include Lakes Tawakoni, Holbrook, Hawkins, Quitman, Lake Fork, Winnsboro, Gladewater, Cherokee, Martin, and Murvaul in Zone 1, and Toledo Bend in Zone 2.

Lake Tawakoni and Lake Fork are owned and operated by the Sabine River Authority of Texas. The City of Dallas, located in the upper Trinity River Basin, has contracted with the Sabine River Authority for 80 percent of the water supply in Lake Tawakoni, or approximately 184.5 thousand acre-feet annually. The existing 72-inch diameter pipeline facility from Lake Tawakoni to the Dallas area is capable of delivering about 112 thousand acre-feet of water annually. The City of Dallas presently has under construction an additional 84-inch pipeline from Tawakoni and plans to increase the withdrawal capacity from Tawakoni to 200 million gallons per day. In 1980, 35.9 thousand acre-feet of water was delivered from Lake Tawakoni to Dallas; however, in previous years deliveries have exceeded 50 thousand acre-feet. Additional existing exports from the Sabine River Authority's remaining supply in Lake Tawakoni include deliveries to the City of Commerce in the Sulphur River Basin (933 acre-feet in 1980). The City of Terrell in the Trinity River Basin has also contracted with the Sabine River Authority for supplemental supplies from Lake Tawakoni. Lake Tawakoni also supplies water to Greenville, Wills Point, and other small cities in the Sabine River Basin. Deliveries to these areas totaled about 6.6 thousand acre-feet in 1980.

Lakes Holbrook, Quitman, Hawkins, and Winnsboro are owned and operated by Wood County Fresh Water Supply District and are utilized for recreation and flood-regulation purposes.

Lake Gladewater, owned and operated by the City of Gladewater, provides municipal and manufacturing water supplies for the City of Gladewater and its customers in Gregg and Upshur Counties. Diversions from the reservoir in 1980 totaled 1.2 thousand acre-feet.

Lake Cherokee, owned and operated by the Cherokee Water Company, provides cooling water for Southwestern Electric Power Company's Knox Lee Power Plant located at the reservoir, and municipal and manufacturing water for the Cities of Kilgore, Longview, and White Oak in Gregg County.

Martin Lake, located on Martin Creek in Rusk and Panola Counties, is owned and operated by a consortium of electric power utility companies to provide cooling water and related water needs for four 750 megawatt capacity steam-electric power plant units near the reservoir.

Lake Murvaul, owned by Panola County Fresh Water Supply District, provides municipal and manufacturing water supplies for the City of Carthage and its customers in Panola County.

Lake Fork Reservoir, completed in 1981, is owned by the Sabine River Authority. Provisions of the amended permit issued by the Texas Water Commission allow annual use of 77,940 acre-feet of water for municipal purposes, 70,500 acre-feet for municipal or industrial, and 16,500 acre-feet for industrial purposes.

In addition, the Sabine River Authority, the City of Dallas, and Texas Utilities Generating Company have entered into a Water Supply Contract and Conveyance affecting the 120,000 acre-feet portion of the water covered by this permit, as follows:

1. The City of Dallas would be entitled to 74 percent of the yield from Lake Fork Reservoir, not to exceed 120,000 acre-feet per year, reduced by the amount that Phillips Coal Company (30,000 acre-feet per year maximum), Tenneco Coal Company (20,000 acre-feet per year maximum), and Texas Utilities Generating Company (17,000 acre-feet per year maximum as set forth in paragraph No. 2 below) decide to take.

2. The City of Dallas gives Texas Utilities Generating Company an option to purchase up to 17,000 acre-feet of water annually out of its 120,000 acre-feet, which option must be exercised prior to September 1, 1994.

3. In the event either Phillips or Tenneco fail to take all of the water to which each is entitled under their respective agreements with the Sabine River Authority, then the Authority has the right to sell up to an additional 10,000 acre-feet out of the City of Dallas' 120,000 acre-feet.

4. The term of this Contract runs from October 1, 1981, until November 1, 2014, and it is to be renewed for additional terms of 40 years unless the City of Dallas terminates its option to renew.

The Sabine River Authority has also agreed to enter into a Water Purchase Agreement with Texas Utilities Generating Company to sell 20,000 acre-feet of water annually in addition to the amount to be sold to the City of Dallas. Out of this amount, Texas Utilities Generating Company will release 3,500 acre-feet of water annually upon request by the Authority to be sold for municipal use.

The Sabine River Authority has been granted changes to the permit contemplated as a result of the contracts. These include a request for authorization to transfer as much as 120,000 acre-feet of water per year from Lake Fork in the Sabine River Basin to the Trinity River Basin.

Within Zone 1, water is also diverted from the main stem of the Sabine River under existing permits. Major diversions occur in Gregg and Harrison Counties, principally for manufacturing use.

In Zone 2, Toledo Bend Reservoir, owned jointly by the Sabine River Authorities of Texas and Louisiana, is the fifth largest reservoir in the United States with a total capacity of 4.477 million acre-feet. The project, completed in 1968, is operated jointly by the two river Authorities in accordance with terms of the Sabine River Compact between Texas and Louisiana. Toledo Bend Reservoir provides water for municipal, manufacturing, irrigation, hydroelectric power generation, and recreation purposes. The existing permit issued to the Sabine River Authority of Texas by the Texas Water Rights Commission provides for use of 100 thousand, 600 thousand, and 50 thousand acre-feet annually for municipal, industrial, and irrigation purposes, respectively. At the present time, the only cities obtaining municipal supplies from the reservoir are Hemphill, in Sabine County and Huxley, in Shelby County. In addition, several private water companies have contracted with the Authority for water from the reservoir.

In accordance with a contract between the two Authorities and several utility companies in both Louisiana and Texas, the Authorities are compensated by the payment of an aggregate sum of money each year for hydroelectric power generated through releases of water through the dam between elevations 172.0 and 162.2 mean sea level (top of power head storage). Subject to the availability of water in storage, releases are made through the two turbines sufficient to produce at least 65.7 million kilowatt hours of electricity during the period May to September each year.

Below Toledo Bend Reservoir, the Sabine River branches, and part of the river flow enters Old River, in Louisiana, through Cutoff Bayou. Privately owned companies in Louisiana periodically divert these flows through the Krause and Managon Canal and Sabine Canal Systems for rice irrigation. Several miles downstream from Cutoff Bayou, part of the flow of the river enters Indian Bayou in Texas. The Sabine River Authority of Texas periodically diverts these flows through its diversion channel westward for irrigation and manufacturing uses. In 1980, approximately 35.5 thousand acre-feet of water was diverted through this system and used by manufacturing plants in the Orange area under contracts with the Sabine River Authority of Texas. In addition, 3.6 thousand acre-feet was supplied through the system in the Orange area for cooling water in steam-electric power generation.

During periods of low flow, saline water from the Gulf and Sabine Lake intrudes significant distances upstream into both the Sabine and Old Rivers such that diversion facilities are negatively affected, especially by Louisiana diverters. However, this has not been a problem since Toledo Bend Reservoir became operational in 1968.

Water Rights

A total of 1,671,505 acre-feet of surface water was authorized or claimed for diversion and use in the Sabine River Basin as of December 31, 1983 (Table III-5-1). Municipal use accounted for 37.4 percent of the total amount of water authorized and/or claimed in the basin (Table III-5-2). Zone 2 accounted for the greater portion of authorized or claimed water use, with 902,338 acre-feet or 54.0 percent of the total.

Table III-5-1. Authorized or Claimed Amount of Water, by Type of Right, Sabine River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	116	1,648,076
Claims	190	23,429
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	306	1,671,505

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-5-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Sabine River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	31	492,885	131,460	624,345
Industrial[2]	25	199,329	671,735	871,064
Irrigation	173	15,246	98,868	114,294
Mining	3	951	0	951
Recreation	82	60,576	275	60,851
Other	1	0	0	0
Total	306[1]	769,167	902,338	1,671,505

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include an authorized diversion of saline water in Zone 2 in the amount of 360,000 acre-feet/year.

Water Quality

The Sabine River below the Longview area and the Adams Bayou have experienced periodic dissolved-oxygen depressions and recurrent fish kills attributable primarily to discharge of treated municipal and industrial effluents. However, improved waste treatment in the past few years has improved the water quality. The tidally affected areas of the basin, particularly in the area of Adams and Cow Bayous, are experiencing rapid increases in population and industrial growth resulting in high volumes of treated industrial wastewaters.

Flooding, Drainage, and Subsidence

According to the U.S. Army Corps of Engineers, the Sabine River Basin has incurred damages from major flooding 11 times since 1957. Damages from Hurricane Carla in 1961 were not as substantial to Orange County as they were in other coastal counties. However, damages totaled over $750 thousand, mostly nonagricultural. The most costly flood occurred in 1974 when agriculture losses amounted to $582.2 thousand and nonagricultural damages amounted to $2.64 million. Major floods in 1979 and 1980 in the lower basin produced major damages in Orange County and Bridge City. During the period 1978-1981, 203 flood insurance claims were filed for $869 thousand in flood damages. Floods in April 1979 and Tropical Storm Claudette in July 1979 resulted in two Presidential disaster declarations with the expenditure of slightly over $1.2 million in disaster relief by various federal agencies.

The Federal Emergency Management Agency has designated 49 cities in the Sabine River Basin as having one or more special flood-hazard areas. Currently, 27 of these cities are participating in the National Flood Insurance Program. Flood insurance rate studies have been completed for the Cities of Gladewater, Kilgore, Longview, Marshall, Greenville and 100-year base flood elevations are available. The incorporated cities within Orange County are currently being studied to determine 100-year flood elevations.

In the upper Sabine River Basin, drainage problems occur in the river bottomlands and adjoining terraces above Toledo Bend Reservoir. On-farm drainage improvements and lateral ditching can abate most of the problems. Drainage problems in the lower basin are more complex and require substantial improvements to achieve proper drainage, particularly where large quantities of irrigation water are used to flood rice farms. Accumulations of surface water from intense storm activity associated with hurricanes or tropical storms compound drainage problems in the lower basin.

Land subsidence due to compaction of clays caused by ground-water withdrawals and oil production is a potential problem in southern Newton, southern Jasper, and eastern Orange Counties within the Sabine River Basin. Also, fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain. Subsidence and fault movement also are caused locally by extractions of sulfur and other minerals in the Gulf Coastal Plain.

Recreation Resources

Sixteen percent of the total surface area of all reservoirs (5.0 thousand acre-feet capacity or more) in the State is located in the Sabine River Basin. The Sabine River Basin is exceeded only by the Trinity River Basin in total number of reservoir surface acres available for water-oriented recreation activities. Toledo Bend Reservoir in Zone 2 of the basin, with 181.6 thousand surface acres, is the largest lake in the State in terms of surface area. It is the only major reservoir in Zone 2, but accounts for over 75 percent of the basin's total reservoir surface area. Toledo Bend Reservoir offers excellent black bass, crappie, and white bass fishing. There are also many facilities for picnicking and camping. Lake Tawakoni (36.7 thousand surface acres) is the largest of the nine fresh water impoundments in Zone 1, providing approximately 63 percent of the available water-oriented recreation resources in the Zone.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Sabine River Basin is projected to increase by 97 percent between 1980 and 2030 (Table III-5-3). By 2000, the population is expected to grow by 37 percent; from 2000 to 2030, a 45 percent increase is projected.

Gregg County (including the Cities of Gladewater, Kilgore, and Longview) is the most populous county in the basin with 24 percent of the basin's total population in 1980. By 2030, a projected increase in population of 91 percent is expected. Orange County population was 14 percent of the basin total in 1980 and is expected to remain at 14 percent in 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Municipal water requirements in the Sabine River Basin are estimated to increase from 23 to 88 percent by the year 2000 over the 1980 level of 61.8 thousand acre-feet. By 2030, municipal water requirements are expected to range from 102.8 to 167.6 thousand acre-feet. Seventy-five percent of the projected basin requirements in 2000 and 76 percent in 2030 is located in Zone 1.

Industrial

Manufacturing water requirements in 1980 were 84.3 thousand acre-feet in the Sabine River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Sabine River Basin are projected to increase more than fourfold by the year 2030 from the 1980 level. In 1980, Zone 2 of the

Table III-5-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Sabine River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			296.8			364.5			416.4			468.6			535.9			609.2
Municipal	18.9	26.2	45.1	11.2	63.2	74.4	11.7	75.3	87.0	12.1	85.9	98.0	12.9	99.1	112.0	14.2	113.0	127.2
Manufacturing	1.9	35.9	37.8	0.3	60.5	61.8	1.3	86.5	87.8	1.3	117.3	118.6	1.3	151.4	152.7	1.3	195.0	196.3
Steam Electric	0.0	17.5	17.5	0.0	39.5	39.5	0.0	48.4	48.4	11.2	58.3	69.5	7.1	75.8	82.9	6.9	93.2	100.1
Mining	6.3	0.5	6.8	6.4	0.2	6.6	6.1	16.4	22.5	5.5	24.8	30.3	4.8	33.2	38.0	4.1	25.6	29.7
Irrigation	0.1	0.5	0.6	0.2	0.4	0.6	0.2	0.5	0.7	0.2	0.5	0.7	0.2	0.5	0.7	0.2	0.5	0.7
Livestock	3.1	4.1	7.2	1.5	7.0	8.5	1.5	8.4	9.9	1.5	8.4	9.9	1.5	8.4	9.9	1.3	8.6	9.9
Zone Total Water	30.3	84.7	115.0	20.6	170.8	191.4	20.8	235.5	256.3	31.8	295.2	327.0	27.8	368.4	396.2	28.0	435.9	463.9
Zone 2																		
Population			110.5			126.6			139.8			153.9			171.6			194.7
Municipal	14.3	2.4	16.7	15.5	10.2	25.7	17.4	11.7	29.1	18.1	13.9	32.0	18.8	16.8	35.6	19.8	20.6	40.4
Manufacturing	7.6	38.9	46.5	14.5	71.7	86.2	14.5	100.1	114.6	14.5	126.8	141.3	14.5	157.8	172.3	14.5	195.1	209.6
Steam Electric	1.5	5.5	7.0	0.0	7.0	7.0	0.0	8.8	8.8	0.0	19.3	19.3	0.0	37.5	37.5	0.0	51.9	51.9
Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigation	0.0	8.4	8.4	0.0	3.3	3.3	0.0	3.3	3.3	0.0	3.3	3.3	0.0	3.3	3.3	0.0	3.3	3.3
Livestock	0.9	0.6	1.5	1.2	0.6	1.8	1.2	0.9	2.1	1.3	0.8	2.1	1.3	0.8	2.1	1.2	0.9	2.1
Zone Total Water	24.3	55.8	80.1	31.2	92.8	124.0	33.1	124.8	157.9	33.9	164.1	198.0	34.6	216.2	250.8	35.5	271.8	307.3
BASIN TOTALS																		
Population			407.3			491.1			556.2			622.5			707.5			803.9
Municipal	33.2	28.6	61.8	26.7	73.4	100.1	29.1	87.0	116.1	30.2	99.8	130.0	31.7	115.9	147.6	34.0	133.6	167.6
Manufacturing	9.5	74.8	84.3	15.8	132.2	148.0	15.8	186.6	202.4	15.8	244.1	259.9	15.8	309.2	325.0	15.8	390.1	405.9
Steam Electric	1.5	23.0	24.5	0.0	46.5	46.5	0.0	57.2	57.2	11.2	77.6	88.8	7.1	113.3	120.4	6.9	145.1	152.0
Mining	6.3	0.5	6.8	6.4	0.2	6.6	6.1	16.4	22.5	5.5	24.8	30.3	4.8	33.2	38.0	4.1	25.6	29.7
Irrigation	0.1	8.9	9.0	0.2	3.7	3.9	0.2	3.8	4.0	0.2	3.8	4.0	0.2	3.8	4.0	0.2	3.8	4.0
Livestock	4.0	4.7	8.7	2.7	7.6	10.3	2.7	9.3	12.0	2.8	9.2	12.0	2.8	9.2	12.0	2.5	9.5	12.0
Basin Total Water	54.6	140.5	195.1	51.8	263.6	315.4	53.9	360.3	414.2	65.7	459.3	525.0	62.4	584.6	647.0	63.5	707.7	771.2

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

basin accounted for 55 percent of the total industrial water use; by 2030, 52 percent of the projected water need is in Zone 2. Orange County accounted for most of the Zone 2 requirement in 1980 and is anticipated to continue to dominate water use in 2030. Major water-using industries in Orange County include industrial organic chemicals, plastic materials, synthetics, paperboard mills, and petroleum refineries.

In Zone 1 of the Sabine River Basin, Harrison County accounts for the majority of the 1980 manufacturing water requirements.

Steam-Electric Power Generation

Large near-surface lignite deposits and available water supplies are supporting growth of steam-electric power generating capacity in the Sabine River Basin. Additional growth of plant capacity in the coastal area, using fresh and saline water for cooling, is also projected to occur. In 1980, 24.5 thousand acre-feet of water was consumed for steam-electric power generation, with 71 percent occurring in Zone 1. Future growth was projected for two demand cases for electricity. Water requirements are projected to range from 55.4 to 57.2 thousand acre-feet by 2000; and increase from 98 to 161 percent by 2030 (low and high case, respectively).

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Sabine River basin are projected to decrease from the 1980 level of 9.0 thousand acre-feet by a projected maximum 56 percent by the year 2000 in the high and the low case. In the year 2030, water requirements in the Basin are projected to be about 4.0 thousand acre-feet annually, in both the low and high case, respectively, to irrigate about 2.0 thousand acres.

Zone 2 is projected to account for about 83 percent of total basin irrigation requirements in 2000 and 2030. Zone 1 is projected to account for about 17 percent of the total.

Livestock

A projected increase in livestock production in the Sabine River Basin would increase livestock water needs. It is estimated that annual livestock water requirements will increase from 8.7 thousand acre-feet in 1980 to 12 thousand acre-feet by 2030. Livestock water use in Zone 1 is expected to increase from 7.2 thousand acre-feet in 1980 to 9.9 thousand acre-feet in 2030. Livestock water needs on Zone 2 are projected to expand from 1.5 thousand acre-feet in 1980 to 2.1 thousand acre-feet by 2030.

Mining

Total mining water requirements in the Sabine River Basin are projected to increase significantly during the planning period primarily from the production of Frasch sulfur and synfuels. In 1980, mining water requirements were 6.8 thousand acre-feet, with use concentrated in Zone 1. By 2000, water requirements are projected to increase 231 percent mostly due to the production of synfuels. From 2000 to 2030, water use estimates are projected to increase another 32 percent to 29.7 thousand acre-feet.

Navigation

If a last downstream lock is maintained at river mile 19.4 north of Orange, then freshwater requirements are projected to be 18.5 thousand acre-feet in 2000, and 20.8 thousand acre-feet in 2030.

Hydroelectric Power

There are currently no plans or federal authorizations to expand the existing 85 megawatts of installed hydroelectric capacity in the Sabine River Basin. With the construction of additional reservoirs, water needs for hydroelectric power could increase.

Estuarine Freshwater Inflows

The Sabine River, along with the Neches River, discharges into the Sabine-Neches estuary. Estimates of freshwater inflow needs for the Sabine-Neches estuary are based on the total flow from both river basins.

The Subsistence Alternative estimate of gaged river inflows necessary to sustain monthly salinities within a range of desirable salinities and maintain historical marsh inundation frequency totals about 5.69 million acre-feet annually (Table III-5-4). The annual inflow from ungaged portions of the Sabine and Neches River Basins is estimated at 1.S3 million acre-feet. The Biotic Species Viability Alternative estimate of gaged river inflows necessary to maintain the short-term (monthly) upper viability limits for salinity in the Sabine-Neches estuarine system totals about 2.02 million acre-feet per year (Table III-5-4).

Table III-5-4. Gaged River Inflow Needs of the Sabine-Neches Estuary Under Two Alternative Levels of Fisheries Production[1]

Month	Ecosystem Subsistence	Biotic Species Viability
January	350.7	211.0
February	361.7	212.1
March	340.4	215.1
April	535.4	253.0
May	1,282.3	228.6
June	477.5	186.1
July	204.3	89.7
August	178.5	76.5
September	132.2	130.2
October	1,282.3	134.9
November	189.1	107.1
December	352.0	175.8
Annual	5,686.4	2,020.1

[1]Combined gaged streamflow of Sabine River near Ruliff and Neches River at Evadale in thousand acre-feet.

The freshwater inflow needs for the two additional Alternatives (Fisheries Harvest Maintenance and Fisheries Harvest Enhancement) could not be evaluated for this estuary because the fisheries harvest equations derived for this estuary were not valid for the range of possible flows. If the freshwater inflows were consistently limited to those estimated by the Subsistence Alternative, the salinity regime of Sabine Lake would shift from the existing low salinity regime to a more truly estuarine environment. This change in the salinity regime could increase the species diversity and productivity in Sabine Lake, presuming an absence of toxic materials and assuming that existing marsh habitats are maintained. However, the quantity and quality of possible changes in the estuary cannot be accurately assessed from existing data which reflect only past conditions in the estuary. The Sabine-Neches estuary is the only estuary, of six estuaries studied, for which it was not possible to compute estimates of freshwater inflow needs for all four of the Alternatives.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Sabine River Basin to the year 2030 is 244.8 thousand acre-feet with the following amounts annually available by aquifer: 54.0 thousand acre-feet from the Gulf Coast Aquifer, 45.2 thousand acre-feet from the Carrizo-Wilcox Aquifer, 7.4 thousand acre-feet from the Sparta Aquifer, 0.4 thousand acre-feet from the Trinity Group Aquifer, and 137.8 thousand acre-feet from the Queen City Aquifer. Since the ground water available from the Queen City Aquifer within the basin has high concentrations of iron and high acidity (low pH), it should not be considered a suitable source of water for municipal and most manufacturing purposes. However, Queen City ground water is suitable for irrigation, steam-electric power generation (cooling), mining and livestock-watering purposes. At the end of the year 2029, the annual yield of the Trinity Group Aquifer within the basin would be reduced from 0.4 thousand acre-feet to zero, because all of the ground water in recoverable artesian storage would have been removed. Since the artesian portion of the Trinity Group Aquifer within the basin does not receive any effective recharge, the yield of the aquifer in the year 2030 would be zero. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual effective recharge of 44.0 thousand acre-feet per year. These reductions decrease the total ground-water availability within the basin in 2030 to 243.2 thousand acre-feet.

The projected annual ground-water use within the Sabine River Basin by decade from 1990 through 2030 is expected to be from 51.8 to 65.7 thousand acre-feet per year (Table III-5-3). The approximate average annual projected ground-water use within the basin is expected to be about 59.5 thousand acre-feet per year. Of the 59.5 thousand acre-feet of average annual projected use, about 54 percent is expected to be from the Gulf Coast Aquifer, about 43 percent from the Carrizo-Wilcox Aquifer, and about 3 percent from the Queen City Aquifer.

Surface-Water Availability and Proposed Development

Projected surface-water needs in the Sabine River Basin can be fully met from existing and potential reservoirs through the year 2030 (Table III-5-5, Figure III-5-2). Currently available surface-water resources in the Sabine River Basin are sufficient to meet all projected surface-water needs within the basin through the year 2030, except in Zone 1.

Zone 1

Surface-water resources, existing and proposed, are estimated to exceed surface-water requirements in Zone 1, including water export needs to adjacent river basins, by about 36.2 thousand acre-feet in the year 2030 (Table III-5-6, Figure III-5-3). Approximately 301.8 thousand acre-feet of the year 2030 total water requirements in this Zone is estimated for export, principally to the upper Trinity River Basin. In that same year, approximately 59.1 thousand acre-feet is projected for import, primarily from the Toledo Bend Reservoir in Zone 2 of the Basin, to meet water needs in this Zone.

Water needs in Zone 1 may be met through the development by the year 1990 of the Big Sandy Reservoir project in the Sabine River Basin, although it is highly unlikely that the project can be constructed by that time. The Big Sandy Reservoir project, authorized by Congress in 1970, will be located on Big Sandy Creek in Wood County, with the dam located about 13 miles upstream above the confluence of Big Sandy Creek and the Sabine River. Additional studies of the project are currently underway by the U.S. Bureau of Reclamation and are likely to result in modifications to the authorized project. The authorized project would provide a dependable yield of 76.9 thousand acre-feet annually. Water from the project is proposed to be used by 1990 to supply the Marshall and Kilgore areas with municipal and manufacturing water.

Between 2020 and 2030, additional surface water will be needed in the Marshall area. Water pumped by pipeline from Toledo Bend Reservoir in Zone 2 of the basin is proposed to meet the needs. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major intrabasin transfer of water.

The City of Longview is currently studying the proposed Prairie Creek Reservoir on Prairie Creek in Gregg and Smith Counties. The project is estimated to supply a yield of 40.0 thousand acre-feet annually with approximately 30.0 thousand acre-feet of this yield supplied as a result of direct diversion of water from the Sabine River. For planning purposes, this reservoir is proposed to be constructed by 2000 to meet the additional future water needs of the City of Longview.

The City of Dallas has contracted with the Sabine River Authority for 53.0 thousand acre-feet of firm annual supply from Lake Fork. By 2000, Dallas will need this supply to meet future needs and will have to construct pumping and pipeline facilities to convey this water.

By the year 2020, steam-electric power requirements in the upper Sabine River Basin are projected to exceed available supplies necessitating the development of additional water resources to avoid shortages. An alternative to meet this need and provide water for export to the upper Trinity River Basin for the City of Dallas is the Carl Estes Reservoir on the Sabine River below Lake Tawakoni. Pipeline facilities would be required to convey water to the City of Dallas through Lake Tawakoni.

The authorized Carl L. Estes Reservoir project has undergone advanced engineering and design studies by the Corps of Engineers. The Corps determined that the project was not a currently feasible federal project in part due to extensive shallow lignite beds under the reservoir site. The Corps estimates that the lignite could be mined by 2020 thereby allowing construction of the project before 2020.

Considerable study has also been given to the feasibility of the Carthage Reservoir project, which would be located in Zone 1. This project could be on the main stem of the Sabine River above Toledo Bend Reservoir at about river mile 321. Additional studies are needed to determine the firm water supply available from this project.

Zone 2

Total surface-water supplies are projected to exceed in-basin and export water demands in Zone 2 of the Sabine River Basin by 499.9 thousand acre-feet in the year 2030 under existing and proposed surface-water development (Table III-5-7, Figure III-5-4). The surface-water requirements for this zone in 2030 are estimated at approximately 1.27 million acre-feet, with about 961.7 thousand acre-feet projected to be exported from this zone to other basins in the year 2030. This water is projected as the supply for import into the Houston-Galveston area to meet projected municipal and manufacturing water needs.

Zone 2 of the Sabine River Basin will continue to have substantial supplies of surface water surplus to projected in-basin needs. Except during recurrences of critical drought period, surpluses in excess of both in-basin needs

Table III-5-5. Water Resources of the Sabine River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	**In Basin**	**Intra-Basin**	**Return Flow**	**Import**	**Total**	**In Basin**	**Intra-Basin**	**Export**	**Total**	**M & I**	**Irrigation (Shortage)**	**Total**
1990												
Ground Water	51.8	—	—	—	51.8	51.8	—	—	51.8	.0	.0	.0
Surface Water	1762.3	—	62.0	19.3	1843.6	226.1	—	141.8	367.9	1475.7	.0	1475.7
Total	1814.1	—	62.0	19.3	1895.4	277.9	—	141.8	419.7	1475.7	.0	1475.7
2000												
Ground Water	53.9	—	—	—	53.9	53.9	—	—	53.9	.0	.0	.0
Surface Water	1802.3	—	78.1	19.7	1900.1	321.0	—	251.6	572.6	1327.5	.0	1327.5
Total	1856.2	—	78.1	19.7	1954.0	374.9	—	251.6	626.5	1327.5	.0	1327.5
2010												
Ground Water	65.7	—	—	—	65.7	65.7	—	—	65.7	.0	.0	.0
Surface Water	1814.5	—	95.2	19.5	1929.2	420.1	—	615.4	1035.5	893.7	.0	893.7
Total	1880.2	—	95.2	19.5	1994.9	485.8	—	615.4	1101.2	893.7	.0	893.7
2020												
Ground Water	62.4	—	—	—	62.4	62.4	—	—	62.4	.0	.0	.0
Surface Water	1905.8	—	114.5	19.3	2039.6	545.3	—	655.6	1200.9	838.7	.0	838.7
Total	1968.2	—	114.5	19.3	2102.0	607.7	—	655.6	1263.3	838.7	.0	838.7
2030												
Ground Water	63.5	—	—	—	63.5	63.5	—	—	63.5	.0	.0	.0
Surface Water	2279.5	—	168.1	20.1	2467.7	668.1	—	1263.5	1931.6	536.1	.0	536.1
Total	2343.0	—	168.1	20.1	2531.2	731.6	—	1263.5	1995.1	536.1	.0	536.1

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-face supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

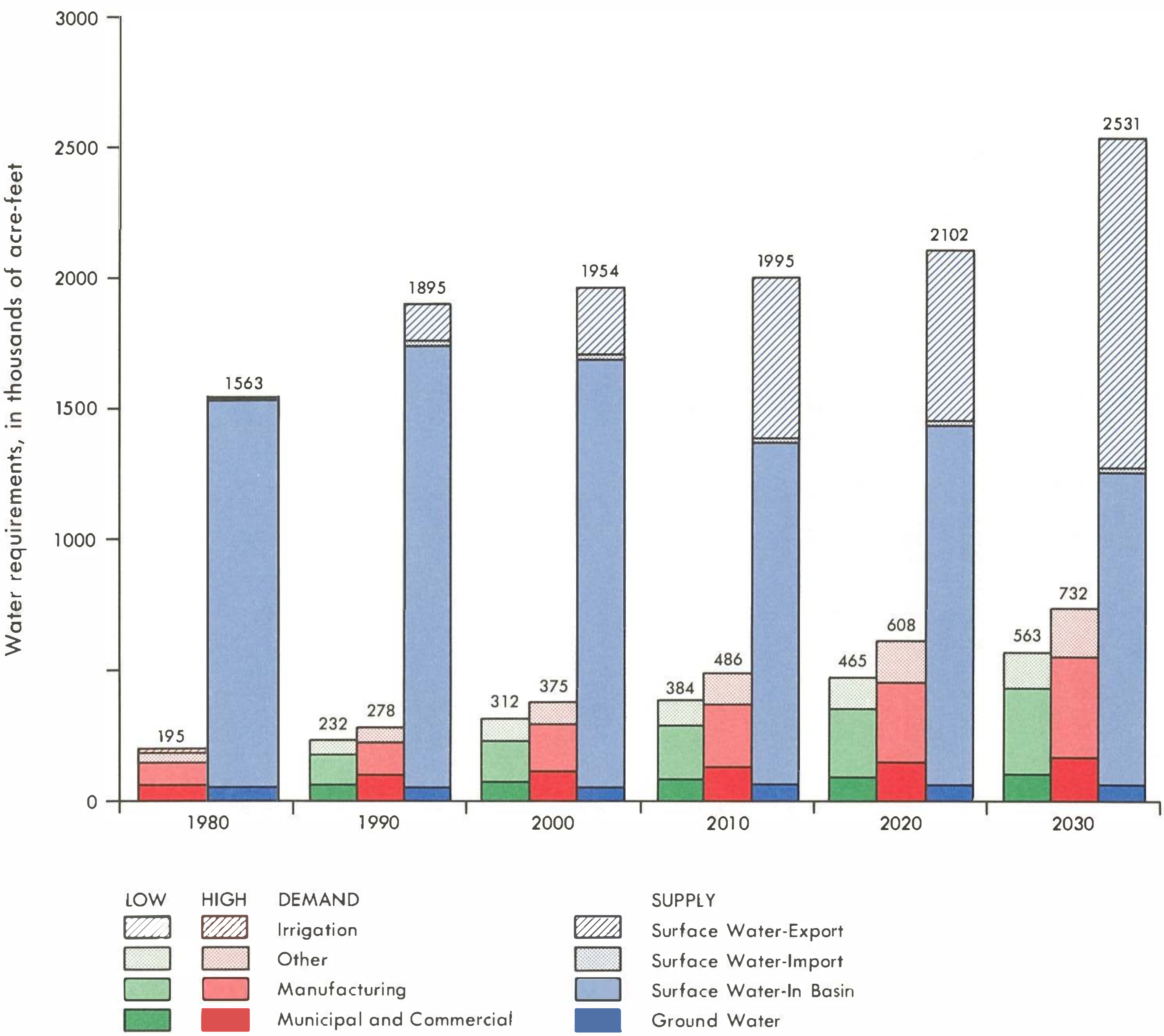

Figure III-5-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Sabine River Basin, 1980-2030

and freshwater requirements of the Sabine Lake estuarine system will be available for conveyance to water-deficient areas provided appropriate institutional arrangements can be made. Studies performed by and for the Department indicate that it is physically feasible to convey relatively large quantities of water from the lower Sabine River to the Trinity River Basin in order to meet the severe water shortages projected to occur in the San Jacinto River Basin and contiguous areas in the coastal area beyond the year 2000.

Existing surface-water resources in the Brazos and San Jacinto River Basins and San Jacinto-Brazos and Brazos-Colorado Coastal Basins are estimated to be insufficient to satisfy projected surface-water needs in these basins. Water supplies from Toledo Bend Reservoir, that are surplus to the projected Sabine River Basin needs could be diverted through a gravity flow and pumping conveyance system to the Houston metropolitan area and lower Brazos River Basin (Zone 6) and adjacent coastal basins to

Table III-5-6. Water Resources of the Sabine River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	20.6	—	—	—	20.6	20.6	—	—	20.6	.0	.0	.0
Surface Water	508.3	.0	6.9	15.1	530.3	137.2	.0	136.2	273.4	256.9	.0	256.9
Total	528.9	.0	6.9	15.1	550.9	157.8	.0	136.2	294.0	256.9	.0	256.9
2000												
Ground Water	20.8	—	—	—	20.8	20.8	—	—	20.8	.0	.0	.0
Surface Water	548.3	.0	8.1	14.8	571.2	200.4	.0	245.1	445.5	125.7	.0	125.7
Total	569.1	.0	8.1	14.8	592.0	221.2	.0	245.1	466.3	125.7	.0	125.7
2010												
Ground Water	31.8	—	—	—	31.8	31.8	—	—	31.8	.0	.0	.0
Surface Water	568.3	.0	9.3	14.6	592.2	260.1	.0	259.8	519.9	72.3	.0	72.3
Total	600.1	.0	9.3	14.6	624.0	291.9	.0	259.8	551.7	72.3	.0	72.3
2020												
Ground Water	27.8	—	—	—	27.8	27.8	—	—	27.8	.0	.0	.0
Surface Water	667.5	.0	10.7	14.4	692.6	333.2	.0	298.7	631.9	60.7	.0	60.7
Total	695.3	.0	10.7	14.4	720.4	361.0	.0	298.7	659.7	60.7	.0	60.7
2030												
Ground Water	28.0	—	—	—	28.0	28.0	—	—	28.0	.0	.0	.0
Surface Water	667.5	43.9	11.9	15.2	738.5	400.5	.0	301.8	702.3	36.2	.0	36.2
Total	695.5	43.9	11.9	15.2	766.5	428.5	.0	301.8	730.3	36.2	.0	36.2

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-face supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

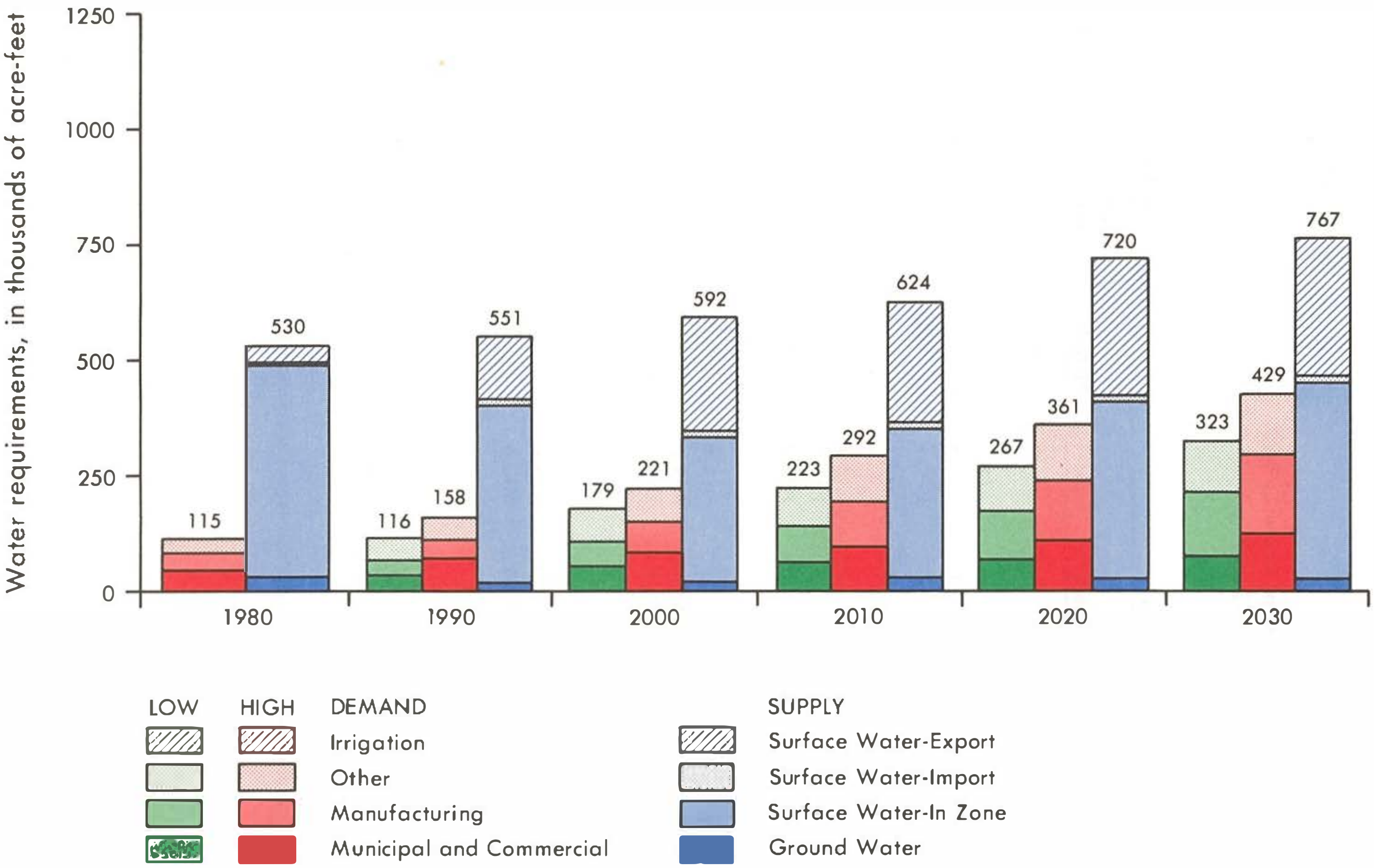

Figure III-5-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Sabine River Basin, Zone 1, 1980-2030

meet these anticipated shortages. Water from Zone 2 of the Sabine River Basin could be needed by year 2010. Anticipated increases in water needs in the Houston area that could be met from the Sabine River Basin are projected to exceed the available surface water from Toledo Bend Reservoir between 2020 and 2030.

The potential Bon Wier Reservoir project, studied by the Corps of Engineers and included in the Report of Sabine River Basin Comprehensive Study, would provide additional water supply, recreation, and possibly hydroelectric power generation in the lower Sabine River Basin. The project, with the dam site tentatively located at river mile 102, would also provide re-regulation of hydroelectric power generation releases from Toledo Bend Dam. Based on preliminary design criteria, without flood control as a project purpose Bon Wier Reservoir would have a conservation storage of 339.8 thousand acre-feet, 23 thousand acre-feet of sediment storage, and a dependable yield of about 441.5 thousand acre-feet annually. With 124.5 thousand acre-feet of storage capacity allocated to flood control and/or re-regulation of power releases from Toledo Bend Dam, the alternative project would have a dependable yield of approximately 381.5 thousand acre-feet. Additional surface water for the Houston area could be developed by the construction of the Bon Weir Reservoir project by year 2030.

Additional studies will have to be performed by the Texas Department of Water Resources and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

The Cities of Newton, Jasper, and Kirbyville and several rural water-supply corporations in Jasper and Newton Counties have worked for many years toward the development of a central water supply and regional treated-water system to serve these areas in Zone 2 of the Sabine River

Table III-5-7. Water Resources of the Sabine River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply: In Zone	Water Supply: Intra-Basin	Water Supply: Return Flow	Water Supply: Import	Water Supply: Total	Water Demand: In Zone	Water Demand: Intra-Basin	Water Demand: Export	Water Demand: Total	Surplus or Shortage: M & I	Surplus or Shortage: Irrigation (Shortage)	Surplus or Shortage: Total
1990												
Ground Water	31.2	—	—	—	31.2	31.2	—	—	31.2	.0	.0	.0
Surface Water	1254.0	.0	55.1	4.2	1313.3	88.9	.0	5.6	94.5	1218.8	.0	1218.8
Total	1285.2	.0	55.1	4.2	1344.5	120.1	.0	5.6	125.7	1218.8	.0	1218.8
2000												
Ground Water	33.1	—	—	—	33.1	33.1	—	—	33.1	.0	.0	.0
Surface Water	1254.0	.0	70.0	4.9	1328.9	120.6	.0	6.5	127.1	1201.8	.0	1201.8
Total	1287.1	.0	70.0	4.9	1362.0	153.7	.0	6.5	160.2	1201.8	.0	1201.8
2010												
Ground Water	33.9	—	—	—	33.9	33.9	—	—	33.9	.0	.0	.0
Surface Water	1246.2	.0	85.9	4.9	1337.0	160.0	.0	355.6	515.6	821.4	.0	821.4
Total	1280.1	.0	85.9	4.9	1370.9	193.9	.0	355.6	549.5	821.4	.0	821.4
2020												
Ground Water	34.6	—	—	—	34.6	34.6	—	—	34.6	.0	.0	.0
Surface Water	1238.3	.0	103.8	4.9	1347.0	212.1	.0	356.9	569.0	778.0	.0	778.0
Total	1272.9	.0	103.8	4.9	1381.6	246.7	.0	356.9	603.6	778.0	.0	778.0
2030												
Ground Water	35.5	—	—	—	35.5	35.5	—	—	35.5	.0	.0	.0
Surface Water	1612.0	.0	156.2	4.9	1773.1	267.6	43.9	961.7	1273.2	499.9	.0	499.9
Total	1647.5	.0	156.2	4.9	1808.6	303.1	43.9	961.7	1308.7	499.9	.0	499.9

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-face supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

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Export: A transfer of water to another river basin.

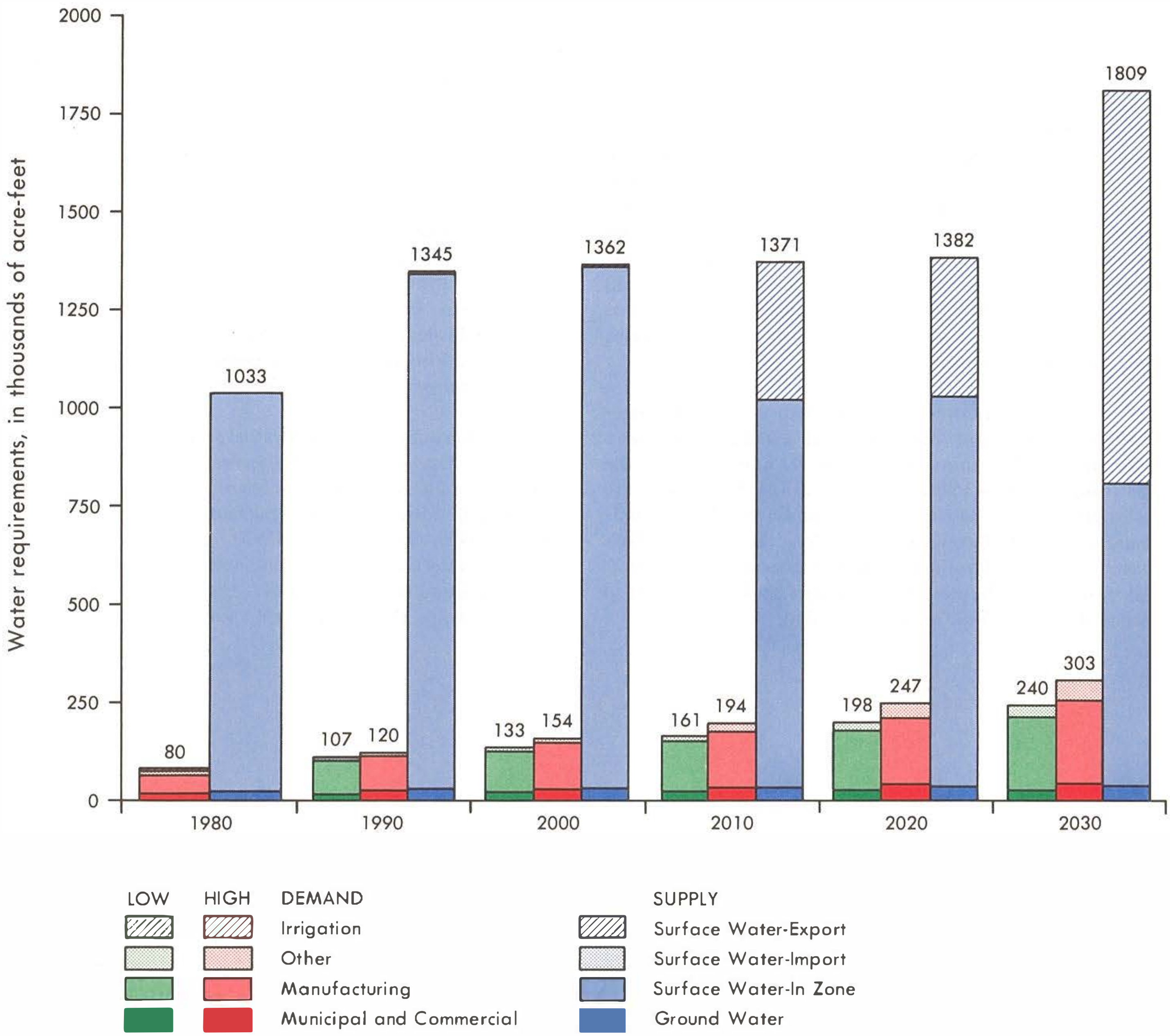

Figure III-5-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Sabine River Basin, Zone 2, 1980-2030

Basin. Although additional ground-water supplies can be developed in the Gulf Coast Aquifer in the Jasper-Newton Counties region, the ground water contains objectionable concentration of iron and is excessively corrosive due to low pH. Studies of the feasibility of a reservoir project on Big Cow Creek in Newton County have been carried on since 1955. The Sabine River Basin Comprehensive Study Report included Big Cow Creek Reservoir as a long-range project for the lower Sabine River Basin, as does the Sabine River Authority Master Plan. Independent studies completed by the Sabine River Authority indicate that a dam on Big Cow Creek approximately four miles northwest of the City of Newton, Newton County, would create a 34.2 thousand acre-foot capacity reservoir with a dependable yield of 34 thousand acre-feet annually. Construction of the Big Cow Creek project will depend upon decisions of the local interests.

Water Quality Protection

A water quality management plan for the Sabine River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Beaumont-Port Arthur-Orange Metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants forwaste-treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities. The list of projects, with projects costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Construction costs associated with municipal wastewater collection and treatment facilities needs have been estimated to be approximately $170.8 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Sabine River Basin with approximately $91.1 million required in Zone 1, while approximately $79.7 million are projected necessary in Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available.

Additional water quality management costs, such as for control of oil and gas, industrial, and agricultural pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Greenville Channel Improvement and Little Cypress Creek Levee represent two Corps of Engineers flood damage prevention projects constructed within the Sabine River Basin. Under the Corps of Engineers' Small Flood Control Project Authority, a study has been initiated on Trout and Pin Oak Creeks to assess flood damage prevention measures in Kirbyville, Texas.

Construction of floodwater-retarding structures by the U.S. Department of Agriculture, Soil Conservation Service includes 70 square miles of drainage area above 22 existing floodwater-retarding structures within the Sabine River Basin. As of October 1980, an additional 16 structures, with a combined drainage area of 62 square miles, were planned for construction. The existing and planned structures are all located within Zone 1 of the basin.

6. NECHES RIVER BASIN

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6. NECHES RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Neches River Basin is bounded on the north and east by the Sabine River Basin, on the west by the Trinity River Basin, and on the south by the Neches-Trinity Coastal Basin. The northeastern one-third of the basin area is drained by the Angelina River, while the remaining two-thirds of the 10,011 square-mile area of the basin is drained by the Neches River, Pine Island Bayou, and Village Creek. The basin empties into the Sabine Lake estuary. The Angelina River originates near Freeneytown (Rusk County) at an elevation of 290 feet and joins the Neches River at Lake B.A. Steinhagen. Headwaters of the Neches River originate near Colfax (Van Zandt County) at an elevation of about 550 feet. Downstream from the confluence with the Angelina River, the Neches River is joined by Pine Island Bayou about three miles north of Beaumont before flowing into the Sabine Lake estuary. The Neches River Basin is divided into two zones for planning purposes (Figure III-6-1).

Surface Water

The average annual runoff from 1941-70 was 522 acre-feet per square mile, and ranged from about 930 acre-feet per square mile at the mouth of the Neches River to about 376 acre-feet per square mile at the upper end of the basin. Ten of the twelve lowest annual flows from 1941 to 1970 occurred in two periods, 1951-56 and 1963-67. During 1951-56, the average annual runoff was 312 acre-feet per square mile. During 1963-67, runoff averaged 203 acre-feet per square mile annually.

The comparatively wide flood plains in the Neches River Basin have small main channels with generally flat slopes. High rainfall rates produce frequent flooding of low-lying areas, and floods of large magnitude occur on an average five-year frequency. Heavy timber and vegetation in floodways cause backwater flood problems by retarding surface runoff and flood flows. Floods in the basin are lengthy in duration, and are characterized by low flow velocities and slowly rising and falling flood peaks. Because runoff is usually slow, a broad but flat-crested flood is set in motion when substantial amounts of rain occur over periods lasting several days. The lowest portion of this basin usually remains inundated for many days, and sometimes even several weeks, during flood events.

Since virtually all of the Neches River Basin is at least 50 miles from the Gulf of Mexico, the inhabitants of the basin are not directly subject to many of the hazards associated with hurricanes. Only the extreme southern tip of the basin is concerned with destructive storm surges.

Except for localized conditions of stream degradation, inorganic water quality of the Neches River Basin is excellent with low dissolved solids and low hardness. Striker Creek Reservoir and its tributaries have experienced increased salinity due to runoff from the East Texas Oil Field. Dissolved-solids concentrations generally exceed 500 milligrams per liter (mg/l). The Angelina River near Lufkin, several miles upstream from Sam Rayburn Reservoir, contains dissolved-solids concentrations less than 150 mg/l about one-half the time, and the Neches River near Evadale in southern Jasper County also contains dissolved-solids concentrations less than 150 mg/l about 50 percent of the time.

Ground Water

Covering the upper half of the Neches River Basin is the Carrizo-Wilcox Aquifer. Thickness of this part of the aquifer ranges from about 400 feet in the outcrop to more than 2,000 feet in the downdip areas. Large-capacity wells have yields which average about 400 gallons per minute (gpm), although locally wells produce as much as 1,200 gpm. Generally, water produced from this aquifer contains less than 1,000 mg/l total dissolved solids and is suitable for most uses.

The Gulf Coast Aquifer covers the southern part of the Neches River Basin. The aquifer extends to depths of greater than 2,800 feet. Large-capacity well yields average about 1,600 gpm, but locally wells produce as much as 4,500 gpm. Total dissolved-solids concentrations of waters pumped from the aquifer are less than 500 mg/l in most areas.

The Queen City Aquifer has an extensive outcrop area which covers much of the extreme northern part of the Neches River Basin. Thickness of the aquifer ranges up to about 600 feet. Yields of wells range upward to about 400 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids, but quality deteriorates downdip.

The Sparta Aquifer occurs as a thin band in the central part of the Neches River Basin. Downdip, the aquifer ranges in thickness from 250 to 350 feet. No large-capacity wells are completed in the aquifer in the basin;

Figure III-6-1. Neches River Basin and Zones

however, based on reservoir characteristics, it is estimated that large-capacity wells would yield up to 500 gpm. Water pumped from the aquifer generally contains less than 500 mg/l total dissolved solids, but quality deteriorates rapidly downdip.

Ground waters contained in the shallow water-bearing sands of the Carrizo-Wilcox and Queen City Aquifers within the basin usually have excessive concentrations of iron and low pH (high acidity) values. Also, due to excessive pumpage, saline-water encroachment may occur from saline water-bearing sands laterally adjacent to or beneath the fresh water-bearing sands of the aquifers.

Population and Economic Development

The population of the Neches River Basin was reported at 506.3 thousand in 1980. Tyler is the largest city in the basin, having an in-basin population of 70,500 in 1980. Other basin cities having major in-basin populations are Beaumont, Lufkin, and Nacogdoches. The economy of the Neches River Basin is based on a significant timber and wood products industry, agriculture, agribusiness, manufacturing, oil, gas, and other mineral production, and recreation and tourism.

Water Use

Municipal water use in the Neches River Basin in 1980 was approximately 80.0 thousand acre-feet. Fresh water use in Zone 1 was 55 percent of basin total; Zone 2 used 45 percent of the total. Smith County, including the City of Tyler, in Zone 1 used 26 percent of the basin's total fresh water supply in 1980. In Zone 2, Angelina and Jefferson Counties consumed 28 percent of the basin total.

Industries engaged in manufacturing activities used 180.2 thousand acre-feet of fresh water in 1980. Almost 96 percent of all uses originated in Zone 2. Industries located in Zone 2 include paper and allied products, chemical, and petroleum refining industries. These are primarily located in Angelina, Jasper, and Jefferson Counties.

In 1980, there was 1,102 megawatts of steam-electric power generating capacity in the Neches River Basin. Total fresh water consumption during 1980 from surface-water sources was approximately 7.3 thousand acre-feet (this includes 2.9 thousand acre-feet of estimated net evaporation from power plant cooling resevoirs). An additional 4.9 thousand acre-feet of ground water was used.

Irrigation is not widespread in the basin, although rice production is quite important in the lower portion of Zone 2 in the coastal area. An estimate of irrigation in 1980 showed 32.4 thousand acre-feet of water was used in irrigating about 8.5 thousand acres in the basin. Surface diversions water accounted for about 24.9 thousand acre-feet. Only 0.3 thousand acre-feet was used for irrigation in Zone 1 in 1980.

In 1980, an estimated total of 4.9 thousand acre-feet of freshwater was used for mining purposes in the Neches River Basin. Of this total, mining industries in Zone 1, primarily in Anderson County, used about 2.6 thousand acre-feet, principally for petroleum and natural gas production. About 2.3 thousand acre-feet of water was used in Zone 2, principally for nonmetal mining operations.

Livestock water use in the Neches River Basin for 1980 totaled about 8.3 thousand acre-feet. About 6.7 thousand acre-feet was used in Zone 1 and 1.6 thousand acre-feet was used in Zone 2.

Navigation facilities in the Neches River Basin include portions of the Sabine-Neches Waterway—the Sabine-Neches Canal and the Neches River to Beaumont. These marine navigation facilities have no regulated freshwater requirements.

Hydroelectric power generating facilities are located in Sam Rayburn Dam, which has a hydroelectric generating capacity of 52 megawatts. Maximum design work release rating of the turbines is 0.205 feet per second per kilowatt.

Return Flows

Of the 164.7 thousand acre-feet of municipal and manufacturing return flows in the Neches River Basin in 1980, industrial fresh water return flows totaled 128.9 thousand acre-feet.

Practically all of the irrigation return flows in the Neches River Basin were from rice-producing acreage in the lower basin. Return flows represented about 40 percent of the water applied for irrigation, or about 7.4 thousand acre-feet in 1980. Most return flows from rice irrigation are discharged near the Coast and therefore are unavailable for reuse.

Current Ground-Water Development

In 1980, approximately 147.6 thousand acre-feet of ground water was used in the Neches River Basin. Of this amount, 35.3 thousand acre-feet was used in Zone 1, and 112.3 thousand acre-feet in Zone 2. In Zone 1 in 1980, about 83 percent of the ground water used was from the Carrizo-Wilcox Aquifer, and about 13 percent was from the Queen City Aquifer. In Zone 2, about 70 percent of the ground water used was from the Gulf Coast Aquifer, and about 25 percent was from the Carrizo-Wilcox Aquifer.

Of the 147.6 thousand acre-feet of ground water used in the basin approximately 129.1 thousand acre-feet or 87 percent was used for municipal and manufacturing purposes.

In 1980, overdrafts of ground water did not occur in Zone 1 of the basin. However, significant overdrafts of ground water occurred in Zone 2, and were evident in Angelina County from the Carrizo-Wilcox Aquifer for manufacturing purposes, and in Jasper and Orange Counties from the Gulf Coast Aquifer for manufacturing and steam-electric power generation purposes.

Current Surface-Water Development

There are ten existing major reservoirs located in the Neches River Basin, seven in Zone 1 and three in Zone 2. Major reservoirs located in Zone 1 are Athens, Palestine, Jacksonville, Tyler, Striker Creek, Nacogdoches, and Pinkston. Lake Athens, owned by the Athens Municipal Water Authority, is located on Flat Creek in Henderson County and provides municipal water to the City of Athens in the Trinity River Basin. Lake Palestine, located on the Neches River in Anderson and Cherokee Counties, is owned and operated by the Upper Neches River Municipal Water Authority for municipal and industrial purposes. Conservation storage in the reservoir is allocated by agreement to the Upper Neches River Municipal Water Authority (46.27 percent) and to the City of Dallas (53.73 percent) in the Trinity River Basin. Lake Jacksonville, located on Gum Creek in Cherokee County, is owned by the City of Jacksonville for municipal and recreational uses. Lake Tyler is located upstream from the confluence of Mud and Prairie Creeks in Smith County. Separate dams impound two individual reservoirs joined by a connecting canal which collectively form Lake Tyler. The reservoir is owned and operated by the City of Tyler for municipal water supplies. Striker Creek Reservoir, owned by the Angelina and Nacogdoches Counties Water Control and Improvement District No. 1, is located on Striker Creek in Rusk and Cherokee Counties. The reservoir provides water for industrial purposes and steam- electric power plant cooling. Lake Nacogdoches is located on Bayou Loco in Nacogdoches County. The reservoir is owned and operated by the City of Nacogdoches for municipal water supply purposes. Pinkston Reservoir, located on Sandy Creek southwest of Shelby in Shelby County, is owned and operated by the City of Center in the Sabine River Basin, and supplies the city's municipal water needs.

Zone 2 reservoirs include Kurth, Sam Rayburn, and B.A. Steinhagen. Lake Kurth is located in Angelina County and is operated as an off-channel storage project for industrial water diversions from the Angelina River by Southland Paper Mills, Inc. Sam Rayburn Reservoir and B.A. Steinhagen Lake were constructed and are operated by the Corps of Engineers. Sam Rayburn, located on the Angelina River in Jasper County, provides storage for municipal, industrial, and irrigation supplies; hydroelectric power generation; and flood control. B.A. Steinhagen Lake is located on the Neches River below the confluence of the Neches and Angelina Rivers in Tyler and Jasper Counties. Permit provisions authorize the Lower Neches Valley Authority to appropriate water for municipal, industrial, and irrigation uses from Sam Rayburn Reservoir, such waters to be impounded and re-regulated in B.A. Steinhagen Lake.

Water Rights

A total of 1,787,721 acre-feet of surface water was authorized or claimed in the Neches River Basin as of December 31, 1983 (Table III-6-1). Municipal use

Table III-6-1. Authorized or Claimed Amount of Water, by Type of Right, Neches River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	130	1,325,907
Claims	331	369,424
Certified Filings	4	92,390
Certificates of Adjudication	0	0
Total Authorizations and Claims	465	1,787,721

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include 7 authorized diversions of saline water amounting to 1,019,653 acre-feet/year. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

accounted for 26.7 percent of the total amount of water authorized and/or claimed in the basin (Table III-6-2). Over 78 percent of the total quantity of water authorized or claimed in the basin for all uses is in Zone 2.

Water Quality

Lowlands along the Neches River consist of fresh- and salt-water marsh areas. Stagnant water is flushed into the Neches River during high runoff conditions. Problems of low dissolved-oxygen concentrations occur locally during low-flow conditions and during the warm weather seasons. Areas adjacent to the tidally-influenced reach of the Neches River are heavily industrialized. Upstream diversions, particularly during the rice growing season, result in the lower reach of the river being frequently composed entirely of treated municipal and industrial effluent. Cedar Creek below Lufkin frequently contains low dissolved-oxygen concentrations due to discharges of treated municipal and industrial effluents. Since more than 75 percent of the drainage area of the upper Neches River is forested, decaying vegetation creates natural non-point pollution sources, with the decaying matter in the river and its tributaries exerting seasonally variable oxygen demands on the stream. Relatively high fluoride concentrations occur locally in the Sparta and Carrizo-Wilcox Aquifers, and high iron concentrations occur in all of the aquifers in the basin. In many areas, water in the Queen City Aquifer is corrosive and therefore objectionable without pretreatment.

Flooding, Drainage, and Subsidence

Flood damages in the upper part of the basin are primarily restricted to agricultural property, timberlands, and logging facilities. Urban damages occur along Ayish Bayou at San Augustine, Bayou LaNana at Nacogdoches, and several small communities located on principal tributaries. Significant urban flood damages also occur in the general vicinity of Beaumont. Floods in 1957, 1969, 1973, 1974, 1975, and 1976 caused an estimated $2.8 million in damages to property within the basin. Damages were severe enough in Jefferson and Orange Counties during the June 1973 flood to warrant a Presidential disaster declaration. Hardin, Jasper, and Tyler Counties were included in the 12-county disaster areas due to severe flooding in July 1973.

As a result of the February 1975 flood in Nacogdoches County, five political entities received over $300 thousand in federal disaster relief funds. Heavy flooding hit the lower basin again in 1979 and 1980. Hardin, Orange, and Tyler Counties were included in a Presidential flood disaster declaration in April 1979 with over $1.3 million spent in the federal relief effort. A major flood in Nacogdoches again resulted in another disaster declaration with over $72 thousand in federal money spent for flood relief. During the period 1978-1981, 373 flood insurance claims were made for over $2.7 million in flood damages.

Use of the National Flood Insurance Program to provide a means of protection against financial losses due to flooding has not been widespread in the Neches River Basin. Of the 50 cities within the basin designated as flood prone by the Federal Emergency Management Agency, only 28 cities have adopted the flood-plain management criteria necessary for participation in the Program. Officials of Hardin, San Augustine, Smith, Liberty, Jefferson, and Orange Counties have adopted FEMA's flood-plain management standards to make flood insurance available to residents of the unincorporated areas. The City of Port Neches is currently a participant in the Regular Phase of the Program. Detailed flood insurance rate studies used to convert communities to Regular Program status are currently underway for the Cities of Nacogdoches, Vidor, and in all unincorporated areas and incorporated cities in Hardin County.

Inadequate natural drainage compounds drainage problems in the Neches River Basin system. Narrow channels and depressions which drain the basin have very low gradients. Surface runoff from heavy rainfall moves slowly through vegetation-choked channels, resulting in frequent inundation of wide areas for long periods of time. In many areas, soil conditions inhibit adsorption of surface water, thus compounding the drainage problem.

Land subsidence due to compaction of clays caused by ground-water withdrawals from the Gulf Coast Aquifer is a

Table III-6-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Neches River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	23	315,141	162,483	477,624
Industrial[2]	28	31,371	1,027,628	1,058,999
Irrigation	333	14,958	203,702	218,660
Mining	2	60	0	60
Recreation	90	23,461	8,877	32,338
Other	1	40	0	40
Total	465[1]	385,031	1,402,690	1,787,721

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include 8 authorized diversions of saline water in Zone 2 amounting to 1,019,653 acre-feet/year.

potential problem in southern Hardin, southern Jasper, northern Jefferson, and western Orange Counties within the Neches River Basin. Also, fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain. Subsidence and fault movement also are caused locally by withdrawals of petroleum and associated saline waters and by extractions of sulfur and other minerals in the Gulf Coastal Plain.

Recreation Resources

Reservoirs within the Neches River Basin provide over 168.0 thousand surface acres available for water-oriented recreation activities. Three of these reservoirs located in Zone 2 account for approximately 77 percent of the total basin surface-water area. Sam Rayburn Reservoir, located in Zone 2, is the second largest lake in the State with 114.5 thousand surface acres. Over 2.6 million visitors were reported by the U.S. Army Corps of Engineers at Sam Rayburn Reservoir during 19S0. Lake Palestine (25.6 thousand surface acres) is the largest reservoir in Zone 1 of the basin.

PROJECTED WATER REQUIREMENTS

Population Growth

The Neches River Basin population should increase by 111 percent by the year 2030, approaching 1.1 million residents (Table Ill-6-3). A 39 percent increase is anticipated by 2000, and a 52 percent increase from 2000 to 2030. These growth rates are slightly below those of the entire State, which are 49 percent and 62 percent, respectively, for the 1980-2000 and 2000-2030 time periods.

Smith County, including Tyler, had the largest share of the basin population in 1980, 22.1 percent. Tyler's population should increase to nearly 25 percent of the basin total by 2030. Angelina County is the next most populous county, containing 13 percent of the basin total.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on population changes and per capita water use. Water requirements in the Neches River Basin are projected to increase by 22 to 86 percent by 2000; low and high case, respectively. By 2030, water requirements are projected to range from 135.9 thousand acre-feet (low case) to 224.7 thousand acre-feet (high case). Municipal water requirements are almost equally divided between zones.

Industrial

Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing freshwater requirements in the Neches River Basin are projected to more than double by the year 2030, from a 1980 requirement of 180.2 thousand acre-feet to a 2030 requirement of 371.1 to 417.0 thousand acre-feet annually (Table Ill-6-3). In comparison, State manufacturing freshwater requirements will more than double over the planning period (230 percent relative to 130 percent for the Neches River Basin). Consequently, while 11.9 percent of 1980 State manufacturing freshwater requirement originated in the Neches, this basin is projected to provide only 8.3 percent of the 2030 total.

Zone 2 (Jefferson, Jasper, and Angelina Counties) of the Neches River Basin is expected to require over 92 percent of the 2030 basin demands. Petroleum refining and chemical production are projected as the heaviest industrial freshwater users in Jefferson County. Paperboard mills in Jasper County and Angelina County will constitute the major sources of increased water requirements.

Steam-Electric Power Generation

Although near-surface lignite deposits are substantially lower in the Neches River Basin than in the Sabine and Trinity Basins, these deposits will still be a factor in the future growth of steam-electric power generating capacity in the basin.

Future growth was projected for two electricity demand cases. Water requirements are projected to increase from 12.2 thousand acre-feet for 1980 by 275 to 518 percent by 2030; low and high case, respectively. The increased demand for electricity is divided approximately equally between zones.

Table III-6-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Neches River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			259.9			323.7			366.6			410.5			465.5			526.4
Municipal	26.2	17.6	43.8	24.4	43.8	68.2	26.4	52.8	79.2	28.0	60.6	88.6	30.3	70.1	100.4	33.1	80.3	113.4
Manufacturing	3.5	4.4	7.9	5.5	7.8	13.3	5.9	10.9	16.8	6.3	14.2	20.5	6.8	18.2	25.0	7.4	23.1	30.5
Steam Electric	0.3	5.3	5.6	0.0	5.6	5.6	0.0	12.4	12.4	0.0	21.7	21.7	0.0	31.1	31.1	0.0	40.4	40.4
Mining	2.1	0.5	2.6	1.3	0.7	2.0	0.5	16.9	17.4	10.7	7.7	18.4	11.5	7.9	19.4	3.2	1.3	4.5
Irrigation	0.1	0.2	0.3	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.3
Livestock	3.1	3.6	6.7	2.2	5.7	7.9	2.2	7.0	9.2	2.1	7.1	9.2	2.1	7.1	9.2	2.2	7.0	9.2
Zone Total Water	35.3	31.6	66.9	33.4	63.9	97.3	35.0	100.3	135.3	47.1	111.6	158.7	50.7	134.7	185.4	45.9	152.4	198.3
Zone 2																		
Population			246.4			296.8			338.7			391.5			457.2			544.2
Municipal	29.1	7.1	36.2	30.2	29.4	59.6	36.1	33.5	69.6	45.2	37.8	80.3	49.0	44.6	93.6	57.1	54.2	111.3
Manufacturing	70.3	102.0	172.3	14.8	196.8	211.6	15.1	234.9	250.0	17.3	270.3	287.6	15.5	317.3	332.8	14.9	371.6	386.5
Steam Electric	4.6	2.0	6.6	2.0	4.6	6.6	2.0	11.4	13.4	2.0	18.6	20.6	2.0	25.8	27.8	2.0	33.0	35.0
Mining	0.1	2.2	2.3	0.1	2.8	2.9	0.1	3.4	3.5	0.1	4.0	4.1	0.1	4.5	4.6	0.0	5.1	5.1
Irrigation	7.4	24.7	32.1	5.4	14.1	19.5	5.4	14.1	19.5	5.4	14.1	19.5	5.4	14.1	19.5	2.8	16.7	19.5
Livestock	0.8	0.8	1.6	0.7	1.2	1.9	0.7	1.5	2.2	0.8	1.4	2.2	0.7	1.5	2.2	0.8	1.4	2.2
Zone Total Water	112.3	138.8	251.1	53.2	248.9	302.1	59.4	298.8	358.2	68.1	346.2	414.3	72.7	407.8	480.5	77.6	482.0	559.6
BASIN TOTALS																		
Population			506.3			620.5			705.3			802.0			922.7			1,070.6
Municipal	55.3	24.7	80.0	54.6	73.2	127.8	62.5	86.3	148.8	70.5	98.4	168.9	79.3	114.7	194.0	90.2	134.5	224.7
Manufacturing	73.8	106.4	180.2	20.3	204.6	224.9	21.0	245.8	266.8	23.6	284.5	308.1	22.3	335.5	357.8	22.3	394.7	417.0
Steam Electric	4.9	7.3	12.2	2.0	10.2	12.2	2.0	23.8	25.8	2.0	40.3	42.3	2.0	56.9	58.9	2.0	73.4	75.4
Mining	2.2	2.7	4.9	1.4	3.5	4.9	0.6	20.3	20.9	10.8	11.7	22.5	11.6	12.4	24.0	3.2	6.4	9.6
Irrigation	7.5	24.9	32.4	5.4	14.4	19.8	5.4	14.4	19.8	5.4	14.4	19.8	5.4	14.4	19.8	2.8	17.0	19.8
Livestock	3.9	4.4	8.3	2.9	6.9	9.8	2.9	8.5	11.4	2.9	8.5	11.4	2.8	8.6	11.4	3.0	8.4	11.4
Basin Total Water	147.6	170.4	318.0	86.6	312.8	399.4	94.4	399.1	493.5	115.2	457.8	573.0	123.4	542.5	665.9	123.5	634.4	757.9

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Neches River Basin are projected to decrease from the 1980 level of 32.4 thousand acre-feet by a projected maximum 39 percent by the year 2000 in the high and low case. In the year 2030, water requirements in the Basin are projected to remain at 19.8 thousand acre-feet annually in both the low and high case, respectively, to irrigate about 8.5 thousand acres.

Zone 2 is projected to account for about 98 percent of total basin irrigation requirements in 2000 and 2030. Zone 1 is projected to account only for about two percent of the total.

Livestock

In 1980, livestock water requirements within the basin were 8.3 thousand acre-feet annually (Table III-6-3). Approximately 81 percent of the total was used in Zone 1. By 2030, 11.4 thousand acre-feet of water will be required for livestock needs.

Mining

Mining freshwater use in the Neches River Basin is projected to increase from 4.9 thousand acre-feet in 1980 to 9.6 thousand acre-feet in 2030 (Table III-6-3). Fuel extraction water requirements (crude petroleum and natural gas) will decline from 2,170 acre-feet to 215 acre-feet annually in 2030, while the basin nonmetal mining freshwater requirements are expected to double over the 50-year period.

Navigation

As part of an authorized comprehensive study of the Neches River and its tributaries, the Corps of Engineers has completed and released a report relating to construction of a permanent salt water barrier on the Neches River. The freshwater requirements associated with the navigation aspects of the project would be approximately 10,000 acre-feet annually.

Hydroelectric Power

Hydroelectric power generation capacity in the Neches River Basin is limited to 52 megawatts at Sam Rayburn Dam. There are no current plans to expand generating capacity.

Estuarine Freshwater Inflows

The Neches River, along with the Sabine River, discharges into the Sabine-Neches estuary. Estimates of freshwater inflow needs for the Sabine-Neches estuary are based on the total flow from both river basins. These estimates are presented in Table III-5-4, of the Sabine Basin discussion.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Neches River Basin to the year 2030 is 570.8 thousand acre-feet with the following amounts annually available by aquifer: 154.1 thousand acre-feet from the Carrizo-Wilcox Aquifer, 101.0 thousand acre-feet from the Gulf Coast Aquifer, 54.4 thousand acre-feet from the Sparta Aquifer, and 261.3 thousand acre-feet from the Queen City Aquifer. Since the ground water available from the Queen City Aquifer within the basin has high concentrations of iron and high acidity (low pH), it should not be considered a suitable source of water for municipal and most manufacturing purposes. However, Queen City ground water is suitable for irrigation, steam-electric power generation (cooling), mining, and stock watering purposes. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual recharge of 150.0 thousand acre-feet per year. This reduction decreases the total ground-water availability within the basin in 2030 to 566.7 thousand acre-feet. Consequently, since less ground water will be available in 2030, the total ground-water use projected for the basin in 2030 also may be reduced.

The projected annual ground-water use within the Neches River Basin by decade from 1990 through 2030 is expected to be from 86.6 to 123.5 thousand acre-feet per year (Table III-6-3). The approximate average annual projected ground-water use within the basin is expected to be about 108.7 thousand acre-feet per year. Of the 108.7 thousand acre-feet of average annual projected use, about 49 percent is expected to be from the Gulf Coast Aquifer, about 47 percent from the Carrizo-Wilcox Aquifer, and about 1 percent from the Queen City Aquifer.

Surface-Water Availability and Proposed Development

Surface-water requirements projected for the Neches River Basin and for adjacent areas supplied by exports from this basin are estimated to be fully satisfied through the year 2030, except for minor irrigation shortages, based upon supplies from existing and proposed reservoir development (Table III-6-4, Figure III-6-2).

Zone 1

Zone 1 of the Neches River is projected to have a surface-water surplus for existing reservoirs of 67.9 thousand acre-feet in the year 2030 (Table III-6-5, Figure III-6-3). Total surface-water supply available is projected to be some 364.4 thousand acre-feet in year 2030, with surface-water requirements totaling an estimated 296.5 thousand acre-feet. Approximately 142.5 thousand acre-feet of the water demand on Zone 1 in 2030 is assigned for export to the upper Trinity River Basin.

There are three potential reservoir projects in Zone 1 of the Neches River Basin, Weches, Ponta, and Eastex Reservoirs. The proposed site of Weches Reservoir is located on the Neches River in Houston and Cherokee Counties. As presently designed, it would provide for flood control, water conservation and supply, recreation, and potentially could be used for hydroelectric power production. Although presently inactive, studies have been performed by the Corps of Engineers to examine the possibility of enlarging the authorized design capacity of the authorized Rockland Reservoir Project in Zone 2, downstream of Weches, and eliminating this potential project.

The proposed site of Ponta Reservoir is located on the Angelina River in Cherokee and Nacogdoches Counties upstream from Sam Rayburn Reservoir. Ponta Reservoir has been studied extensively by the Corps of Engineers. The project would provide 649.2 thousand acre-feet of flood-control storage and 804.8 thousand acre-feet of conservation storage, as well as recreation and the potential for hydroelectric power generation.

The proposed Lake Eastex is located in Cherokee County, upstream of the proposed Ponta Reservoir. The project has been studied by local interests as a water supply reservoir for municipal and industrial purposes. Construction of the project will depend upon local initiative.

Zone 2

A projected surface-water surplus of 18.6 thousand acre-feet based upon existing and proposed reservoirs is estimated to occur in year 2030 in Zone 2 of the basin (Table III-6-6, Figure III-6-4). Approximately 1.23 million acre-feet of the total estimated 1.71 million acre-feet of surface-water requirement on the zone in 2030 is projected to occur outside of the basin. The majority of this export demand in the year 2030 would be in the San Jacinto, San Jacinto-Brazos, and lower Brazos River Basins. Slight shortages in projected future irrigation are forecast to occur in this zone due to limiting supplies of ground water.

Although additional reservoir projects are not needed in Zone 2 to meet water supply needs of the basin through 2030, a major water storage facility is needed now to solve a long-standing water supply problem. During periods of low flow and high water withdrawals, salt water from the Gulf of Mexico intrudes up the Neches River in sufficient quantity to contaminate the freshwater supplies diverted from the river by the City of Beaumont and the Lower Neches Valley Authority. To prevent contamination of its water supply, the Lower Neches Valley Authority, through the years, has adopted the practice of installing temporary salt-water barriers downstream from their diversion points for 4 to 6 months every year. Although these temporary barriers are effective and economical, they completely block navigation by recreational and commercial vessels.

Construction of the Corps of Engineers authorized Salt Water Barrier project at Beaumont would permanently eliminate this problem. The project would provide a

Table III-6-4. Water Resources of the Neches River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	86.6	—	—	—	86.6	86.6	—	—	86.6	.0	.0	.0
Surface Water	1255.1	—	90.0	6.1	1351.2	289.2	—	474.8	764.0	589.4	(2.2)	587.2
Total	1341.7	—	90.0	6.1	1437.8	375.8	—	474.8	850.6	589.4	(2.2)	587.2
2000												
Ground Water	94.4	—	—	—	94.4	94.4	—	—	94.4	.0	.0	.0
Surface Water	1253.5	—	104.2	7.1	1364.8	373.2	—	456.9	830.1	536.9	(2.2)	534.7
Total	1347.9	—	104.2	7.1	1459.2	467.6	—	456.9	924.5	536.9	(2.2)	534.7
2010												
Ground Water	115.2	—	—	—	115.2	115.2	—	—	115.2	.0	.0	.0
Surface Water	1240.7	—	118.0	8.1	1366.8	431.2	—	660.5	1091.7	277.3	(2.2)	275.1
Total	1355.9	—	118.0	8.1	1482.0	546.4	—	660.5	1206.9	277.3	(2.2)	275.1
2020												
Ground Water	123.4	—	—	—	123.4	123.4	—	—	123.4	.0	.0	.0
Surface Water	1910.4	—	134.1	9.4	2053.9	515.0	—	1153.5	1668.5	387.6	(2.2)	385.4
Total	2033.8	—	134.1	9.4	2177.3	638.4	—	1153.5	1791.9	387.6	(2.2)	385.4
2030												
Ground Water	123.5	—	—	—	123.5	123.5	—	—	123.5	.0	.0	.0
Surface Water	1897.6	—	153.6	11.1	2062.3	606.5	—	1369.3	1975.8	91.2	(4.7)	86.5
Total	2021.1	—	153.6	11.1	2185.8	730.0	—	1369.3	2099.3	91.2	(4.7)	86.5

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

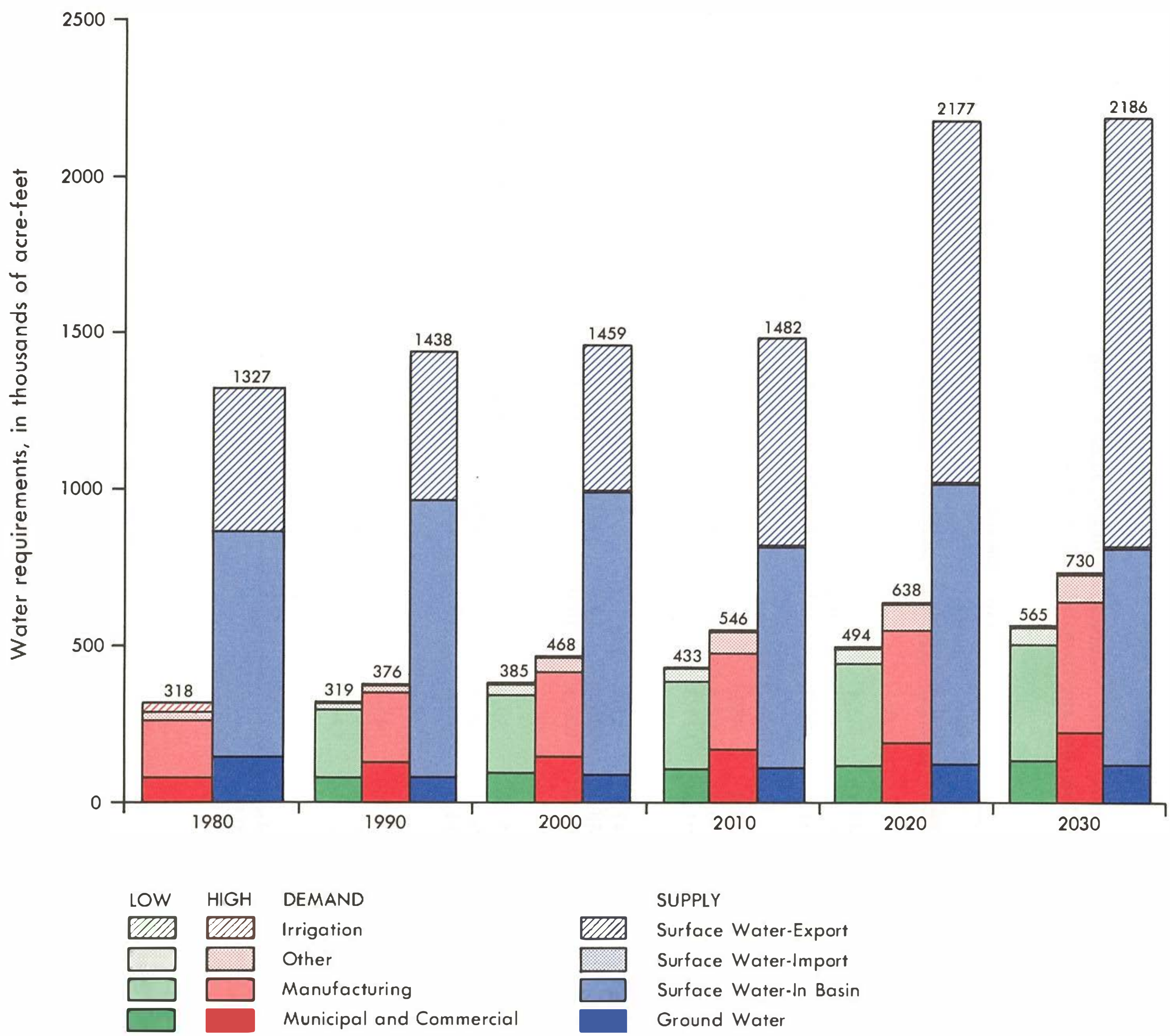

Figure III-6-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches River Basin, 1980-2030

navigation gate by-pass channel, auxiliary dam, and appurtenances to permanently control salt-water intrusion in the Neches River and tributaries. The freshwater requirements associated with the navigational aspects of the project would be approximately 10,000 acre-feet annually. These requirements can be met from projected surplus supplies in Zone 2 of the Neches River Basin.

Existing surface-water resources in the Neches River Basin exceed projected surface-water needs in the Neches River Basin and Zone 1 of the Neches-Trinity Coastal Basin through the year 2030. However, projected needs in the Houston-Galveston metropolitan area and in Zone 6 of the Brazos River Basin could necessitate providing additional water supplies for that area. Studies performed by

Table III-6-5. Water Resources of the Neches River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply: In Zone	Water Supply: Intra-Basin	Water Supply: Return Flow	Water Supply: Import	Water Supply: Total	Water Demand: In Zone	Water Demand: Intra-Basin	Water Demand: Export	Water Demand: Total	Surplus or Shortage: M & I	Surplus or Shortage: Irrigation (Shortage)	Surplus or Shortage: Total
1990												
Ground Water	33.4	—	—	—	33.4	33.4	—	—	33.4	.0	.0	.0
Surface Water	335.2	.0	18.5	.5	354.2	57.3	9.8	134.2	201.3	152.9	.0	152.9
Total	368.6	.0	18.5	.5	387.6	90.7	9.8	134.2	234.7	152.9	.0	152.9
2000												
Ground Water	35.0	—	—	—	35.0	35.0	—	—	35.0	.0	.0	.0
Surface Water	333.6	.0	22.0	.7	356.3	92.3	10.0	136.2	238.5	117.8	.0	117.8
Total	368.6	.0	22.0	.7	391.3	127.3	10.0	136.2	273.5	117.8	.0	117.8
2010												
Ground Water	47.1	—	—	—	47.1	47.1	—	—	47.1	.0	.0	.0
Surface Water	332.4	.0	25.1	.8	358.3	103.3	10.0	137.8	251.1	107.2	.0	107.2
Total	379.5	.0	25.1	.8	405.4	150.4	10.0	137.8	298.2	107.2	.0	107.2
2020												
Ground Water	50.7	—	—	—	50.7	50.7	—	—	50.7	.0	.0	.0
Surface Water	331.0	.0	29.0	.9	360.9	126.2	10.0	139.9	276.1	84.8	.0	84.8
Total	381.7	.0	29.0	.9	411.6	176.9	10.0	139.9	326.8	84.8	.0	84.8
2030												
Ground Water	45.9	—	—	—	45.9	45.9	—	—	45.9	.0	.0	.0
Surface Water	329.8	.0	33.6	1.0	364.4	144.0	10.0	142.5	296.5	67.9	.0	67.9
Total	375.7	.0	33.6	1.0	410.3	189.9	10.0	142.5	342.4	67.9	.0	67.9

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-face supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

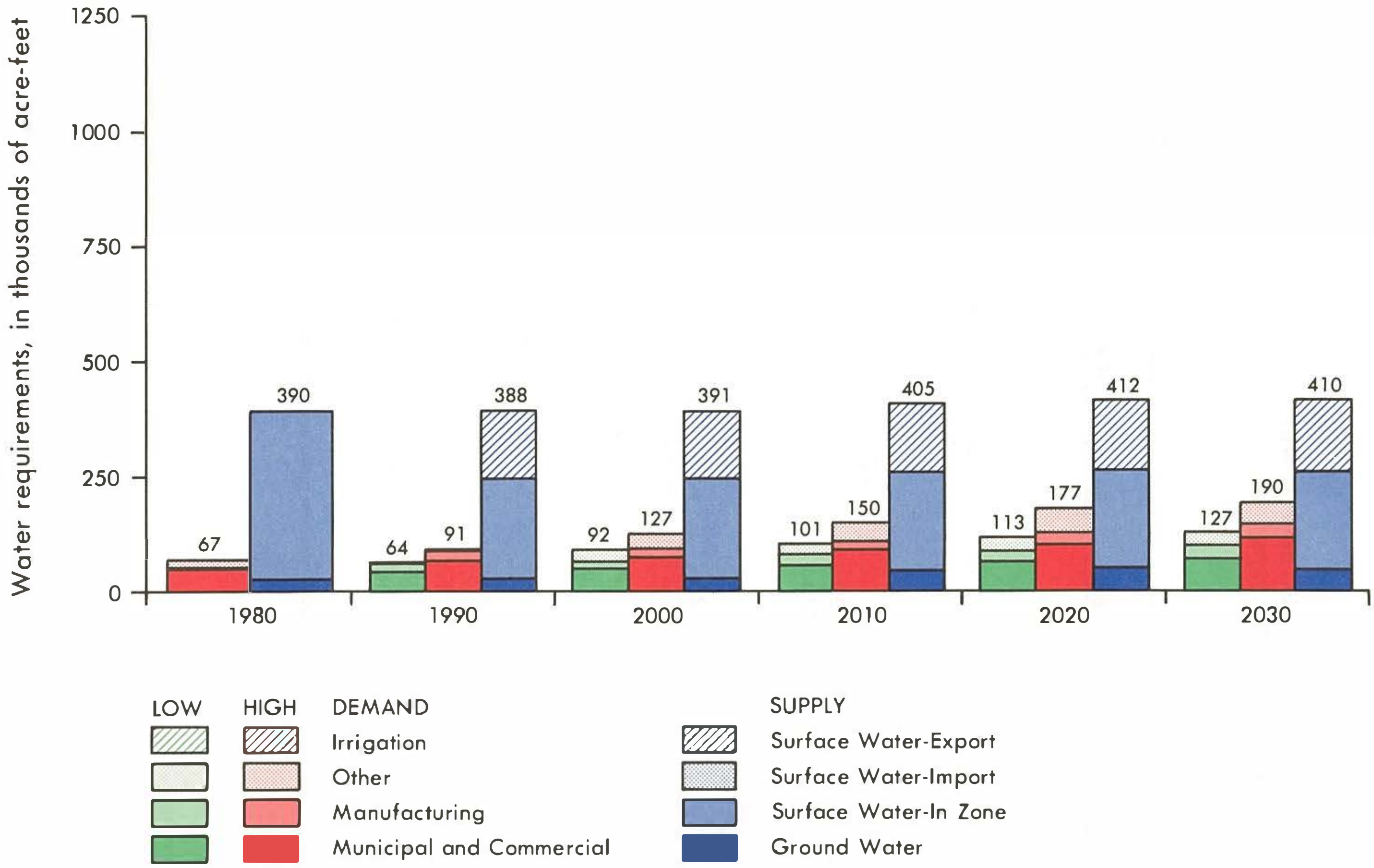

Figure III-6-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches River Basin, Zone 1, 1980-2030

and for the Texas Department of Water Resources indicate that it is physically feasible to convey relatively large quantities of water from the Neches River to the Trinity River Basin in order to meet the severe water shortages projected to occur in the San Jacinto River Basin and contiguous areas along the Coast by the year 2000. Preliminary design and cost studies have been performed. Water conveyance systems consisting of open channels and pipelines from the Neches River Basin would need to be constructed. Supplies currently available in the Neches River Basin to meet this export need could be depleted by the year 2020. Rockland Reservoir on the Neches River upstream of B.A. Steinhagen Reservoir is proposed for construction by 2020 to meet this need. Rockland Reservoir, as presently authorized, would provide a dependable yield of 682.7 thousand acre-feet annually. Surpluses in excess of in-basin needs and freshwater requirements of the Sabine Lake estuary would be available for conveyance to water-deficient areas provided appropriate institutional arrangements can be consumated.

Additional studies are planned to examine the engineering alternatives and the institutional and environmental considerations that would be involved in implementing such a project. There is clearly an opportunity for such an undertaking to provide for maximum beneficial use of surplus waters over and above in-basin needs and the freshwater requirements of the Sabine Lake estuarine system.

Water Quality Protection

A water quality management plan for the Neches River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Beaumont-Port Arthur-Orange metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facil-

Table III-6-6. Water Resources of the Neches River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	53.2	—	—	—	53.2	53.2	—	—	53.2	.0	.0	.0
Surface Water	919.9	9.8	71.5	5.6	1006.8	231.9	.0	340.6	572.5	436.5	(2.2)	434.3
Total	973.1	9.8	71.5	5.6	1060.0	285.1	.0	340.6	625.7	436.5	(2.2)	434.3
2000												
Ground Water	59.4	—	—	—	59.4	59.4	—	—	59.4	.0	.0	.0
Surface Water	919.9	10.0	82.2	6.4	1018.5	280.9	.0	320.7	601.6	419.1	(2.2)	416.9
Total	979.3	10.0	82.2	6.4	1077.9	340.3	.0	320.7	661.0	419.1	(2.2)	416.9
2010												
Ground Water	68.1	—	—	—	68.1	68.1	—	—	68.1	.0	.0	.0
Surface Water	908.3	10.0	92.9	7.3	1018.5	327.9	.0	522.7	850.6	170.1	(2.2)	167.9
Total	976.4	10.0	92.9	7.3	1086.6	396.0	.0	522.7	918.7	170.1	(2.2)	167.9
2020												
Ground Water	72.7	—	—	—	72.7	72.7	—	—	72.7	.0	.0	.0
Surface Water	1579.4	10.0	105.1	8.5	1703.0	388.8	.0	1013.6	1402.4	302.8	(2.2)	300.6
Total	1652.1	10.0	105.1	8.5	1775.7	461.5	.0	1013.6	1475.1	302.8	(2.2)	300.6
2030												
Ground Water	77.6	—	—	—	77.6	77.6	—	—	77.6	.0	.0	.0
Surface Water	1567.8	10.0	120.0	10.1	1707.9	462.5	.0	1226.8	1689.3	23.3	(4.7)	18.6
Total	1645.4	10.0	120.0	10.1	1785.5	540.1	.0	1226.8	1766.9	23.3	(4.7)	18.6

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

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Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

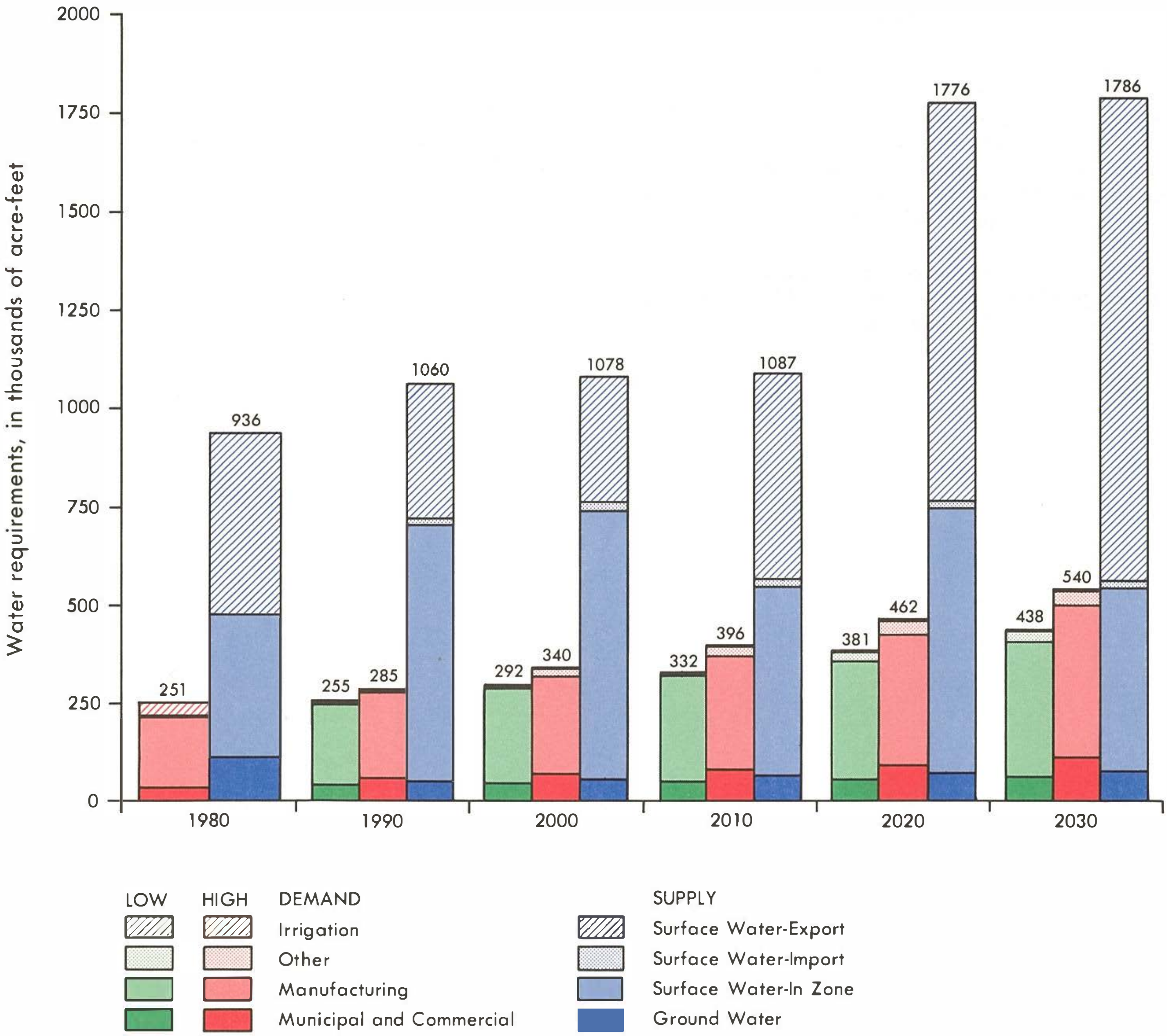

Figure III-6-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches River Basin, Zone 2, 1980-2030

ities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $149.9 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Neches River Basin with approximately $88.6 million required in Zone 2, while approximately $61.3 million is projected necessary in Zone 1. All costs are in January 1980 dollars and are subject to revision as new data becomes available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of industrial, oil and gas, and agricultural pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Sam Rayburn Reservoir is the only reservoir in the Neches River Basin which currently provides flood-control storage. The reservoir has 1,099.4 thousand acre-feet of flood control storage capacity. Construction of the authorized Rockland Reservoir, as presently designed, would provide an additional 1,020 thousand acre-feet of flood-control storage capacity for the basin.

The Corps of Engineers is currently conducting a flood damage prevention study on Pine Island Bayou. The study report is scheduled for completion January 1987.

Construction of floodwater-retarding structures by the U.S. Department of Agriculture, Soil Conservation Service includes about 45 square miles of drainage area above 12 existing floodwater-retarding structures within the Neches River Basin. As of October 1980, an additional 17 structures with a drainage area of 117 square miles were planned.

7. NECHES-TRINITY COASTAL BASIN

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7. NECHES-TRINITY COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Neches-Trinity Coastal Basin is bounded on the east by Sabine Lake and Sabine Pass, on the north by the Neches and the Trinity River Basins, and on the west by Trinity and Galveston Bays. Maximum elevation in the basin is about 50 feet, although most of the basin is less than 25 feet in elevation. Total basin drainage area is 769 square miles. For planning purposes, the Neches-Trinity Coastal Basin has been divided into two zones (Figure III-7-1). Sabine Lake and Taylor Bayou are in Zone 1 of the Neches-Trinity Coastal Basin. Oyster Bayou, East Bay Bayou, and the East and West Forks of Double Bayou constitute the drainage system of Zone 2 of the Neches-Trinity Coastal Basin.

Surface Water

Average annual runoff in the basin ranges from a maximum of about 850 acre-feet per square mile in the eastern part to about 550 acre-feet per square mile in the western part of the basin. The runoff varies widely from year to year and between periods of wet and dry years. Because most of the natural watercourses contain return flows, have been modified, are tidally-influenced, or are affected by upstream drainage operations, reliable data on low-flow characteristics are unavailable.

Extremely flat slopes and poorly-defined natural drainage systems produce ponding and shallow sheet flooding during periods of heavy rainfall. Average ground elevations of five feet above mean sea level, and the close proximity of the Gulf, pose serious hazards to structural developments from tidal overflow due to hurricanes.

Streams in the western part of the basin are subject to tidal intrusion. Much of the major drainage system in the eastern part of the basin has been modified for the regulation and distribution of irrigation supplies delivered from the Neches and Trinity River Basins; upstream intrusion of tidal waters in these canals and channels is inhibited by systems of barriers and diversion dams. Taylor Bayou, which is the longest and largest stream in the basin, exhibits good water quality except for occasional problems with low dissolved oxygen and dense algae populations. Sabine Lake has the most serious potential water-quality problem since it receives treated municipal and industrial return flows from the Beaumont-Port Arthur area. The natural runoff from the basin normally contains dissolved-solids concentration below 500 milligrams per liter (mg/l).

Ground Water

The Gulf Coast Aquifer occurs over all but the southern edge of the Neches-Trinity Coastal Basin. The aquifer extends to a maximum depth of about 800 feet in the upper part of the basin. Yields from large capacity wells average about 250 gallons per minute (gpm); however, locally wells are capable of producing up to 1,500 gpm. The chemical quality of the ground water varies widely, ranging from fresh to slightly saline.

Population and Economic Development

The population of the Neches-Trinity Coastal Basin was reported at 203.7 thousand in 1980. Presently, 95 percent of the basin population resides in Jefferson County. Beaumont is the largest city, with over 80 thousand of its population in the Neches-Trinity Coastal Basin. It is closely followed by Port Arthur with an in-basin population of more than 59 thousand. Together, these two cities comprise 69 percent of the total basin population. The only other basin cities with a 1980 population of 10 thousand or more are Nederland and Groves, making up eight percent and five percent of the basin population, respectively. The basin population is dense and more urban than the State as a whole.

The economy of the area is based on chemical and petrochemical manufacturing, oil production, agriculture, agribusiness, and shipping activities associated with the Ports of Beaumont and Port Arthur, which rank second and fifth among Texas ports. Commercial fishing rounds out the area's highly-diversified economy, although numerous recreational attractions including beaches, fresh and saltwater fishing, and hunting (principally waterfowl) support a large tourist industry.

Water Use

Municipal water use in the Neches-Trinity Coastal Basin totaled 31.0 thousand acre-feet in 1980. Surface-water sources supplied over 78 percent of the total use. Almost 95 percent of total basin municipal water use was in Jefferson County (Zone 1), including the City of Beaumont which used about 47 percent of the municipal use in the basin.

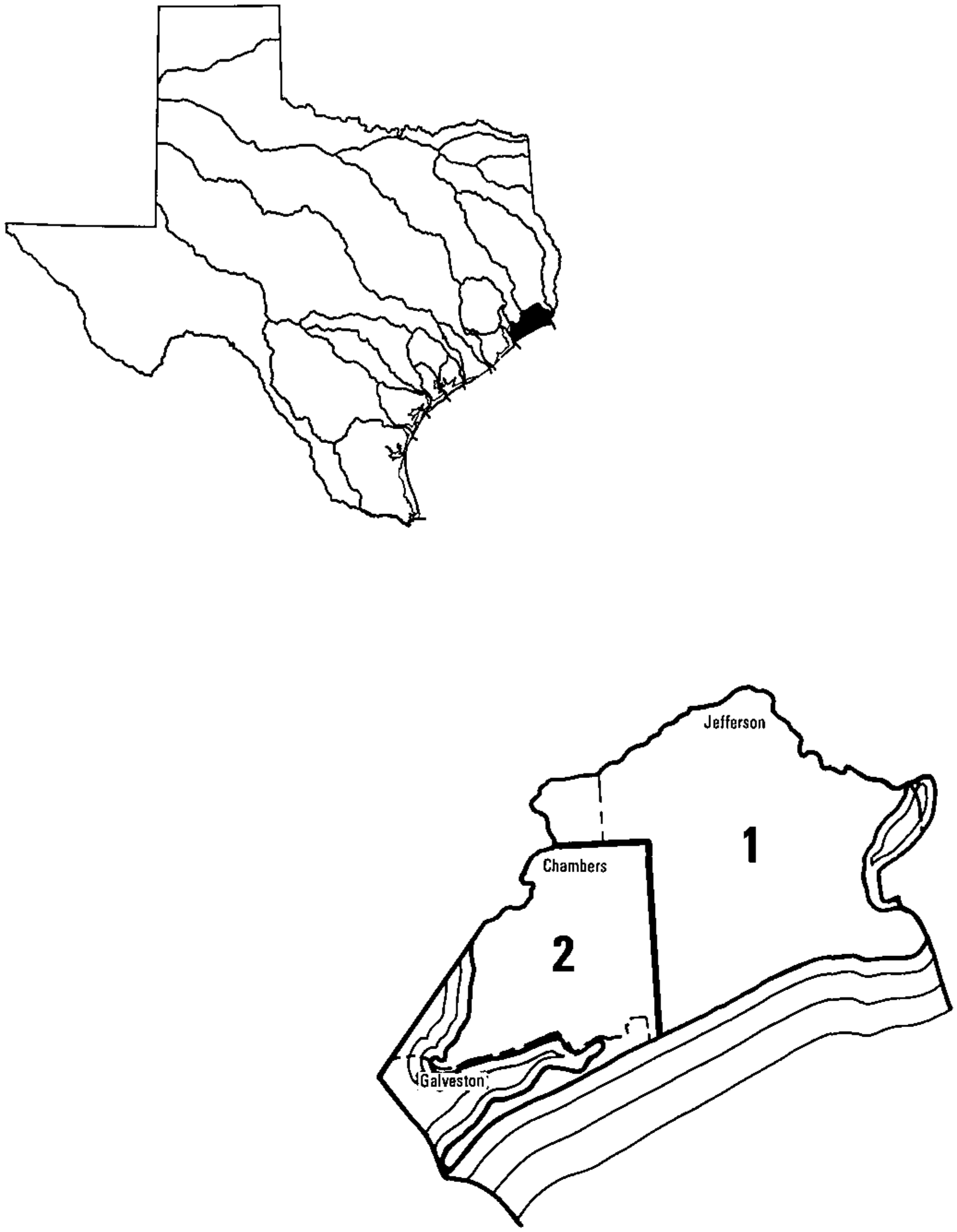

Figure III-7-1. Neches-Trinity Coastal Basin and Zones

Freshwater use by manufacturing industries in the Neches-Trinity Coastal Basin totaled 78.1 thousand acre-feet in 1980. This use was concentrated within the Beaumont and Port Arthur area where petroleum refining and chemical industries are the major users.

Irrigation estimates indicated 544.9 thousand acre-feet of water use to irrigate about 119 thousand acres in the basin in 1980. All irrigation water was derived from surface-water supplies. Zone 1 accounted for 362.5 thousand acre-feet of this water use, while Zone 2 utilized 182.4 thousand acre-feet. Most of the water for irrigation is delivered through major canal and appurtenant conveyance facilities, except for minor quantities diverted locally from streams. In Zone 1, the Lower Neches Valley Authority supplies water to irrigators from the Neches River Basin; however, Zone 2 irrigators obtain water from the Trinity River Basin through the Trinity River Authority's Devers Canal Company system and the Chambers-Liberty Counties Navigation District facilities. Existing systems for water delivery are physically adequate to meet current and near-term future irrigation needs provided water supplies continue to be available. Rice farming constitutes the basin's major irrigation water requirements.

Mining industries in the Neches-Trinity Coastal Basin used an estimated 1.4 thousand acre-feet of freshwater in 1980. The most intensive use of mining water is concentrated in Zone 1, which accounted for approximately 64 percent of the total basin water use. Nonmetal mining water use in Jefferson County was approximately 43 percent of the quantity of mining water used in the basin.

Livestock water requirements totaled about 0.8 thousand acre-feet in the basin in 1980. About 500 acre-feet was derived from ground-water resources. Of the total livestock water used, Zone 1 accounted for 427 acre-feet while Zone 2 utilized 362 acre-feet.

Navigation facilities in the Neches-Trinity Coastal Basin include portions of the Sabine-Neches Waterway—the Sabine Pass Channel and Port Arthur Canal, the Gulf Intracoastal Waterway, the Anahuac Channel, Double Bayou Channel, the lower reach of the Trinity River Channel from its intersection with the Houston Ship Channel to below Anahuac, and the lower reach of the Houston Ship Channel. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, total municipal and manufacturing return flows in the Neches-Trinity Coastal Basin exceeded 95.8 thousand acre-feet. Only about 34 thousand acre-feet of these return flows had dissolved-solids concentrations sufficiently low to be considered potentially reusable.

In 1980, irrigation return flows, primarily from rice production, constituted about 40 percent of the irrigation water applied from ground- or surface-water supplies. Irrigation return flows in the basin in 1980 were estimated to total 114 thousand acre-feet. Of this amount, 65.2 thousand acre-feet originated in Zone 1, while Zone 2 contributed the remaining 48.8 thousand acre-feet. Although these return flows are of considerable magnitude, they do not constitute a major supply for reuse since in most areas they are discharged into estuarine waters.

Current Ground-Water Development

In 1980, approximately 9.7 thousand acre-feet of ground water was used in the Neches-Trinity Coastal Basin. Of this amount, 7.9 thousand acre-feet was used in Zone 1, and 1.8 thousand acre-feet in Zone 2 of the basin. All of the ground water used in both zones of the basin was from the Gulf Coast Aquifer.

Of the 9.7 thousand acre-feet of ground water used in the basin, approximately 8.6 thousand acre-feet, or almost 89 percent, was used for municipal and manufacturing purposes.

Within both zones of the basin, the only area having overdrafts of ground water was in Jefferson County where excessive withdrawals from the Gulf Coast Aquifer occurred for municipal, manufacturing and mining purposes.

Current Surface-Water Development

There are presently no major water-supply reservoirs in the basin. J.D. Murphree Wildlife Management Area Impoundments, a group of shallow impoundments having a capacity of 32 thousand acre-feet, is owned and operated by the Texas Parks and Wildlife Department for wildlife management purposes. Surface-water supplies are delivered into the basin by the major canal systems originating in the Neches and Trinity River Basins.

Water Rights

The total amount of surface water authorized or claimed for diversion and use in the Neches-Trinity Coastal Basin was 510,237 acre-feet as of December 31, 1983 (Table III-7-1). Authorizations and claims for irrigation use amounted to 206,656 acre-feet, or 40.5 percent of the

Table III-7-1. Authorized or Claimed Amount of Water, by Type of Right, Neches-Trinity Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	52	356,276
Claims	49	110,248
Certified Filings	16	43,713
Certificates of Adjudication	0	0
Total Authorizations and Claims	117	510,237

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include 2 authorized diversions of saline water amounting to 2,613,117 acre-feet/year. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

basin total. Zone 1 accounted for 440,617 acre-feet, or 86.4 percent of total authorized and claimed water in the basin (Table III-7-2).

Water Quality

Water-quality problems in this basin are confined principally to Taylor Bayou and its tributaries, where low dissolved oxygen levels and high nutrient levels occur periodically. These conditions result in part from sluggish flow characteristics and assimilation of waste loads from the Hillebrandt Bayou tributary. Low dissolved oxygen problems in Hillebrandt Bayou result primarily from treated municipal effluents with some contribution from industrial effluents. The problem extends for a short distance below the confluence with Taylor Bayou. Recent construction of a new municipal wastewater treatment plant for the City of Beaumont has improved the situation considerably.

Flooding, Drainage, and Subsidence

Commercial and industrial properties and the high density residential concentrations around Beaumont and Port Arthur are subject to varying degrees of damage from flooding. Hurricane Audrey in 1957 caused nine deaths and approximately $700 thousand in damages to urban property. Major damages were inflicted on the area by Hurricane Carla in 1961 when Chambers County suffered $1.1 million in damages to nonagricultural property, and in Jefferson County damages amounted to nearly $16.7 million. Agricultural losses in both counties were estimated at $3.5 million.

In 1962, a hurricane levee protection system was authorized by Congress for the Port Arthur area. Hurricane Cindy, which caused damages in Jefferson County in 1963, further emphasized the need for hurricane protection. Areas flooded by Hurricanes Carla and Cindy in Jefferson County were declared disaster areas by the President. In Jefferson County, areas damaged as a result of the June 1973 flood were included in a massive 12-county disaster declaration.

Massive flooding again returned to the Beaumont-Port Arthur area in 1979 and 1980. Floods in April, 1979 and Tropical Storm Claudette in July 1979 produced Presidential disaster declarations in the basin with over $1 million spent in federal relief funds. Flood insurance claims in 1979 totaled 741 for $5 million in flood damages and in 1980, 1217 claims were filed for $5.9 million in flood damages.

The Federal Emergency Management Agency has designated eight cities in the basin as having one or more potential flood-hazard areas. Seven of these cities are participants in the National Flood Insurance Program.

Table III-7-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Neches-Trinity Coastal Basin[1]

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	0	0	0	0
Industrial[2]	6	2,526	6,320	8,846
Irrigation	107	164,356	42,300	206,656
Mining	2	239,335	0	239,335
Recreation	3	34,400	21,000	55,400
Total	117[1]	440,617	69,620	510,237

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include 2 authorized diversions of saline water in Zone 1 amounting to 2,613,117 acre-feet/year.

Detailed flood insurance rates studies and maps with 100-year floodwater surface elevations have been prepared for six communities participating in the Regular Program. Jefferson and Chambers Counties are participating in the Emergency Program; however, rate studies are underway to provide detailed flood data for the county unincorporated areas. The Beaumont-Port Arthur area, one of the earliest participants in the National Flood Insurance Program, has a level of coverage on insurable structures and contents now amounting to well over $100 million.

The major area needing drainage improvements in the Neches-Trinity Coastal Basin is the Coastal Prairie land-resource area where intensive rice farming occurs. Some of the area under cultivation is satisfactorily drained due to previous improvements. Heavy clay soils and large quantities of water from rainfall and irrigation necessitate use of on-farm drainage improvements. As in most coastal areas where terrain is flat and natural drainage is poorly defined, work will be necessary to provide outlets for collection systems and to improve and maintain the few existing natural outlets. However, drainage necessary for successful agricultural operations and prevention of residential flooding conflicts with natural wetlands preservation in some areas.

Since 1918 within the Neches-Trinity Coastal Basin, more than 0.5 foot of subsidence has occurred in several areas of northern and eastern Jefferson County and in extreme eastern Galveston County on the Bolivar Peninsula. The most subsidence attributed to ground-water withdrawals was about 0.75 foot near the center of the City of Beaumont. Oil, gas, sulfur, and associated saline-water withdrawals have caused more than 15 feet of subsidence in eastern Jefferson County in the Spindletop Dome area. Petroleum and associated saline-water withdrawals have caused more than 3.0 feet of subsidence in the Port Acres area of eastern Jefferson County. Also fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

Major freshwater recreation resources in the Neches-Trinity Coastal Basin include the J.D. Murphree Wildlife Management Area lakes, with approximately 7 thousand surface acres. The Sabine Lake estuary covers a total of 45 square miles. It receives large volumes of fresh water from the Neches and Sabine Rivers, but becomes increasingly saline toward the Gulf.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Neches-Trinity Coastal Basin is projected to increase 61 percent by the year 2030, from the present 203.7 thousand to 327.4 thousand (Table III-7-3). An 18 percent increase to 239.5 thousand is expected from 1980 to the year 2000, and a higher growth rate of 37 percent is projected for the 2000 to 2030 period. Jefferson County's percentage of the Neches-Trinity Coastal Basin is expected to drop from 95 percent in 1980 to 90 percent in the year 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. In 1980, water demands were 31.0 thousand acre-feet. This requirement is projected to increase 12 percent by 2000 in the lowcase projection. By 2030 municipal water requirements are projected to increase an additional 26 to 37 percent; low and high case, respectively. Approximately 95 percent of the basin's 1980 requirement occurs in Zone 1; this predominance of use is expected to continue throughout the planning period.

Industrial

Manufacturing water requirements in 1980 were 78.1 thousand acre-feet in the Neches-Trinity Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water use in the Neches-Trinity Coastal Basin is projected to increase from 3 to 19 percent by the year 2030, from a 1980 use of 78.1 thousand acre-feet to a 2030 requirement of 80.8 to 93.3 thousand acre-feet annually (low and high case, respectively). Virtually all of this growth in manufacturing water requirements is expected to occur in Zone 1 of the basin.

Table III-7-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Neches-Trinity Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			193.0			206.8			223.3			242.0			264.6			300.6
Municipal	5.1	24.2	29.3	0.1	43.7	43.8	0.1	47.9	48.0	.1	51.9	52.0	0.1	56.8	56.9	0.2	64.4	64.6
Manufacturing	1.9	76.1	78.0	1.2	84.9	86.1	1.2	89.8	91.0	1.2	87.8	89.0	1.2	89.7	90.9	1.2	92.1	93.3
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.6	0.3	0.9	0.9	0.2	1.1	1.1	0.2	1.3	1.2	.2	1.4	1.3	0.2	1.5	1.5	0.1	1.6
Irrigation	0.0	362.5	362.5	0.0	244.1	244.1	0.0	213.1	213.1	.0	213.1	213.1	0.0	213.1	213.1	0.0	213.1	213.1
Livestock	0.3	0.1	0.4	0.1	0.4	0.5	0.1	0.5	0.6	.1	.5	.6	0.1	0.5	0.6	0.1	0.5	0.6
Zone Total Water	7.9	463.2	471.1	2.3	373.3	375.6	2.5	351.5	354.0	2.6	353.5	356.1	2.7	360.3	363.0	3.0	370.2	373.2
Zone 2																		
Population			10.7			12.8			16.2			20.4			24.2			26.8
Municipal	1.5	0.2	1.7	2.2	0.5	2.7	2.8	0.8	3.6	3.7	.8	4.5	4.5	0.9	5.4	5.0	0.9	5.9
Manufacturing	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	0.0
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.0	0.5	0.5	0.0	0.5	0.5	0.1	0.4	0.5	.1	.3	.4	0.0	0.3	0.3	0.0	0.2	0.2
Irrigation	0.0	182.4	182.4	0.0	172.8	172.8	0.0	168.4	168.4	.0	168.4	168.4	0.0	168.4	168.4	0.0	168.4	168.4
Livestock	0.2	0.2	0.4	0.1	0.3	0.4	0.1	0.4	0.5	.1	.4	.5	0.1	0.4	0.5	0.1	0.4	0.5
Zone Total Water	1.8	183.3	185.1	2.3	174.1	176.4	3.0	170.0	173.0	3.9	169.9	173.8	4.6	170.0	174.6	5.1	169.9	175.0
BASIN TOTALS																		
Population			203.7			219.6			239.5			262.4			288.8			327.4
Municipal	6.6	24.3	31.0	2.3	44.2	46.5	2.9	48.7	51.6	3.8	52.7	56.5	4.6	57.7	62.3	5.2	65.3	70.5
Manufacturing	2.0	76.1	78.1	0.2	84.9	86.1	1.2	89.8	91.0	1.2	87.8	89.0	1.2	89.7	90.9	1.2	92.1	93.3
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.6	0.8	1.4	0.9	0.7	1.6	1.2	0.6	1.8	1.3	.5	1.8	1.3	0.5	1.8	1.5	0.3	1.8
Irrigation	0.0	544.9	544.9	0.0	416.9	416.9	0.0	381.5	381.5	.0	381.5	381.5	0.0	381.5	381.5	0.0	381.5	381.5
Livestock	0.5	0.3	0.8	0.2	0.7	0.9	0.2	0.9	1.1	.2	.9	1.1	0.2	0.9	1.1	0.2	0.9	1.1
Basin Total Water	9.7	646.5	656.2	4.6	547.4	552.0	5.5	521.5	527.0	6.5	523.4	529.9	7.3	530.3	537.6	8.1	540.1	548.2

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

The rate of increase projected for manufacturing water requirements in the basin is less than the State average (3 to 19 percent for 1980-2030, compared to 178 to 230 percent for the State). Much of the difference is due to the fact that the petroleum refining and chemical industries are expected to significantly improve their water use efficiency through increased recirculation and technological change.

Steam-Electric Power Generation

Currently, there are no steam-electric power plants located in the Neches-Trinity Coastal Basin and none are planned through 2030. Therefore, there is no projected freshwater requirement for steam-electric power generation in this basin. It is possible that a power plant could be located within the basin using saline water as a cooling source. If this occurs, such a plant would also require freshwater for boiler feedwater makeup and sanitary and ground maintenance purposes. Such uses are small when compared to the power plant cooling water requirements. If the plant were a coal-fired plant, significant quantities of freshwater would be required if stackgas scrubbers (based on current technology which requires freshwater for scrubber makeup) were used for sulfur dioxide control.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Neches-Trinity Coastal Basin are projected to decrease from the 1980 level of 544.9 thousand acre-feet by a projected maximum 30 percent by the year 2000 in the high case, and also in the low case. In the year 2030, water requirements in the basin are projected to remain at 381.5 thousand acre-feet annually in both the low and high case, respectively, to irrigate about 119 thousand acres.

Zone 1 is projected to account for about 56 percent of total basin irrigation requirements in 2000 and 2030. Zone 2 is projected to account for about 44 percent of the total.

Livestock

Livestock production is not expected to increase significantly in the basin. It is anticipated that annual livestock water requirements will reach 1.1 thousand acre-feet by 2030 (0.6 thousand acre-feet, Zone 1; 0.5 thousand acre-feet, Zone 2).

Mining

Mining water use in the Neches-Trinity Coastal Basin is projected to increase 29 percent from 1980 to 2030 (from 1.4 thousand to 1.8 thousand acre-feet). Nonmetals mining water use is projected to increase from 622 acre-feet in 1980 to 1.5 thousand acre-feet in 2030, primarily in Zone 1.

Navigation

No navigation facilities are planned in the Neches-Trinity Coastal Basin.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the Neches-Trinity Coastal Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Neches-Trinity Coastal Basin through the year 2030 is

11.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the Neches-Trinity Coastal Basin by decade from 1990 through 2030 is expected to be from 4.6 to 8.1 thousand acre-feet per year (Table III-7-3). The approximate average annual projected ground-water use within the basin is expected to be about 6.4 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

The projected surface-water needs of the Neches-Trinity Coastal Basin can be fully met through the year 2030 (Table III-7-4, Figure III-7-2). In Zone 1 of the basin, the total annual surface-water requirement of 351.9 thousand acre-feet projected in 2030 is proposed to be met through the importation of surface water from the Neches River (Table III-7-5, Figure III-7-3). The surface water would be provided through existing conveyance sys-

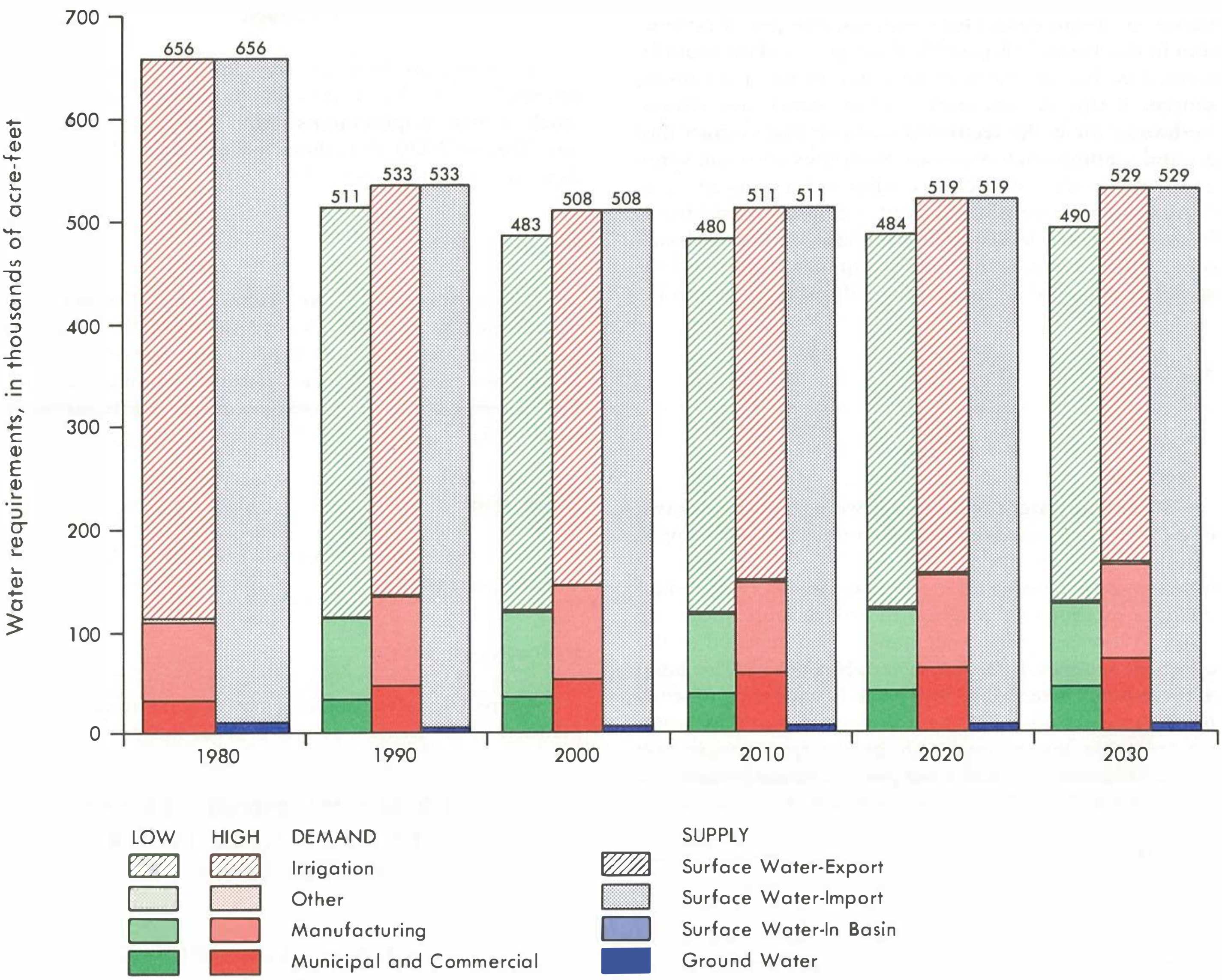

Figure III-7-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches-Trinity Coastal Basin, 1980-2030

Table III-7-4. Water Resources of the Neches-Trinity Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply: In Zone	Water Supply: Intra-Basin	Water Supply: Return Flow	Water Supply: Import	Water Supply: Total	Water Demand: In Zone	Water Demand: Intra-Basin	Water Demand: Export	Water Demand: Total	Surplus or Shortage: M & I	Surplus or Shortage: Irrigation (Shortage)	Surplus or Shortage: Total
1990												
Ground Water	4.6	—	—	—	4.6	4.6	—	—	4.6	.0	.0	.0
Surface Water	.0	—	.0	528.4	528.4	528.4	—	.0	528.4	.0	.0	.0
Total	4.6	—	.0	528.4	533.0	533.0	—	.0	533.0	.0	.0	.0
2000												
Ground Water	5.5	—	—	—	5.5	5.5	—	—	5.5	.0	.0	.0
Surface Water	.0	—	.0	502.4	502.4	502.4	—	.0	502.4	.0	.0	.0
Total	5.5	—	.0	502.4	507.9	507.9	—	.0	507.9	.0	.0	.0
2010												
Ground Water	6.5	—	—	—	6.5	6.5	—	—	6.5	.0	.0	.0
Surface Water	.0	—	.0	504.3	504.3	504.3	—	.0	504.3	.0	.0	.0
Total	6.5	—	.0	504.3	510.8	510.8	—	.0	510.8	.0	.0	.0
2020												
Ground Water	7.3	—	—	—	7.3	7.3	—	—	7.3	.0	.0	.0
Surface Water	.0	—	.0	511.3	511.3	511.3	—	.0	511.3	.0	.0	.0
Total	7.3	—	.0	511.3	518.6	518.6	—	.0	518.6	.0	.0	.0
2030												
Ground Water	8.1	—	—	—	8.1	8.1	—	—	8.1	.0	.0	.0
Surface Water	.0	—	.0	521.1	521.1	521.1	—	.0	521.1	.0	.0	.0
Total	8.1	—	.0	521.1	529.2	529.2	—	.0	529.2	.0	.0	.0

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

Table III-7-5. Water Resources of the Neches-Trinity Coastal Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	2.3	—	—	—	2.3	2.3	—	—	2.3	.0	.0	.0
Surface Water	.0	.0	.0	355.1	355.1	355.1	.0	.0	355.1	.0	.0	.0
Total	2.3	.0	.0	355.1	357.4	357.4	.0	.0	357.4	.0	.0	.0
2000												
Ground Water	2.5	—	—	—	2.5	2.5	—	—	2.5	.0	.0	.0
Surface Water	.0	.0	.0	333.2	333.2	333.2	.0	.0	333.2	.0	.0	.0
Total	2.5	.0	.0	333.2	335.7	335.7	.0	.0	335.7	.0	.0	.0
2010												
Ground Water	2.6	—	—	—	2.6	2.6	—	—	2.6	.0	.0	.0
Surface Water	.0	.0	.0	335.2	335.2	335.2	.0	.0	335.2	.0	.0	.0
Total	2.6	.0	.0	335.2	337.8	337.8	.0	.0	337.8	.0	.0	.0
2020												
Ground Water	2.7	—	—	—	2.7	2.7	—	—	2.7	.0	.0	.0
Surface Water	.0	.0	.0	342.0	342.0	342.0	.0	.0	342.0	.0	.0	.0
Total	2.7	.0	.0	342.0	344.7	344.7	.0	.0	344.7	.0	.0	.0
2030												
Ground Water	3.0	—	—	—	3.0	3.0	—	—	3.0	.0	.0	.0
Surface Water	.0	.0	.0	351.9	351.9	351.9	.0	.0	351.9	.0	.0	.0
Total	3.0	.0	.0	351.9	354.9	354.9	.0	.0	354.9	.0	.0	.0

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
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Export: A transfer of water to another river basin.

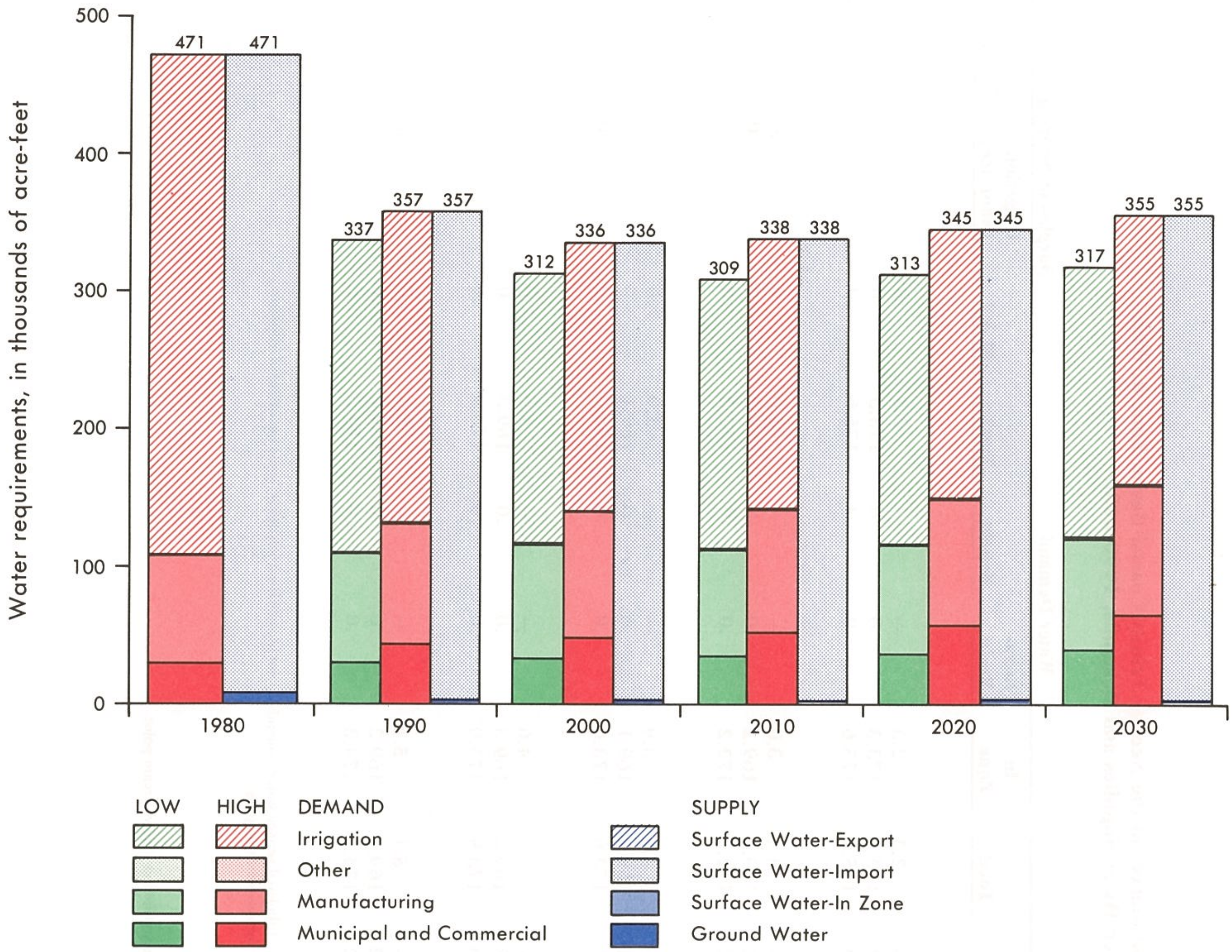

Figure III-7-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches-Trinity Coastal Basin, Zone 1, 1980-2030

tems. In Zone 2, a total surface-water requirement of 169.2 thousand acre-feet per year in 2030 is projected to be fully satisfied through surface-water importation from the Trinity River Basin through existing diversion systems (Table III-7-6, Figure III-7-4).

There are no major reservoirs proposed for this coastal basin. Future surface-water needs in the basin will have to be met through the conveyance of surface waters from the Neches and Trinity River Basins through existing canal systems of the Lower Neches Valley Authority and the Trinity River Authority, respectively.

Water Quality Protection

A water quality management plan for the Neches-Trinity Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Beaumont-Port Arthur-Orange metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Table III-7-6. Water Resources of the Neches-Trinity Coastal Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	2.3	—	—	—	2.3	2.3	—	—	2.3	.0	.0	.0
Surface Water	.0	.0	.0	173.3	173.3	173.3	.0	.0	173.3	.0	.0	.0
Total	2.3	.0	.0	173.3	175.6	175.6	.0	.0	175.6	.0	.0	.0
2000												
Ground Water	3.0	—	—	—	3.0	3.0	—	—	3.0	.0	.0	.0
Surface Water	.0	.0	.0	169.2	169.2	169.2	.0	.0	169.2	.0	.0	.0
Total	3.0	.0	.0	169.2	172.2	172.2	.0	.0	172.2	.0	.0	.0
2010												
Ground Water	3.9	—	—	—	3.9	3.9	—	—	3.9	.0	.0	.0
Surface Water	.0	.0	.0	169.1	169.1	169.1	.0	.0	169.1	.0	.0	.0
Total	3.9	.0	.0	169.1	173.0	173.0	.0	.0	173.0	.0	.0	.0
2020												
Ground Water	4.6	—	—	—	4.6	4.6	—	—	4.6	.0	.0	.0
Surface Water	.0	.0	.0	169.3	169.3	169.3	.0	.0	169.3	.0	.0	.0
Total	4.6	.0	.0	169.3	173.9	173.9	.0	.0	173.9	.0	.0	.0
2030												
Ground Water	5.1	—	—	—	5.1	5.1	—	—	5.1	.0	.0	.0
Surface Water	.0	.0	.0	169.2	169.2	169.2	.0	.0	169.2	.0	.0	.0
Total	5.1	.0	.0	169.2	174.3	174.3	.0	.0	174.3	.0	.0	.0

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $112.5 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Neches-Trinity Coastal Basin with approximately $100.7 million required in Zone 1, while approximately $11.8 million is projected necessary in Zone 2. All costs are in January 1980 dollars and are subject to revision as new data becomes available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for the control of industrial, oil and gas, and agricultural pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Valuable residential, commercial, and industrial developments are subject to hazardous flooding from hurricanes and associated storms in the basin. The Flood Control Act of 1962 authorized the U.S. Army Corps of Engineers to provide protection from hurricane flood tides to Port Arthur and vicinity. The Port Arthur Hurricane-Flood Protection project, begun in 1966, enlarged and strengthened existing levees and floodwalls and provided for 29 miles of new and enlarged earth levees. The project was completed in 1981.

The Taylor Bayou project, now under construction by the Corps of Engineers, provides for 47 miles of channel improvements, construction of a diversion channel and a

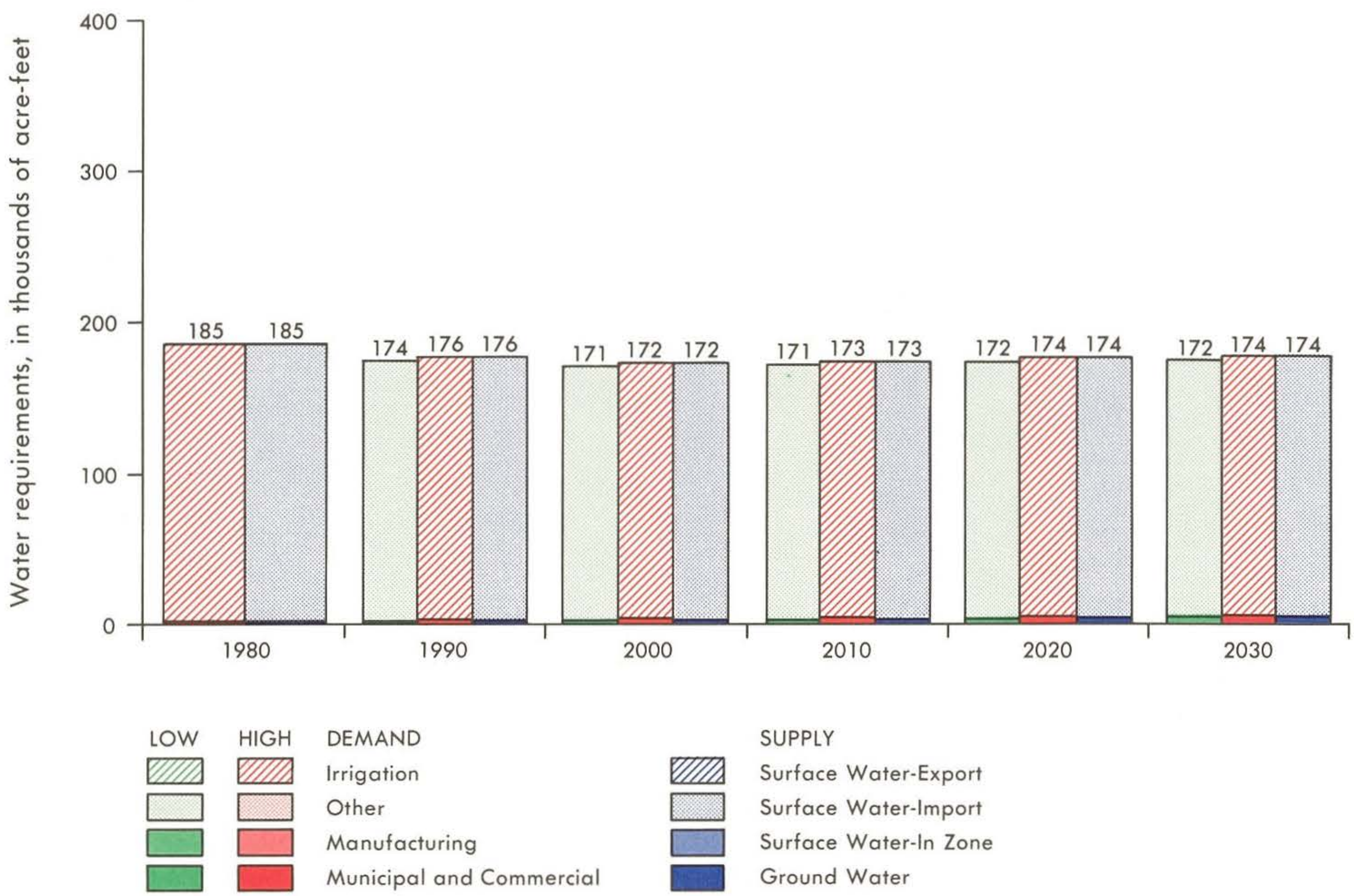

Figure III-7-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Neches-Trinity Coastal Basin, Zone 2, 1980-2030

gated salt-water barrier structure. The project will provide flood protection for parts of the City of Beaumont and will improve agricultural drainage when completed in 1990.

Additional levee and channel improvement projects will be needed locally to provide protection to urban developments, landfills, and sewage treatment facilities. Political subdivisions within the basin must rely heavily on nonstructural flood-plain management such as zoning and flood-plain construction standards to reduce flood damage potential.

There are no U.S. Soil Conservation Service floodwater-retarding structures in the Neches-Trinity Coastal Basin, however, there are about 20 miles of channel improvement work in the basin.

8. TRINITY RIVER BASIN

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8. TRINITY RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Trinity River Basin is bounded on the north by the Red River Basin, on the east by the Sabine and Neches River Basins and the Neches-Trinity Coastal Basin, and on the west by the Brazos and San Jacinto River Basins and the Trinity-San Jacinto Coastal Basin. The West Fork Trinity River heads in southeastern Archer County at an elevation of about 1,200 feet and combines with East Fork, Elm Fork, and Clear Fork, and with Denton, Mountain, and Village Creeks to form the upper Trinity River Basin drainage system. Total basin drainage area is 17,969 square miles, virtually all of which is contributing. For planning purposes, the Trinity River Basin is divided into three zones as shown in Figure III-8-1.

Surface Water

Average annual runoff for the 1941-70 period was 310 acre-feet per square mile for the entire basin, with a range of 153 to 606 acre-feet per square mile from the upper to the lower basin, respectively. During the 1941-70 period, nine of the 11 lowest annual main stem river flows occurred during the 1951-56 and 1962-64 drought years. Annual runoff averaged 114 acre-feet per square mile during 1951-56, while the 1962-64 period runoff averaged 142 acre-feet per square mile. Lowest runoff in 3 consecutive years occurred from 1954 through 1956 and averaged 77 acre-feet per square mile, while the lowest runoff occurred in 1956 when the rate was 53 acre-feet per square mile.

In the upper Trinity River Basin, rolling topography and narrow stream channels, combined with rapid surface runoff during intense thunderstorm activity, produce dangerous flash flooding. These flash floods are common in the small secondary tributaries and upper reaches of primary tributaries and are of short duration; however, high flood peaks and velocities pose serious problems. Extensive urbanization has compounded flood problems in the metropolitan areas due to alteration of drainage patterns which have aggravated storm runoff characteristics.

The middle and lower Trinity River Basin drains all or parts of 14 counties and is characterized by gently rolling to flat terrain with wide, shallow stream channels. Heavy thunderstorm activity and rainfall, often associated with inland movement of tropical weather disturbances, produces slow-moving floods of long duration. Shallow sheet flooding and tidal flooding are also problems in the lower Trinity River Basin. Floods have been particularly damaging to agricultural properties in the lower basin.

The southern extremity of the Trinity River Basin often suffers as well from hurricane-induced surge tides and strong winds, in addition to torrential rains, when a major tropical weather system migrates out of the Gulf of Mexico across the upper coastline. Weather records dating back to 1871 show that the coastal extremity of the Trinity River Basin has been crossed by a hurricane or tropical storm one out of every three years.

The quality of the surface waters of the Trinity River Basin varies widely, from the effluent-dominated, nutrient-rich waters of the main stem below the Dallas-Fort Worth metroplex to the small, clean, headwater streams of the basin. The Trinity River extends some 250 river miles below Dallas and Fort Worth to the headwaters of Livingston Reservoir, and has the poorest water quality in the basin. Water quality in this reach of the river steadily improves going downstream. The river is suitable for all uses in its lower reaches. Several major sewage treatment plants release flow to the river, and during low-flow conditions, the main stem is composed almost entirely of treated effluents from sewage treatment plants. Major sewage treatment plants discharging to the river include Village Creek, and TRA-Central located on the West Fork and Dallas-Central on the main stem of the Trinity River. On the East Fork, Duck Creek sewage treatment plant, just below Ray Hubbard Dam, contributes a significant amount of treated effluent to the river. Texas Municipal Water District sewage treatment plant at Mesquite also makes effluent contributions to the East Fork.

In the headwater reaches of the basin, reservoirs which supply the needs of the metropolitan Fort Worth-Dallas area contain water of excellent quality.

Natural runoff throughout most of the Trinity River Basin is of good quality and is suitable for almost all uses. Runoff generally contains 100 to 250 milligrams per liter (mg/l) of dissolved solids throughout most of the upper basin, and water impounded in existing water supply reservoirs generally contains less than 250 mg/l of dissolved solids. In the main stem of the river near Rosser in southeastern Kaufman County, the discharge-weighted average concentration of dissolved solids is less than 300 mg/l, and the discharge-weighted average concentration near Romayor in northern Liberty County is about 240 mg/l. In

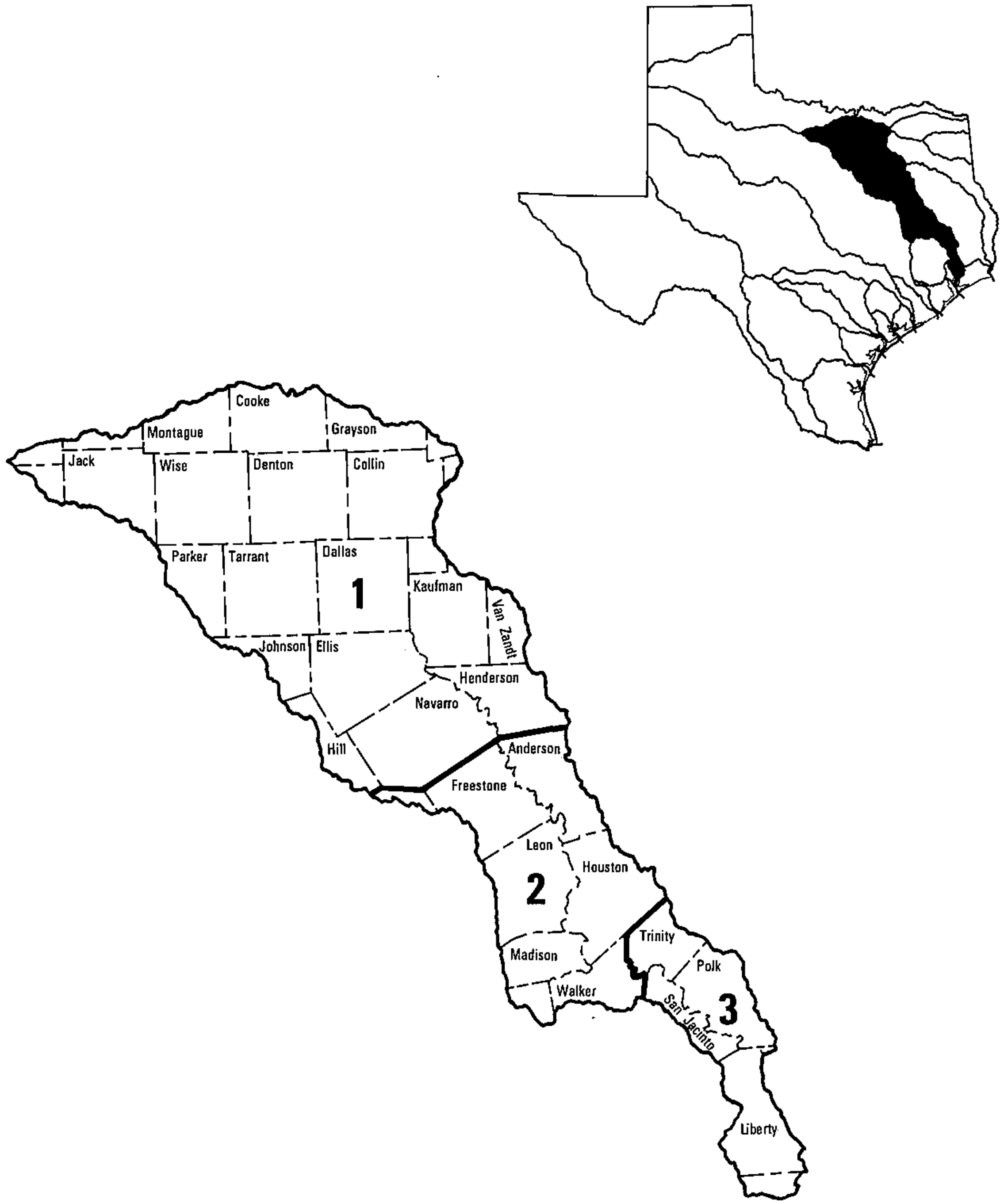

Figure III-8-1. Trinity River Basin and Zones

general, water in the upper part of the basin is harder than water in the lower part of the basin.

Ground Water

Major aquifers in the Trinity River Basin include the Trinity Group, Carrizo-Wilcox, and Gulf Coast. Minor aquifers lying within the basin include the Woodbine, Queen City, Sparta, and Nacatoch.

The Trinity Group Aquifer produces usable-quality ground water in the upper Trinity River Basin. It includes the Paluxy (Antlers), Glen Rose, and Travis Peak (Twin Mountains) Formations. Total thickness of the aquifer ranges from less than 100 to more than 1,200 feet. Yields of large-capacity wells average about 430 gallons per minute (gpm), with wells in some areas yielding more than 2,000 gpm. Water quality ranges from fresh to slightly saline; salinity generally increases with depth.

The Carrizo-Wilcox Aquifer produces usable-quality water in the central part of the Trinity River Basin. It includes the Wilcox Group and the Carrizo Formation of the Claiborne Group. The underlying Wilcox Group consists of interbedded sand, sandstone, sandy shale, shale, and lignite. Aquifer thickness ranges from less than 100 to more than 2,500 feet, with about 50 percent of the thickness being sand. Yields of large-capacity wells average about 420 gpm, with maximum yields of more than 1,000 gpm. The quality of the ground water is generally quite good, but gradually deteriorates downdip. The water ranges from fresh to slightly saline.

The Gulf Coast Aquifer produces usable-quality water in the lower part of the Trinity River Basin. The aquifer includes the Catahoula, Oakville, Fleming, Goliad, Willis, Lissie, and Beaumont Formations, as well as overlying surface deposits of alluvium. This system reaches a maximum thickness of about 3,000 feet, of which about 40 percent is water-bearing sand. Yields of large-capacity wells average 1,500 gpm, but locally wells produce up to 3,400 gpm. Generally, water produced from this aquifer is fresh, but gradually deteriorates in quality downdip and becomes slightly to moderately saline, particularly near the Coast.

The Woodbine Aquifer produces water in the upper part of the Trinity River Basin. Maximum thickness is about 600 feet, with 50 percent commonly consisting of sand. Usable-quality water is produced to a maximum depth of about 2,000 feet. Yields of high-capacity wells average 130 gpm, but locally wells produce as much as 600 gpm. The quality of water produced from the aquifer is relatively poor, exceeding 1,500 mg/l total dissolved solids in most areas. Salinity increases downdip.

The Queen City Aquifer occurs in the middle part of the Trinity River Basin. It ranges from zero to more than 500 feet in thickness, with 60 to 70 percent being sand. Yields of wells are commonly low, generally less than 250 gpm. Water produced from most of this aquifer usually contains less than 500 mg/l total dissolved solids, but quality deteriorates downdip.

The Sparta Aquifer also occurs in the central part of the Trinity River Basin. Thickness ranges up to more than 300 feet, with sand making up about 60 to 70 percent of the total thickness. Yields of large-capacity wells average about 550 gpm, but locally wells produce up to a maximum of approximately 1,200 gpm. Water produced from most of the Sparta Aquifer generally contains less than 500 mg/l total dissolved solids, but water quality deteriorates downdip.

The Nacatoch Aquifer occurs in the upper part of the Trinity River Basin. Thickness ranges from 350 to 500 feet. Yields of high-capacity wells range up to 500 gpm, but generally range from 100 to 200 gpm. Quality of water in the Nacatoch Aquifer ranges from fresh to slightly saline.

During the 1970's, ground-water withdrawals from the Trinity Group Aquifer caused water level declines of 19 to 32 feet per year within the Trinity River Basin. Reductions in artesian pressures that result from lowered water tables significantly increased the potential for saline-water encroachment in Denton, Tarrant, and Dallas Counties. Also, the extremely large regional cone of depression associated with these ground-water withdrawals has probably intercepted the fresh-slightly saline water and slightly saline-moderately saline water interfaces within the aquifer which has probably caused invasion of the fresh and slightly saline waters by the more saline waters. The potential for this condition is greatest in western Kaufman, southeastern Dallas, and eastern Ellis Counties. Similar reductions of artesian pressures within the Woodbine Aquifer has probably caused the same conditions in southwestern Fannin and eastern Ellis Counties within the basin.

Ground waters contained in the shallow water-bearing sands of the Carrizo-Wilcox and Queen City Aquifers within the basin usually have excessive concentrations of iron and low pH (high acidity) values. To alleviate these problems, new wells should be properly cased and cemented from the land surface to at least 150 feet, and properly screened opposite the deepest and most productive freshwater sands encountered below 150 feet. If possible, the ground-water quality in these wells should be closely monitored to detect excessive downward leakage of the poor quality, shallow ground waters due to pumpage of the deeper freshwater sands. Also, due to excessive pumpage, saline-water encroachment may occur from saline water-bearing sands laterally adjacent to or beneath the fresh water-bearing sands of the aquifers. Proper location and again, proper completion of new water wells in these aquifers can effectively control the potential for saline-water encroachment. Locations of new water wells should be as far as possible from the known downdip (coastward) extent of the aquifers. Also, wells should be completed at depths sufficiently above the known base of fresh or slightly saline water-bearing deposits of the Carrizo-Wilcox and Queen City Aquifers.

In southern Liberty and Chambers Counties the fresh-water deposits of the Gulf Coast Aquifer are surrounded by deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled in these coastal areas by proper well location, completion, and pumpage.

Population and Economic Development

The population of the Trinity River Basin was reported at 3.2 million in 1980. Of this basin total, 75 percent reside in Dallas and Tarrant Counties. Dallas, with a 1980 population of 904.1 thousand, is the largest city in the Trinity River Basin followed by Fort Worth, with a population of 385.1 thousand. Together, these two cities comprise 40 percent of the total basin population. Other basin cities with a 1980 population of 50,000 or more are the Cities of Arlington, Garland, Irving, Richardson, Plano, Grand Prairie, and Mesquite, which collectively comprise 22 percent of the basin population.

The principal population center of the Trinity River Basin, the Dallas-Fort Worth metroplex, ranks much higher than the State in population density, percent urban, and median family income.

The economy of the Trinity River Basin is as diverse as the geography and demography of the basin. The Dallas-Tarrant County area is a leading center of insurance, banking, transportation, and manufacturing. The economy of the Dallas-Fort Worth area includes large federal defense-related manufacturing and services industries. Additional transportation-related economic benefits are derived from the Dallas-Fort Worth Regional Airport, one of the nation's largest air transportation facilities. Recreation and tourism round out the metroplex economy, with both cities serving as centers for conventions, trade shows, and professional meetings. The remainder of the basin economy is based on extensive agribusiness.

Water Use

Municipal water use in the Trinity River Basin totaled 675.5 thousand acre-feet in 1980, over 96 percent of which occurred in Zone 1. Dallas County used 53 percent and Tarrant County used 28 percent of the total basin use. Although the basin contains widespread manufacturing activities, most of these industries currently do not require large quantities of water per unit of product. Freshwater used by manufacturing industries in 1980 totaled 97.6 thousand acre-feet. Almost all of the manufacturing water use in the basin was obtained from surface-water sources, most of which was consumed in Zone 1.

In 1980, there was 7,360 megawatts of steam-electric generating capacity in the Trinity River Basin. Most of this capacity (6,202 megawatts) was located in Zone 1. A total of 1.1 thousand acre-feet of ground water was withdrawn from the Trinity Group Aquifer and 100 acre-feet from the Carrizo-Wilcox Aquifer for power plant production. Also an estimated 45.9 thousand acre-feet of fresh surface water was consumed (including 24.1 thousand acre-feet of estimated net adjustment evaporation). In addition, about 320 acre-feet of treated municipal effluent was used for cooling purposes. There were no power plants in Zone 3 of the basin in 1980.

In 1980, a total of 79.9 thousand acre-feet of water was used for irrigating 34.4 thousand acres in the Trinity River Basin, predominantly in the coastal rice-producing area. Almost 79 percent of all the water used for irrigation in 1980 was supplied by surface sources. Development of ground water for irrigation is largely in the lower part of the basin, using water from the Gulf Coast Aquifer.

Estimated freshwater use for mining purposes in the Trinity River Basin totaled 17.3 thousand acre-feet in 1980. Of this total, Zone 1 accounted for 8.8 thousand acre-feet of withdrawals, or approximately 51 percent of the total freshwater use. The most intensive use of water is concentrated in the mining of nonmetals, particularly in Wise, Dallas, and Liberty Counties.

Livestock water use in the Trinity River Basin in 1980 totaled 22.4 thousand acre-feet. Of this total, it is estimated that ground water provided 7.9 thousand acre-feet and surface water 14.5 thousand acre-feet. In 1980, a total of 15.7 thousand acre-feet was used for livestock in Zone 1 and 6.7 thousand acre-feet in Zones 2 and 3.

The Trinity River is presently navigable from Anahuac Channel upstream to Liberty at river mile 41.4. The Channel to Liberty project which currently has an authorized depth of six feet was completed in 1925 and was maintained until 1940. Maintenance of the project was resumed in 1968. There are no regulated freshwater requirements for this navigation channel other than that provided by flows released from upstream reservoirs for other downstream uses.

There are currently no hydroelectric power generation facilities in the Trinity River Basin.

Return Flows

In 1980, return flows from all municipalities and manufacturing industries in the basin totaled 464.6 thousand acre-feet. Of these return flows, 97 percent occurred in Zone 1, which includes the Dallas-Fort Worth area. These return flows constitute a significant part of the total streamflow in the main stem below these two cities, particularly during low-flow periods.

It is estimated that 15 to 20 percent of the ground water applied in the upland irrigation areas of Zones 1 and 2 ultimately returns to streams as return flows, and therefore potentially can be captured for reuse. Most of the surface water supplied irrigation in the upper part of the basin is by direct diversion to the flood plains along the streams. In these areas, return flows amount to as much as 20 to 30 percent of the water applied. A total of 750 acre-feet of agricultural return flows is estimated to occur annually in the upper part of the basin.

Practically all of the irrigation in Zone 3 is for rice production. Return flows of approximately 40 percent of the water applied, or 23.4 thousand acre-feet annually, are returned to streams and bayous near the Coast—most of which is not recoverable for reuse.

Current Ground-Water Development

In 1980, approximately 116.3 thousand acre-feet of ground water was used in the Trinity River Basin. Of this amount, 75.9 thousand acre-feet was used in Zone 1, 14.3 thousand acre-feet in Zone 2, and 26.1 thousand acre-feet in Zone 3. Ground-water use in Zone 1 was about 77 percent from the Trinity Group Aquifer, 16 percent from the Woodbine Aquifer, and 4 percent from the Carrizo-Wilcox Aquifer. Use in Zone 2 was about 31 percent from the Gulf Coast Aquifer, 29 percent from the Carrizo-Wilcox Aquifer, 15 percent from the Sparta Aquifer, and 13 percent from the Queen City Aquifer. Ninety-six percent of the ground-water use in Zone 3 was from the Gulf Coast Aquifer.

Of the 116.3 thousand acre-feet of ground water used in the basin, approximately 82.8 thousand acre-feet or 71 percent was used for municipal purposes, and 16.8 thousand acre-feet or 14 percent was used for irrigation purposes.

In 1980, small to large overdrafts of ground water from the Trinity Group Aquifer occurred within Zone 1 in Cooke, Dallas, Denton, Hood, Johnson, and Tarrant Counties, mainly for municipal purposes. Also, overdrafts occurred in Zone 1 in Ellis, Fannin, and Grayson Counties for municipal purposes from the Woodbine Aquifer. No ground-water overdrafts occurred in Zone 2 of the basin in 1980. In Zone 3 a significant overdraft occurred in Chambers County from the Gulf Coast Aquifer, mainly for mining purposes.

Current Surface-Water Development

There are 27 major reservoirs and four major projects currently under construction in the Trinity River Basin. Of the 27 reservoirs, 23 are located in Zone 1, two in Zone 2, and two in Zone 3. Of the four reservoirs under construction, three projects (Ray Roberts, Lakeview, and Richland Creek) are in Zone 1, with the remaining reservoir, Lake Wallisville, in Zone 3. In Zone 1, six projects including Benbrook, Grapevine, Lewisville, Lavon, Bardwell, and Navarro Mills, were constructed by the U.S. Army Corps of Engineers for flood-control and water-supply purposes. Total allocated flood-control storage in these projects amounts to about 1.37 million acre-feet. Dallas, Denton, Fort Worth, Grapevine, the North Texas Municipal Water District, the Trinity River Authority, and other cities obtain water from these reservoirs through acquisition of storage and/or through contractual arrangements. Locally owned and operated municipal lakes include Eagle Mountain, Amon G. Carter, Arlington, Halbert, Waxahachie, Worth, Weatherford, Terrell, White Rock, Ray Hubbard, Cedar Creek, and Bridgeport. Mountain Creek and North Lakes, owned by Dallas Power and Light Company, and Lake Trinidad and Forest Grove Reservoir, owned by Texas Power and Light Company, are used solely for supplying cooling water for steam-electric plants. Kiowa, owned by Lake Kiowa, Inc., is used solely for recreational purposes.

In Zone 2, most of the smaller public water systems and a significant portion of the manufacturing water demand is supplied by ground water. There are two major reservoirs in Zone 2, Houston County Reservoir and Lake Fairfield. Houston County Reservoir, owned by Houston County WCID No. 1, supplies the Cities of Crockett, Lovelady, and Grapeland. Lake Fairfield, owned by Texas Utilities, Inc., supplies water for cooling purposes at its Big Brown steam-electric power plant in central Freestone County. The City of Mexia, in Limestone County, is supplied from Lake Mexia on the Navasota River in the adjacent Brazos River Basin.

In 1980, municipal and manufacturing water requirements in Zone 3 were supplied totally by ground water, the principal use of surface water being for irrigation in the lower part of the basin. Lake Livingston, a joint project of the Trinity River Authority and the City of Houston, was completed in 1968 and is presently capable of providing a dependable yield of about 1.25 million acre-feet annually under existing conditions of upstream development. The Trinity River Authority holds rights to 30 percent of the yield and the City of Houston the remaining 70 percent.

Lake Anahuac, owned by the Chambers-Liberty Counties Navigation District, will constitute a future municipal water supply for the City of Anahuac, although its principal purpose will continue to be a water supply and regulating facility of the Chambers-Liberty Counties Navigation District's canal system supplying irrigation water for the Lower Trinity River Basin and Neches-Trinity Coastal Basin.

The Wallisville Lake project, authorized for construction by Congress, was nearing completion when construction was halted by order of the Federal District Court in 1973 subsequent to litigation filed under the National Environmental Policy Act of 1969 because of inadequacies in the project's Environmental Impact Statement. The Fifth Circuit Court of Appeals broadly reversed and remanded the case in 1974. The project would provide an initial dependable yield of approximately 28.6 thousand acre-feet annually and, most importantly, would serve as a salt-water barrier to protect the major upstream municipal, industrial, and irrigation diversion systems from salt-water intrusion. A 1979 Corps of Engineers Report estimated that about 200 thousand acre-feet of Lake Livingston yield currently required to combat saltwater intrusion could be made available for water supply. In accordance with provisions of the court order, a supplement to the Environmental Impact Statement on the Wallisville Lake project was prepared by the Corps of Engineers and is currently being reviewed in the Office of the Chief of Engineers in Washington, D.C.

The Coastal Industrial Water Authority (CIWA), created in 1967 by the 60th Texas Legislature, has completed construction of the principal components of a major conveyance and distribution system designed to ultimately convey an average of about 1.4 million acre-feet of water annually from the Trinity River to the Trinity-San Jacinto Coastal Basin and San Jacinto River Basin. Initial deliveries began in 1974 to major industrial plants in southwest Chambers County. Trinity River supplies delivered by the CIWA facility are derived from the City of Houston's share of storage in Lake Livingston, Wallisville Lake (when completed), and water rights associated with the former Southern Canal Company canal system now owned by the City of Houston.

Water Rights

The total quantity of surface water authorized or claimed for diversion and use in the Trinity River Basin was 5,283,841 acre-feet as of December 31, 1983 (Table III-8-1). Authorizations and claims for municipal use amounted to 2,882,134 acre-feet, or 54.7 percent of the basin total (Table III-8-2). Zone 1 has the largest quantity of authorized and claimed water in the basin, with 3,356,267 acre-feet or 63.5 percent of the basin total (Table III-8-2).

Table III-8-1. Authorized or Claimed Amount of Water, by Type of Right, Trinity River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	281	3,242,153
Claims	268	36,790
Certified Filings	8	199,138
Certificates of Adjudication	110	1,805,760
Total Authorizations and Claims	667	5,283,841

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Water Quality

The Trinity River in the vicinity of the Dallas-Fort Worth metropolitan area suffers from pollution as indicated by both chemical and bacteriological data. Treated municipal effluent from the Dallas-Fort Worth metroplex frequently comprises most of the streamflow of the Trinity River downstream from the metropolitan area. Poor water quality conditions occur in the West Fork from Fort Worth to Dallas and in the East Fork below Lake Ray Hubbard Dam to the confluence with the main stem of the Trinity River. Although the quality of the river improves downstream, water quality problems occur all the way downstream to Lake Livingston.

Because of water quality problems, much of the main stem of the Trinity River, as well as portions of the West Fork and East Fork, are normally unsuitable for contact

Table III-8-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Trinity River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Total
Municipal	69	2,160,832	214,355	506,947	2,882,134
Industrial	36	966,237	25,100	760,150	1,751,487
Irrigation	424	188,715	20,994	364,415	574,124
Mining	10	11,765	160	18,000	29,925
Recreation	164	27,169	11,686	5,767	44,622
Other	12	1,549	0	0	1,549
Total	667[1]	3,356,267	272,295	1,655,279	5,283,841

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

and noncontact recreation, domestic water supply, and industrial use (without pretreatment). Downstream, the headwaters of Lake Livingston exhibit pollutant loadings from the main stem in the form of occasional low dissolved oxygen concentrations and high fecal coliform counts. Excessive aquatic growth may be related to high nutrient concentrations contributed from upstream. Algal blooms and excessive growth of water hyacinth and duckweed are examples of specific water quality problems resulting from over-nourishment of lake waters by incoming pollutants. The main pool of Lake Livingston and the other lakes of the basin have only occasional water quality problems, however. The river is designated suitable for fish and wildlife below Trinidad, and Lake Livingston is designated suitable for all uses from its headwaters to Livingston Dam.

Flooding, Drainage, and Subsidence

Due to the intensive use of flood-plain lands within the Trinity River Basin, the damage potential from major floods is extremely high. Since 1953, federal agencies have investigated 23 major floods in the basin but many floods with localized damages were not recorded. Agricultural interests have suffered the most from damaging floods, incurring an estimated $80.3 million in damages. Nonagricultural interests have incurred at least $19.7 million.

The Federal Emergency Management Agency has designated 204 cities within the Trinity River Basin as having one or more potential flood-prone areas within their respective boundaries. Identification and mapping of these designated areas continues at a rapid pace with the Federal Insurance Administration striving to complete 100-year flood elevation/insurance rate studies for the more critical areas of the State by 1985. To date, 51 of the designated cities are participants in the Emergency Phase of the National Flood Insurance Program. Seventy-three cities are participants in the regular program. As more communities enter the program, and future rate studies are completed, a comprehensive basin-wide standard for flood plain nonstructural alternatives will emerge.

Inadequate drainage is a problem in the Trinity River flood plain and many principal tributaries. Areas underlain by heavy clay soils which have low permeability and are subjected to frequent inundation are wetland areas. Blockage of outlets is locally caused by natural levees such as old river channels, debris, and sediment. Drainage outlets are also blocked in some areas by flood-control levees, and lack of maintenance of interior drainage systems has led to loss of potential croplands.

A large percentage of slowly drained cultivated land is found in the rice belt region of the Coast Prairie land resource area. The flat surface of the prairie has a poorly defined natural drainage system of small channels and shallow interconnected depressions. During periods of heavy rainfall and upstream runoff, inland areas are often inundated for considerable periods.

Land subsidence is a potential problem in Liberty and Chambers Counties within the Trinity River Basin. Part of the area of subsidence primarily caused by clay compaction due to ground-water withdrawals in the Houston-Galveston region occurs in southwestern Liberty and western Chambers Counties. Approximately 1.0 to 2.8 feet of subsidence has occurred in these areas since 1906. Subsidence greater than 15 feet has been reported to have occurred at the Moss Bluff Salt Dome in southern Liberty and northern Chambers Counties. This subsidence was caused by extractions of sulfur associated with the salt dome. Fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

Reservoirs within the Trinity River Basin provide approximately 257.0 thousand surface acres of water available for recreational purposes. This is over 17 percent of the State total surface-water area. Reservoirs located in Zone 1 account for 63 percent of the total basin flat-water surface area, with Zone 3 and Zone 2 having approximately 35 percent and 2 percent, respectively. Lake Livingston, located in Zone 3, provides over 32 percent of the flat-water surface area available for recreational opportunities in the basin. Lakes Lewisville and Grapevine, both located in the Dallas-Fort Worth metroplex area and operated by the Corps of Engineers, had a recorded recreation use of more than 10.4 million visits by water-oriented recreationists during 1980. An additional 6.4 million visits by recreationists were recorded during 1980 at other reservoirs operated by the Corps of Engineers within the basin.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Trinity River Basin is projected to more than double by the year 2030, from the present 3.2 million to over 6.8 million. A 42 percent increase, to 4.6 million, is projected between 1980 and the year 2000, and an even larger growth of 50 percent is anticipated from 2000 to 2030 (Table III-8-3).

The Dallas County population is projected to grow from 1.5 million to almost 3.0 million, but its percentage of Trinity River Basin population decreases from 48 percent to 42 percent. The anticipated growth for Tarrant County is from 860.9 thousand in 1980 to 1.4 million in 2030. Denton County population is expected to increase over fourfold, from 143.1 thousand in 1980 to 624.5 thousand in 2030. The Denton County percentage of in-basin population consequently increases from 4.5 percent to 9.1 percent. The Trinity River Basin is anticipated to decrease its percent of State population from 23 percent in 1980 to 20 percent in 2030.

Water Requirements

Municipal

Municipal water requirements were projected for two cases of future growth based on population changes and per capita water use. Water requirements in 1980 for the Trinity River Basin were 675.5 thousand acre-feet; over 96 percent of use occurred in Zone 1. From 1980 to 2030, municipal water requirements are projected to increase from 49 to 138 percent, low and high case, respectively. This projection represents 2 to 20 percent of total municipal requirements for the State in year 2030. Zone 1 is estimated to have almost 95 percent of total basin use in year 2000.

Industrial

Manufacturing water use in the Trinity River Basin for 1980 was 97.6 thousand acre-feet. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections. Total basin use is projected to increase threefold from 1980 to 2030. Zone 1, which includes the Dallas-Fort Worth metroplex, originated almost 99.0 percent of the basin manufacturing water requirements in 1980, and is expected to account for almost the same percentage in 2030.

By 2030, principal industrial water users in Dallas County are projected to be manufacturers of soap, cleaners and toilet goods, electronic components and accessories, and miscellaneous chemical products.

Steam-Electric Power Generation

Steam-electric power generation water requirements are expected to grow rapidly in the Trinity River Basin. By the year 2000, water consumption could more than triple if electric power demand growth rates predicted by the electric power generating industry materialize. Over 68 percent of the water use in 1980 occurred in Zone 1 and the remaining 32 percent in Zone 2. The presence of extensive near-surface lignite deposits in the lower part of Zone 1 and throughout Zone 2 could stimulate additional growth.

Water requirements for steam-electric power generation are projected to range from 84.1 to 98.6 thousand acre-feet by year 2000, and from 151.5 to 211.0 thousand acre-feet in 2030 (low and high case, respectively). Zone 1 is projected to require 60 percent of the total basin need for power generation in 2030.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that

Table III-8-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Trinity River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			3,045.5			3,694.2			4,286.6			4,964.5			5,676.4			6,411.2
Municipal	62.6	588.4	651.0	38.3	830.6	868.9	39.5	980.8	1,020.3	40.5	1,137.7	1,178.2	42.1	1,301.8	1,343.9	40.5	1,474.0	1,514.5
Manufacturing	5.4	90.9	96.3	1.6	145.7	147.3	1.6	206.8	208.4	1.6	272.2	273.8	1.6	350.8	352.4	1.2	447.0	448.2
Steam Electric	1.1	31.4	32.5	0.0	52.5	52.5	.0	59.5	59.5	.0	81.6	81.6	0.0	103.8	103.8	0.0	126.0	126.0
Mining	0.6	8.2	8.8	0.8	9.7	10.5	.6	11.6	12.2	.5	13.4	13.9	0.4	15.3	15.7	0.3	17.1	17.4
Irrigation	1.3	2.9	4.2	2.9	4.7	7.6	2.9	4.7	7.6	2.9	4.8	7.7	2.9	4.8	7.7	2.1	5.6	7.7
Livestock	4.9	10.8	15.7	3.3	15.1	18.4	2.8	18.4	21.2	2.8	18.4	21.2	2.4	18.8	21.2	2.0	19.2	21.2
Zone Total Water	75.9	732.6	808.5	46.9	1,058.3	105.2	47.4	1,281.8	1,329.2	48.3	1,528.1	1,576.4	49.4	1,795.3	1,844.7	46.1	2,088.9	2,135.0
Zone 2																		
Population			103.3			132.5			152.5			173.0			198.5			224.8
Municipal	11.3	4.1	15.4	13.1	14.7	27.8	15.2	17.7	32.9	16.9	20.5	37.4	19.3	23.5	42.8	21.8	26.6	48.4
Manufacturing	0.2	0.9	1.1	1.4	0.3	1.7	1.4	0.9	2.3	1.4	1.6	3.0	1.5	2.3	3.8	1.5	3.4	4.9
Steam Electric	0.1	14.8	14.9	0.0	14.9	14.9	0.0	31.6	31.6	0.0	42.8	42.8	0.0	53.9	53.9	0.0	65.0	65.0
Mining	0.1	0.0	0.1	0.1	0.0	0.1	0.1	10.1	10.2	0.1	21.9	22.0	0.1	33.7	33.8	0.0	35.6	35.6
Irrigation	0.0	3.7	3.7	0.0	2.7	2.7	0.0	2.7	2.7	0.0	2.7	2.7	0.0	2.7	2.7	0.0	2.7	2.7
Livestock	2.6	3.2	5.8	2.1	4.8	6.9	1.7	6.2	7.9	2.1	5.8	7.9	2.1	5.8	7.9	2.0	5.9	7.9
Zone Total Water	14.3	26.7	41.0	16.7	37.4	54.1	18.4	69.2	87.6	20.5	95.3	115.8	23.0	121.9	144.9	25.3	139.2	164.5
Zone 3																		
Population			67.2			93.8			122.5			151.9			177.0			207.7
Municipal	8.9	0.2	9.1	10.5	8.5	19.0	9.6	15.7	25.3	10.3	21.0	31.3	10.9	25.4	36.31	11.4	31.1	42.5
Manufacturing	0.1	0.1	0.2	0.2	0.0	0.2	0.3	0.0	0.3	0.3	0.0	0.3	0.4	0.0	0.4	0.4	0.0	0.4
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5	7.5	0.0	11.7	11.7	0.0	15.8	15.8	0.0	20.0	20.0
Mining	1.2	7.2	8.4	0.0	9.8	9.8	0.1	11.1	11.2	0.1	15.9	16.0	0.0	20.8	20.8	0.0	25.6	25.6
Irrigation	15.5	56.5	72.0	13.0	53.2	66.2	13.0	51.6	64.6	13.0	51.6	64.6	13.0	51.6	64.6	13.0	51.6	64.6
Livestock	0.4	0.5	0.9	0.1	0.9	1.0	0.1	1.1	1.2	0.1	1.1	1.2	0.1	1.1	1.2	0.1	1.1	1.2
Zone Total Water	26.1	64.5	90.6	23.8	72.4	96.2	23.1	87.0	110.1	23.8	101.3	125.1	24.4	114.7	139.1	24.9	129.4	154.3
BASIN TOTALS																		
Population			3,216.0			3,920.5			4,561.6			5,289.4			6,051.9			6,843.7
Municipal	82.8	592.7	675.5	61.9	853.8	915.7	64.3	1,014.2	1,078.5	67.7	1,179.2	1,246.9	72.3	1,350.7	1,423.0	73.7	1,531.7	1,605.4
Manufacturing	5.7	91.9	97.6	3.1	146.0	149.2	3.3	207.7	211.0	3.3	273.8	277.1	3.5	353.1	356.6	3.1	450.4	453.5
Steam Electric	1.2	46.2	47.4	0.0	67.4	67.4	0.0	98.6	98.6	.0	136.1	136.1	0.0	173.5	173.5	0.0	211.0	211.0
Mining	1.9	15.4	17.3	0.9	19.5	20.4	0.8	32.8	33.6	.7	51.2	51.9	0.5	69.8	70.3	0.3	78.3	78.6
Irrigation	16.8	63.1	79.9	15.9	60.6	76.5	15.9	59.0	74.9	15.9	59.1	75.0	15.9	59.1	75.0	15.1	59.9	75.0
Livestock	7.9	14.5	22.4	5.5	20.8	26.3	4.6	25.7	30.3	5.0	25.3	30.3	4.6	25.7	30.3	4.1	26.2	30.3
Basin Total Water	116.3	823.8	940.1	87.4	1,168.1	1,255.5	88.9	1,438.0	1,526.9	92.6	1,724.7	1,817.3	96.8	2,031.9	2,128.7	96.3	2,357.5	2,453.8

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Trinity River Basin are projected to decrease from the 1980 level of 79.9 thousand acre-feet by a projected maximum six percent by the year 2000 in the high case, decreasing about seven percent in the low case. In the year 2030, water requirements in the basin are projected to remain about 74.2 and 75.0 thousand acre-feet annually, in the low and high case, respectively, to irrigate about 34.4 thousand acres.

Zone 3 is projected to account for about 86 percent of total basin irrigation requirements in 2000 and 2030. Zone 1 is projected to account for about 10 percent of the total with Zone 2 accounting for only four percent of the total.

Livestock

Livestock water requirements within the basin in 1980 were 22.4 thousand acre-feet. By 2030, an estimated 30.3 thousand acre-feet of water will be required to satisfy livestock needs in the basin annually. Zone 1 has the greatest water demand, 70 percent of the total basin livestock water needs.

Mining

Mining water use in the Trinity River Basin is projected to increase from 17.3 thousand acre-feet in 1980 to 78.6 thousand acre-feet in 2030. The majority of the Trinity River Basin mining water is used in nonmetal production and the remainder in the secondary recovery of crude petroleum and natural gas. While nonmetal water use accounted for 80 percent of the basin total 1980 mining water requirements, by 2030 over 33.2 thousand acre-feet, or 42 percent of the basin total mining water requirements, is expected to be used in mining nonmetals, primarily in the Dallas-Fort Worth area. Water requirements for the secondary recovery of crude petroleum and natural gas in the Trinity River Basin amounted to 11.2 thousand acre-feet in 1980 and are expected to decrease to a little over 1.3 thousand acre-feet by 2030. Synfuels will require 45.4 thousand acre-feet by 2030, 58 percent of the total basin requirement.

Navigation

There are no anticipated additional water requirements for navigation other than a last lockage requirement of 67.0 thousand acre-feet annually if the multipurpose channel component of the Trinity River project becomes a reality.

Hydroelectric Power

The installation of a 60 megawatt unit at Lake Livingston is under consideration.

Estuarine Freshwater Inflows

The Trinity River discharges into the Trinity-San Jacinto estuary. Analysis of inflows sufficient to provide salinities within acceptable limits for maintaining the viability of estuarine-dependent fishery species, and to provide marsh inundation, yields an estimate of approximately 3.17 million acre-feet per year of gaged inflows from the Trinity River Basin for the Subsistence Alternative (Table III-8-4). Estimated gaged inflow needs from the Trinity River to maintain commercial fish and shellfish harvests at levels equal to or greater than their average for the 1962 through 1976 period amounts to 3.19 million acre-feet per year for the Fisheries Harvest Maintenance Alternative (Table III-8-4). The Fisheries Harvest Enhancement Alternative, which considers maximizing the offshore commercial shrimp harvest for the offshore fishing area (designated as Gulf Area No. 18) adjacent to the estuary, would require an estimated 3.18 million acre-feet of gaged inflow annually from the Trinity River Basin (Table III-8-4). The estimated annual inflow from the ungaged portion of the Trinity River Basin totals approximately 414 thousand acre-feet for each of the above three alternatives. The gaged inflow from the Trinity River Basin necessary to maintain the short-term viability limits of salinity is estimated to be 423 thousand acre-feet per year for the Biotic Species Viability Alternative (Table III-8-4).

Table III-8-4. Gaged River Inflow Needs of the Trinity-San Jacinto Estuary From the Trinity River Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Trinity River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Shrimp Harvest Enhancement	Biotic Species Viability
January	96.1	96.1	96.1	30.2
February	97.1	97.1	97.1	29.3
March	81.4	81.4	81.4	25.2
April	691.2	691.2	691.2	51.1
May	702.2	702.2	702.2	46.7
June	429.9	429.9	429.9	38.7
July	56.5	56.5	56.5	18.7
August	59.0	59.0	69.4	21.7
September	70.2	70.2	70.2	49.9
October	670.2	670.2	670.2	47.6
November	94.8	114.2	94.8	29.2
December	119.1	119.1	119.1	34.8
Annual	3,167.7	3,187.1	3,178.1	423.1

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Gaged streamflow of Trinity River at Romayor.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Trinity River Basin to the year 2030 is 257.9 thousand acre-feet with the following amounts annually available by aquifer: 83.0 thousand acre-feet from the Carrizo-Wilcox Aquifer, 61.4 thousand acre-feet from the Gulf Coast Aquifer, 52.4 thousand acre-feet from the Trinity Group Aquifer, 35.0 thousand acre-feet from the Sparta Aquifer, 11.1 thousand acre-feet from the Woodbine Aquifer, and 15.0 thousand acre-feet from the Queen City Aquifer. Since the ground water available from the Queen City Aquifer within the basin has high concentrations of iron and high acidity (low pH), it should not be considered a suitable source of water for municipal and most manufacturing purposes. However, Queen City ground water may be considered to be suitable for irrigation, steam-electric power generation (cooling), mining, and livestock watering purposes. In the year 2030, the yields of the Carrizo-Wilcox Aquifer and the Trinity Group Aquifer within the basin would be reduced to their average annual effective recharge rates of 79.0 and 45.5 thousand acre-feet per year, respectively. These reductions decrease the total ground-water availability within the basin in 2030 to 247.0 thousand acre-feet.

The projected annual ground-water use within the Trinity River Basin by decade from 1990 through 2030 is expected to be from 87.4 to 96.8 thousand acre-feet per year (Table III-8-3). The approximate average annual projected ground-water use within the basin is expected to be about 92.5 thousand acre-feet per year. Of the 92.5 thousand acre-feet of average annual projected use, about 42 percent is expected to be from the Trinity Group Aquifer, about 28 percent from the Gulf Coast Aquifer, about 14 percent from the Carrizo-Wilcox Aquifer, about 7 percent from the Woodbine Aquifer, and 4 percent from the Sparta Aquifer.

Surface-Water Availability and Proposed Development

Projected surface-water needs in the Trinity River Basin can be fully met from existing and potentially developable water supplies through the year 2030, except for minor irrigation shortages (Table III-8-5, Figure III-8-2).

Table III-8-5. Water Resources of the Trinity River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	87.4	—	—	—	87.4	87.4	—	—	87.4	.0	.0	.0
Surface Water	2065.3	—	644.4	474.4	3184.1	1114.8	—	999.2	2114.0	1072.4	(2.3)	1070.1
Total	2152.7	—	644.4	474.4	3271.5	1202.2	—	999.2	2201.4	1072.4	(2.3)	1070.1
2000												
Ground Water	88.9	—	—	—	88.9	88.9	—	—	88.9	.0	.0	.0
Surface Water	2024.6	—	776.2	566.6	3367.4	1373.3	—	1178.0	2551.3	818.4	(2.3)	816.1
Total	2113.5	—	776.2	566.6	3456.3	1462.2	—	1178.0	2640.2	818.4	(2.3)	816.1
2010												
Ground Water	92.6	—	—	—	92.6	92.6	—	—	92.6	.0	.0	.0
Surface Water	1959.3	—	918.2	591.6	3469.1	1654.5	—	1180.2	2834.7	636.7	(2.3)	634.4
Total	2051.9	—	918.2	591.6	3561.7	1747.1	—	1180.2	2927.3	636.7	(2.3)	634.4
2020												
Ground Water	96.8	—	—	—	96.8	96.8	—	—	96.8	.0	.0	.0
Surface Water	1939.1	—	1071.7	748.1	3758.9	1955.0	—	1211.8	3166.8	594.4	(2.3)	592.1
Total	2035.9	—	1071.7	748.1	3855.7	2051.8	—	1211.8	3263.6	594.4	(2.3)	592.1
2030												
Ground Water	96.3	—	—	—	96.3	96.3	—	—	96.3	.0	.0	.0
Surface Water	1921.1	—	1238.8	1024.0	4183.9	2273.0	—	1224.3	3497.3	689.7	(3.1)	686.6
Total	2017.4	—	1238.8	1024.0	4280.2	2369.3	—	1224.3	3593.6	689.7	(3.1)	686.6

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
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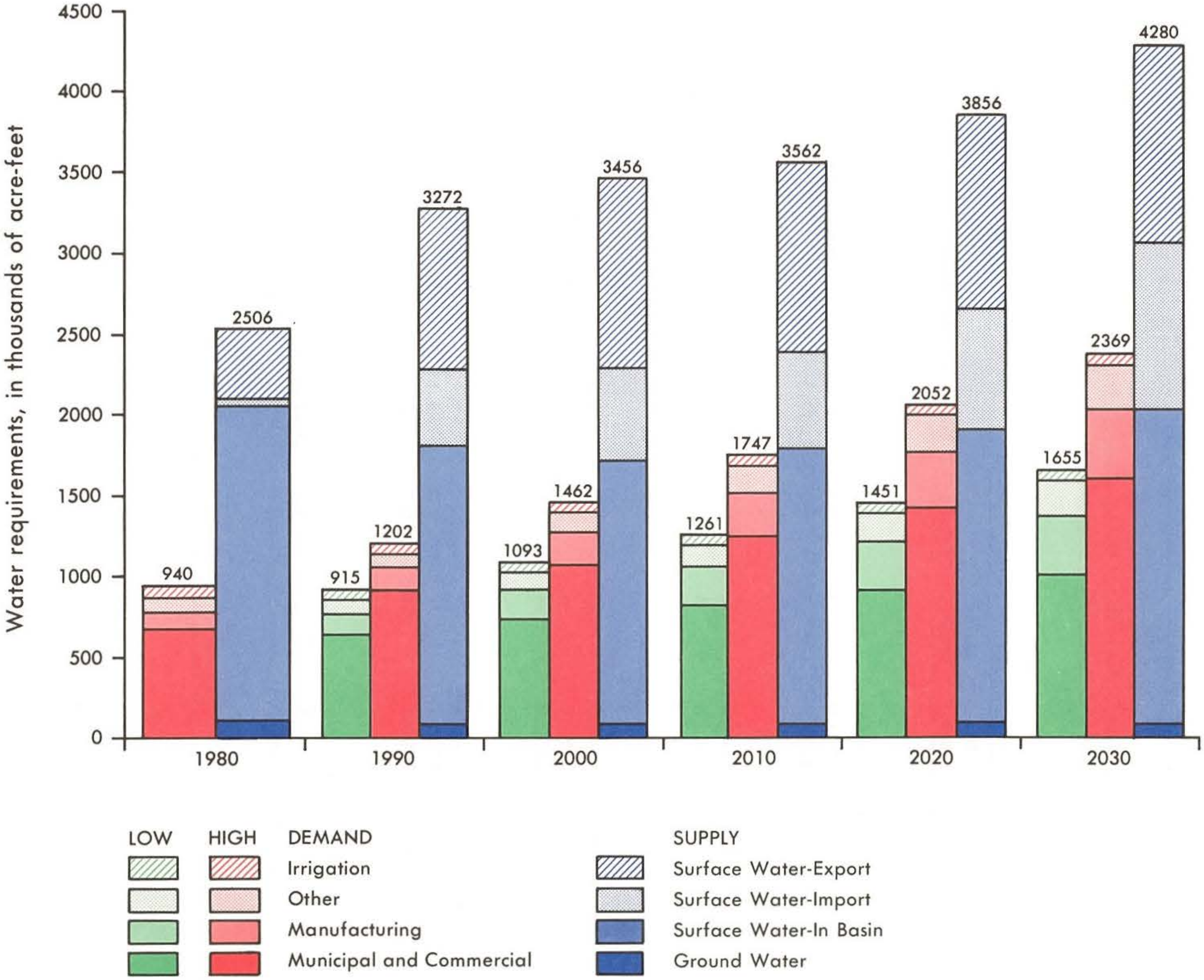

Figure III-8-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Trinity River Basin, 1980-2030

Zone 1

In Zone 1 of the basin, a surface-water requirement of 2.04 million acre-feet in the year 2030 can be fully met from existing and proposed supply sources, including importation into the zone of approximately 1.0 million acre-feet (Table III-8-6, Figure III-8-3). A total net surplus for all purposes of 173.1 thousand acre-feet in the zone, primarily return flows, is projected to occur in year 2030, with 176.2 thousand acre-feet of net surplus available for additional municipal and industrial purposes. An irrigation shortage of 3.1 thousand acre-feet is forecast to occur due to limited ground-water supplies.

Existing surface-water supplies in the Trinity River Basin are not sufficient to meet anticipated surface-water needs through the year 2030 in Zone 1. Analysis of the future water requirements and water supplies for each of the principal water supply systems in Zone 1 is presented below.

Table III-8-6. Water Resources of the Trinity River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	46.9	—	—	—	46.9	46.9	—	—	46.9	.0	.0	.0
Surface Water	1004.5	.0	89.5	471.3	1565.3	1027.0	.3	3.1	1030.4	537.2	(2.3)	534.9
Total	1051.4	.0	89.5	471.3	1612.2	1073.9	.3	3.1	1077.3	537.2	(2.3)	534.9
2000												
Ground Water	47.4	—	—	—	47.4	47.4	—	—	47.4	.0	.0	.0
Surface Water	954.0	.0	118.8	562.6	1635.4	1242.5	.3	4.2	1247.0	390.7	(2.3)	388.4
Total	1001.4	.0	118.8	562.6	1682.8	1289.9	.3	4.2	1294.4	390.7	(2.3)	388.4
2010												
Ground Water	48.3	—	—	—	48.3	48.3	—	—	48.3	.0	.0	.0
Surface Water	946.6	46.8	151.8	586.5	1731.7	1484.6	.3	5.5	1490.4	243.6	(2.3)	241.3
Total	994.9	46.8	151.8	586.5	1780.0	1532.9	.3	5.5	1538.7	243.6	(2.3)	241.3
2020												
Ground Water	49.4	—	—	—	49.4	49.4	—	—	49.4	.0	.0	.0
Surface Water	939.8	46.7	185.4	741.7	1913.6	1746.7	.4	6.3	1753.4	162.5	(2.3)	160.2
Total	989.2	46.7	185.4	741.7	1963.0	1796.1	.4	6.3	1802.8	162.5	(2.3)	160.2
2030												
Ground Water	46.1	—	—	—	46.1	46.1	—	—	46.1	.0	.0	.0
Surface Water	932.9	46.5	220.6	1015.9	2215.9	2034.5	.2	8.1	2042.8	176.2	(3.1)	173.1
Total	979.0	46.5	220.6	1015.9	2262.0	2080.6	.2	8.1	2088.9	176.2	(3.1)	173.1

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
- Intra-Basin: A transfer of water among zones within a river basin.
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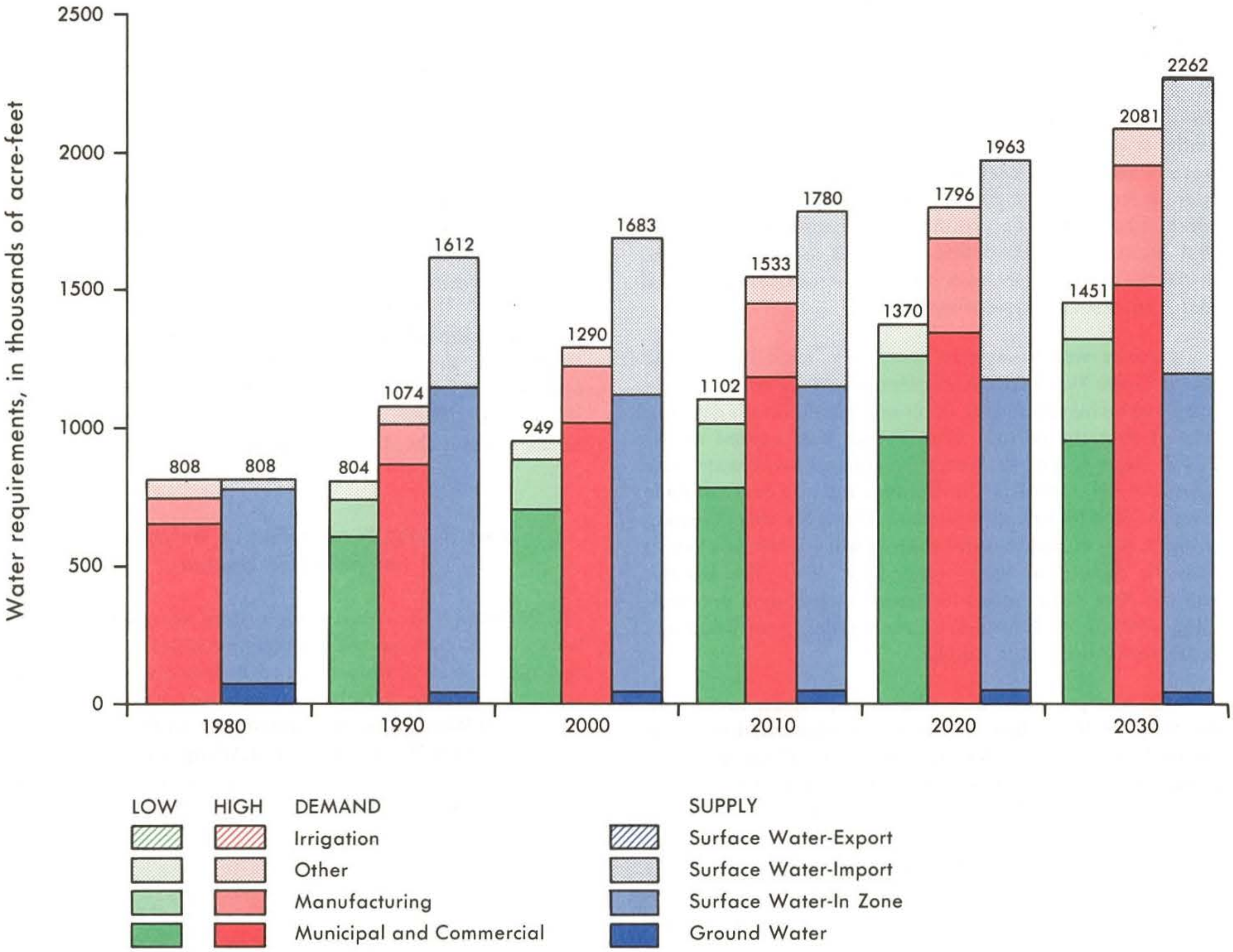

Figure III-8-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Trinity River Basin, Zone 1, 1980-2030

Dallas and North Texas Municipal Water District

Existing and under-construction surface-water storage and conveyance facilities available to the City of Dallas are sufficient to supply Dallas' water needs until year 2000. To meet future needs, Dallas has purchased 53.0 thousand acre-feet per year of firm annual supply from Lake Fork Reservoir in the Sabine River Basin. Construction of pipelines from Lake Fork to Lake Tawakoni and on to Dallas could make this water available to meet the anticipated shortage in 2000.

Additional projected growth in the water needs of Dallas and adjacent communities anticipated to be served by the Dallas system is expected to exceed available supplies including Dallas' portion of the Lake Fork yield. To meet this need, the City of Dallas, which owns 53.63 percent of the conservation storage in Lake Palestine in the Neches River Basin, can further develop by 2010 approximately 114.0 thousand acre-feet annually by construction of pumping and conveyance facilities and delivery of the city's proportional share of the yield of Lake Palestine to the Dallas area.

Additional water will be needed by Dallas in 2020 to meet projected needs. The proposed Carl Estes and Marvin Nichols, Stage I, Reservoirs, in the Sabine and Sulphur River Basins, respectively, are alternative sources to meet these water demands through 2030. For this planning study, it is assumed that water will be available by 2020 from Carl Estes Reservoir and by 2030 from Marvin Nichols Reservoir for the Dallas system. Additional studies will be necessary to determine the economic, engineering, and institutional feasibilities, as well as environmental impacts, of these projects and the associated proposed major interbasin water transfers.

Surface-water supplies currently available to the North Texas Municipal Water District (NTMWD) are estimated to be insufficient to meet current demands during a critical drought period. The District has applied to the Texas Department of Water Resources for a water use permit to divert and use 92.0 thousand acre-feet annually from the Red River below Denison Dam. For this planning study, it is assumed that this project will supply the District with the additional water needed by 1990. The District and the Red River Authority are also studying a potential joint reservoir on Bois d' Arc Creek in the lower Red River Basin for future water supply.

The Cooper Lake and Channels project, located in the Sulphur River Basin, was under construction when halted by an order of the Federal District Court in 1971 pursuant to litigation filed under provisions of the National Environmental Policy Act of 1969. However, in July 1984, the 5th U.S. Circuit Court of Appeals overturned the District Court's ruling. Litigation may continue if this latest decision is appealed. The City of Irving and the North Texas Municipal Water District together hold water rights to 73.7 percent of the 273.0 thousand acre-feet of conservation storage which the project will develop when completed, as well as rights for diversion of their proportional share of the yield into the upper Trinity River Basin. With construction of pumping and conveyance facilities from Cooper Lake to the Dallas area, approximately 90.0 thousand acre-feet of additional water could be delivered annually to the area. Assuming a resolution of the legal proceeding in favor of the project's construction, the project is proposed to supply NTMWD and Irving by the year 2000.

Projected water needs of the NTMWD service area will exceed existing supplies and those available from the proposed Red River Diversion and Cooper Reservoir between 2000 and 2010. The George Parkhouse Reservoir, Stage I, in the Sulphur River Basin and associated water conveyance facilities are proposed in this study as likely additional surface-water sources to meet the District's needs through 2010. Additional shortages expected by 2020 can be met by constructing Stage II of George Parkhouse Reservoir before 2020. Further water supplies will be needed by 2030 to meet projected additional growth in demand. A probable source of these supplies is the potential Marvin Nichols Reservoir, Stage I, in the Sulphur River Basin.

Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such major interbasin transfers of water.

Additional alternative sources of surface water for the District are the potential Bonham (Corps of Engineers) and Bois D'Arc Reservoir projects in Zone 3 of the Red River Basin. These sources could supply long-term needs of the District should the proposed projects not develop.

Fort Worth, Tarrant County WCID No.1, and Arlington System

Assuming the West Fork system of reservoirs continues to be operated under current criteria, and pumping and pipeline facilities are added to move water from the under-construction Richland-Chambers Creek Reservoir to the Fort Worth area, the firm supply for the Fort Worth, Tarrant County WCID No. 1, and Arlington system will be sufficient to meet projected municipal and manufacturing requirements on the system by the year 2000. However, by 2010, additional water supplies will be needed.

The potential Tehuacana Reservoir project, located on Tehuacana Creek in Zone 2, is a logical future supplemental supply for Tarrant County WCID No. 1 as the second stage on an integrated Richland-Tehuacana project. Based on preliminary design criteria, the project would yield 46.8 thousand acre-feet annually. The construction of Tehuacana Creek Reservoir and appurtenant conveyance facilities should provide sufficient supplemental supplies to meet system requirements to the year 2010. By the year 2030, however, increases in municipal, manufacturing, and steam-electric power plant cooling water demands on system reservoirs will create a deficit. The proposed George Parkhouse, Stage II, and Marvin Nichols, Stage I, Reservoirs in the Sulphur River Basin could supply water needed by 2020 and 2030, respectively. These projects could be funded jointly by the Dallas, Tarrant County WCID No. 1, and NTMWD systems since each of these systems could draw additional supplies from them. Further investigations will be needed to provide detailed evaluations of the institutional, engineering, and environmental aspects of these major surface-water development proposals.

Zone 2

In Zone 2 of the Trinity River Basin, all projected water requirements can be fully met through the year 2030 (Table III-8-7, Figure III-8-4). A slight surplus of 2.9 thousand acre-feet for municipal and industrial purposes is projected in 2030. Total surface-water supply in 2030 for the zone, including importation, is projected to be 180.3 thousand acre-feet.

Construction of Tehuacana Reservoir in Zone 2, as a "second stage" of the Richland-Tehuacana project, could provide supplemental supplies for long-range needs beyond the year 2000 in Zone 2, although most of the yield of Tehuacana Reservoir will ultimately be needed in Zone 1.

The authorized Tennessee Colony Reservoir project is needed for flood control in Zones 2 and 3 now and potentially available for supplemental water supply for Zone 3 and adjacent basins. Provided all current issues concerning construction of Tennessee Colony Reservoir are resolved, particularly the conflict between needed development of near-surface lignite deposits and reservoir construction, and the project is constructed, Tennessee Colony Reservoir could offer additional supplies for use in Zone 2 should needs develop.

The Trinity River Authority has prepared a master plan for the entire Trinity River Basin which identified a number of potential reservoir projects in Zones 2 and 3 of the basin. In addition to Tennessee Colony and Tehuacana, the projects identified were Upper Keechi, Big Elkhart, Hurricane Bayou, Lower Keechi, Bedias, Nelson, Harman, Gail, Mustang, Caney, and Long King Reservoirs. The potential Bedias Reservoir, in Madison, Grimes, and Walker Counties, is currently under study by the Trinity River Authority and the U.S. Bureau of Reclamation as a possible water supply for future municipal and industrial purposes in the Houston and local areas.

Zone 3

Projected water supplies exceed projected water requirements on Zone 3 of the basin by approximately 510.7 thousand acre-feet in the year 2030 (Table III-8-8, Figure III-8-5). Of the total surface-water resource available in year 2030 of approximately 1.95 million acre-feet, slightly more than one million acre-feet is due to municipal and manufacturing return flows from Zones 1 and 2 of the basin entering into this Zone. Provided these return flows are not reused upstream to a significant extent, this surplus is available for municipal and industrial purposes should the return flows be allocated under water rights permits for additional water diversions on the lower Trinity River.

The City of Houston holds rights to 70 percent of the yield of Lake Livingston and 42 percent of the authorized Wallisville Lake project. Plans are underway by the City of Houston for construction of the Luce Bayou project, a combined pipeline-canal facility which will divert up to 450.0 thousand acre-feet annually of the city's share of Lake Livingston storage into Lake Houston in the San Jacinto River Basin for municipal and industrial use. Water would be diverted by pumping facilities on the Trinity River in northern Liberty County. To meet anticipated shortages in the City of Houston system, it is assumed for this planning study that the Luce Bayou project will be fully operational by 1990.

Water Quality Protection

A water quality management plan for the Trinity River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Dallas-Fort Worth metropolitan area. These plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $1,167.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Trinity River Basin with approximately $1,102.9 million required for Zone 1, $40.8 million for Zone 3, and $23.9 million for Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Six reservoirs within the Trinity River Basin currently provide major flood-control benefits to many urban areas in the upper part of the basin. Total allocated flood-storage capacity in Benbrook, Lewisville, Grapevine, Lavon, Navarro Mills, and Bardwell Reservoirs amounts to about 1.37 million acre-feet. Construction of Ray Roberts and

Table III-8-7. Water Resources of the Trinity River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	16.7	—	—	—	16.7	16.7	—	—	16.7	.0	.0	.0
Surface Water	7.0	22.3	.0	3.1	32.4	29.7	.0	.4	30.1	2.3	.0	2.3
Total	23.7	22.3	.0	3.1	49.1	46.4	.0	.4	46.8	2.3	.0	2.3
2000												
Ground Water	18.4	—	—	—	18.4	18.4	—	—	18.4	.0	.0	.0
Surface Water	7.0	51.2	.0	4.0	62.2	60.0	.0	.5	60.5	1.7	.0	1.7
Total	25.4	51.2	.0	4.0	80.6	78.4	.0	.5	78.9	1.7	.0	1.7
2010												
Ground Water	20.5	—	—	—	20.5	20.5	—	—	20.5	.0	.0	.0
Surface Water	53.6	76.3	1.8	5.1	136.8	86.5	46.8	.5	133.8	3.0	.0	3.0
Total	74.1	76.3	1.8	5.1	157.3	107.0	46.8	.5	154.3	3.0	.0	3.0
2020												
Ground Water	23.0	—	—	—	23.0	23.0	—	—	23.0	.0	.0	.0
Surface Water	53.6	101.6	2.0	6.4	163.6	113.1	46.7	.5	160.3	3.3	.0	3.3
Total	76.6	101.6	2.0	6.4	186.6	136.1	46.7	.5	183.3	3.3	.0	3.3
2030												
Ground Water	25.3	—	—	—	25.3	25.3	—	—	25.3	.0	.0	.0
Surface Water	53.6	116.3	2.3	8.1	180.3	130.3	46.5	.6	177.4	2.9	.0	2.9
Total	78.9	116.3	2.3	8.1	205.6	155.6	46.5	.6	202.7	2.9	.0	2.9

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
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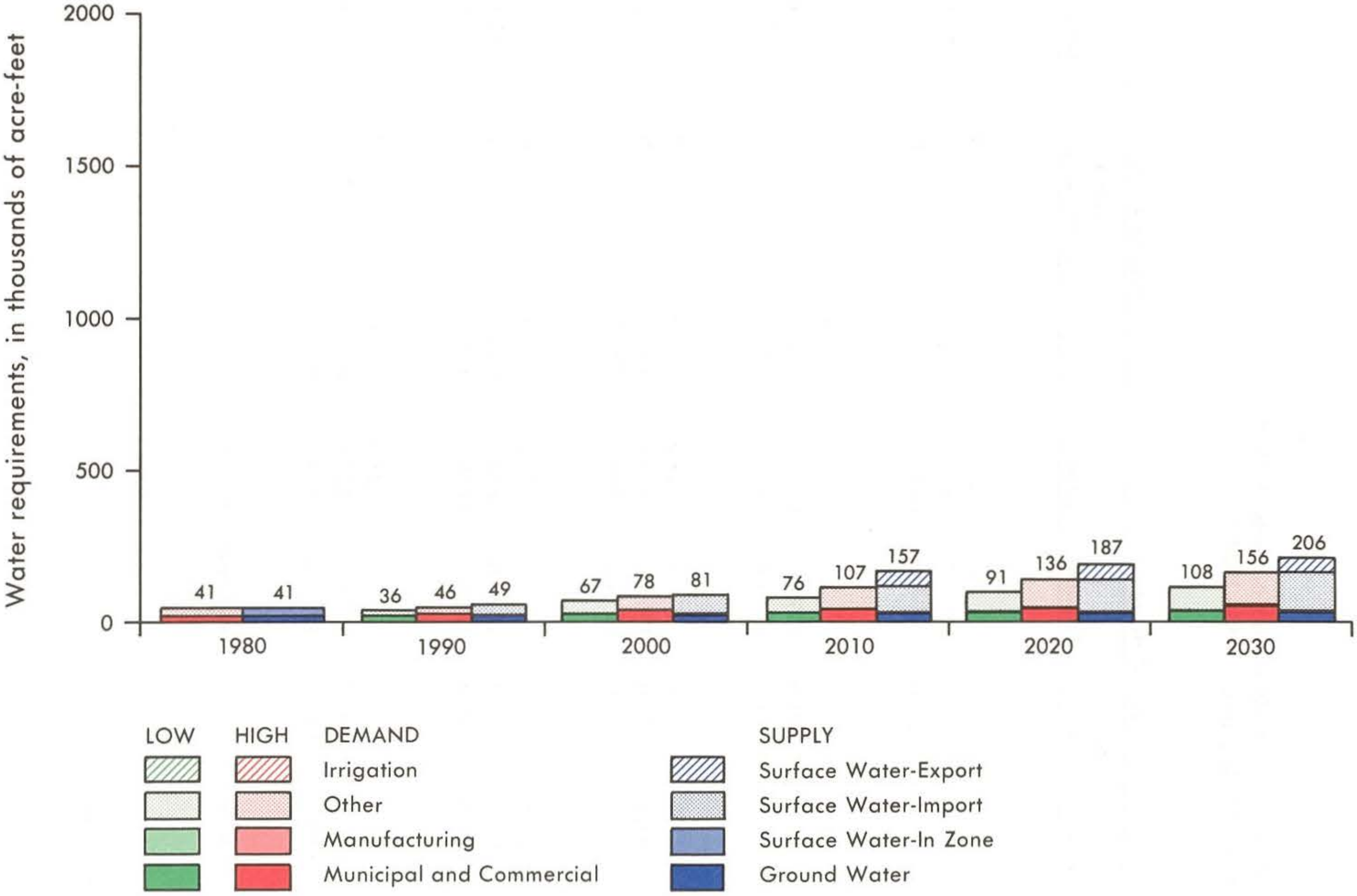

Figure III-8-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Trinity River Basin, Zone 2, 1980-2030

Joe Pool Lakes will increase reservoir flood-storage capacity within the basin by 184.4 thousand acre-feet. Completion of Ray Roberts Lake, with its authorized flood-control storage capacity of 260.8 thousand acre-feet, will allow partial reallocation of flood-storage capacity in Lake Lewisville.

In conjunction with reservoir flood-control storage, additional flood protection has been provided to major urban areas by extensive channel projects, levees, and floodway systems. The Dallas Floodway System, consisting of approximately 23 miles of levee and improved floodway channel, was constructed by local interests during the period 1928-32. Work by the Corps of Engineers to strenghten the levee and improve the channel and drainage facilities was completed in 1960.

Another major project is the Fort Worth Floodway System, completed in 1957. Extensions of the system were completed in 1970 on the Clear Fork up to Benbrook Dam and on the West Fork up to Lake Worth. The Big Fossil Creek project, completed in 1956, consists of channel improvements and levees to provide flood protection for the City of Richland Hills.

Additional federally authorized channel improvements and levee projects are under study and construction is needed. These projects include: the South Dallas Floodway Extension and the Multi-Purpose Channel to Liberty, Texas. Committments from local interests for cost sharing are required before these can move forward.

The Corps of Engineers is currently conducting a flood damage prevention study on Johnson Creek in Arlington, Texas. The study is scheduled for completion in September 1986.

Table III-8-8. Water Resources of the Trinity River Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	23.8	—	—	—	23.8	23.8	—	—	23.8	.0	.0	.0
Surface Water	1053.8	.0	554.9	.0	1608.7	58.1	22.0	995.7	1075.8	532.9	.0	532.9
Total	1077.6	.0	554.9	.0	1632.5	81.9	22.0	995.7	1099.6	532.9	.0	532.9
2000												
Ground Water	23.1	—	—	—	23.1	23.1	—	—	23.1	.0	.0	.0
Surface Water	1063.6	.0	657.4	.0	1721.0	70.8	50.9	1173.3	1295.0	426.0	.0	426.0
Total	1086.7	.0	657.4	.0	1744.1	93.9	50.9	1173.3	1318.1	426.0	.0	426.0
2010												
Ground Water	23.8	—	—	—	23.8	23.8	—	—	23.8	.0	.0	.0
Surface Water	959.1	.0	764.6	.0	1723.7	83.4	76.0	1174.2	1333.6	390.1	.0	390.1
Total	982.9	.0	764.6	.0	1747.5	107.2	76.0	1174.2	1357.4	390.1	.0	390.1
2020												
Ground Water	24.4	—	—	—	24.4	24.4	—	—	24.4	.0	.0	.0
Surface Water	945.7	.0	884.3	.0	1830.0	95.2	101.2	1205.0	1401.4	428.6	.0	428.6
Total	970.1	.0	884.3	.0	1854.4	119.6	101.2	1205.0	1425.8	428.6	.0	428.6
2030												
Ground Water	24.9	—	—	—	24.9	24.9	—	—	24.9	.0	.0	.0
Surface Water	934.6	.0	1015.9	.0	1950.5	108.2	116.0	1215.6	1439.8	510.7	.0	510.7
Total	959.5	.0	1015.9	.0	1975.4	133.1	116.0	1215.6	1464.7	510.7	.0	510.7

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

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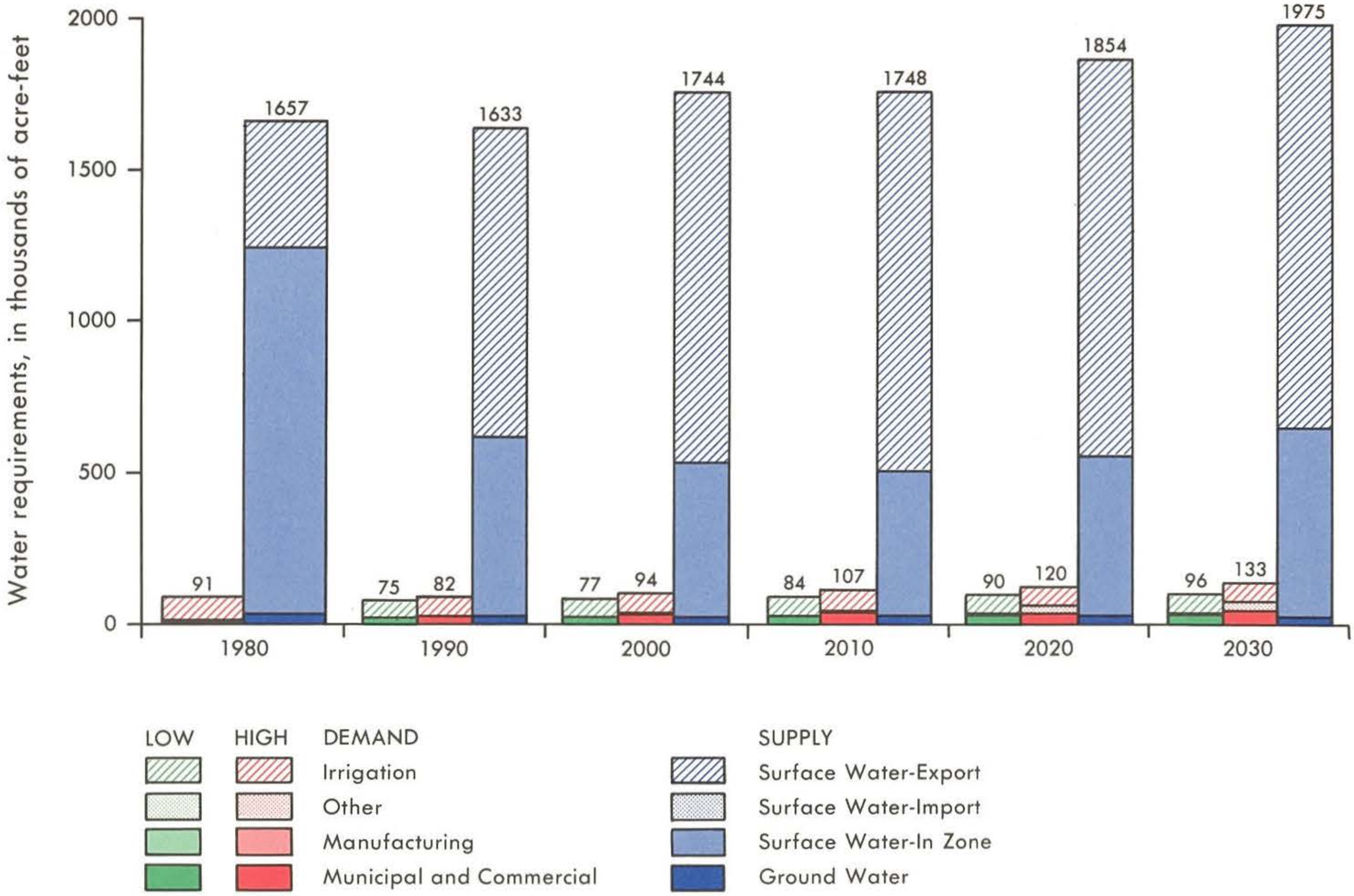

Figure III-8-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Trinity River Basin, Zone 3, 1980-2030

Under the Corps' Small Flood Control Project Authority, flood damage prevention studies have been initiated on Calloway Branch at Hurst, Calloway Branch at North Richland Hills, Elm Fork at Gainesville, Hickory Creek at Balch Springs, Lorean Branch at Hurst, and Pecan Creek at Gainesville. A flood damage prevention project on Wheeler Creek at Gainesville is currently under construction.

Numerous levee projects have been constructed by local interests to provide flood protection to agricultural lands, sanitary landfills, and other urban developments. Review and approval of these types of local projects will be continued by the Texas Water Development Board to assure safety and compliance with State and federal statutes regulating levee construction and alteration of flood plains.

The U.S. Soil Conservation Service, through the Small Watershed Protection Program, has developed plans for providing flood and erosion control primarily to agricultural lands in the subbasins of the Trinity River. To date, 859 floodwater-retarding structures have been constructed and over 99 miles of channel improvement has been completed. Future construction plans provide for an additional 235 retarding structures and 49 miles of channel work to be completed within the Trinity River Basin. Most of the existing and planned structures are in Zone 1, and a few are in Zone 2. There are no existing or planned structures in Zone 3. Studies of the potential for coordinated operation of reservoirs operated by the Corps of Engineers for flood-control purposes and major reservoirs not operated with flood control as a principal project purpose will be intensified. Additional nonstructural flood-control studies are underway.

9. TRINITY-SAN JACINTO COASTAL BASIN

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9. TRINITY-SAN JACINTO COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Trinity-San Jacinto Coastal Basin is bounded on the east by the Trinity River Basin and the Neches-Trinity Coastal Basin, on the west and north by the San Jacinto River Basin and the San Jacinto-Brazos Coastal Basin, and on the south by Trinity and Galveston Bays. The Trinity-San Jacinto Coastal Basin drains directly into Trinity Bay, primarily through Cedar Bayou. Maximum elevation is about 110 feet, but most of the area is less than 50 feet in elevation. Total basin drainage area is 247 square miles. For planning purposes, the basin is treated as a single hydrologic unit (Figure III-9-1).

Surface Water

Average runoff within the basin is approximately 600 acre-feet per square mile. Because most of the natural watercourses contain return flows, have been modified, or are affected by upstream drainage operations, reliable data on low-flow characteristics are unavailable.

The Trinity-San Jacinto Coastal Basin is subject to intense, and often highly localized, thunderstorms of short durations, general storms extending over periods of several days, and torrential rainfall associated with hurricanes and other tropical disturbances. Relatively long durations of flooding from rainfall are the result of flat slopes, small channel capacities, and wide, gently-sloping flood plains. The lower reaches of the basin are subject to inundation from tidal flooding during hurricanes.

The lower reaches of all streams are tidally influenced; therefore, the salinity of these lower reaches is similar to estuarine waters. Dissolved-solids concentrations in the nontidal reach of Cedar Bayou are generally less than 600 milligrams per liter (mg/l), although the salinity of Cedar Bayou increases from the Mount Belvieu area possibly due to saline runoff from oil and gas producing areas.

Ground Water

The Gulf Coast Aquifer extends beneath the Trinity-San Jacinto Coastal Basin. The aquifer extends to a maximum depth of about 2,800 feet. Net sand thickness ranges from 400 to 800 feet. Yields of large-capacity wells average about 1,900 gallons per minute (gpm), but locally wells produce up to 3,400 gpm. Water in the aquifer is fresh over much of the area, usually containing less than 500 mg/l total dissolved solids.

Within the Trinity-San Jacinto Coastal Basin, fresh water deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled within the basin by proper well location, completion, and pumpage.

Population and Economic Development

The population of the Trinity-San Jacinto Coastal Basin was reported at 80.2 thousand in 1980. Of this basin total, 92 percent resides in Harris County, with the remainder living in Chambers and Liberty Counties. Baytown is the largest city with a 1980 population of 56.9 thousand, 71 percent of the total basin population.

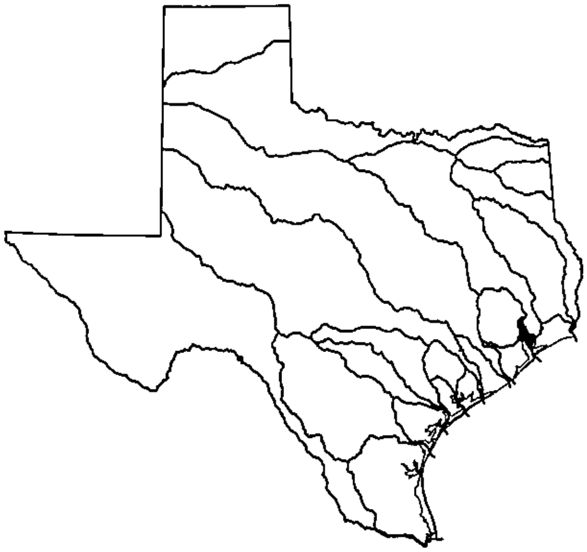
The economy of the Trinity-San Jacinto Coastal Basin is based primarily on petroleum refining and petrochemical and steel manufacturing centered at Baytown. Agriculture, agribusiness, manufacturing, and water-oriented recreation round out the basin economy.

Water Use

Municipal freshwater use in the Trinity-San Jacinto Coastal Basin totaled 11.7 thousand acre-feet in 1980. Ninety-five percent of the total basin water requirement was in the Harris County portion of the basin, and water use in the City of Baytown constituted 74 percent of the total basin water use.

In 1980, manufacturing industries in the basin used 56.0 thousand acre-feet of freshwater. Most of the water use was concentrated in the Baytown area, where almost 86 percent of the 1980 total basin water use occurred.

There are currently no steam-electric power generating plants in the Trinity-San Jacinto Coastal Basin using freshwater for cooling. One 2,250 megawatt capacity unit located in the basin uses saline water. This plant consumed about 16.0 thousand acre-feet of saline water for cooling in 1980, and slightly over 0.9 thousand acre-feet of fresh surface water for boiler feedwater makeup, domestic plant use, and ground maintenance. The plant also used about 100 acre-feet of ground water.



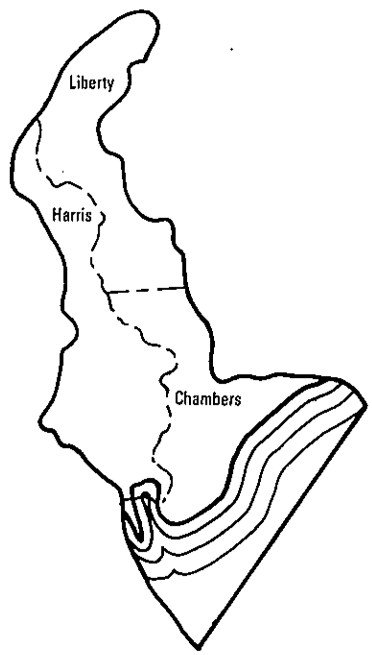


Figure III-9-1. Trinity-San Jacinto Coastal Basin

In 1980, about 16.2 thousand acres of rice was irrigated in the basin using 45.0 thousand acre-feet of water. Ground-water use for irrigation was 14.4 thousand acre-feet and surface-water use for irrigation was 30.6 thousand acre-feet. Surface water used for irrigation is supplied from the Trinity River Basin. Municipal and industrial development is rapidly encroaching on agricultural lands, a trend which is expected to continue.

Mining industries in the Trinity-San Jacinto Coastal Basin used an estimated 13.7 thousand acre-feet of freshwater in 1980. Liberty County is the major water use area for nonmetal production, accounting for 42 percent of the basin's total nonmetal mining water.

Livestock water use in the basin totaled about 200 acre-feet of water in 1980.

Navigation facilities in the Trinity-San Jacinto Coastal Basin include the Cedar Bayou Channel and a portion of the Houston Ship Channel. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, return flows from municipal and manufacturing sources in the Trinity-San Jacinto Coastal Basin totaled more than 19.9 thousand acre-feet. Most return flows originated in the heavily industrialized area along the Houston Ship Channel. Most of the industrial return flows are high in dissolved solids.

Irrigation return flows in the basin in 1980 were estimated at approximately 40 percent of the water applied for irrigation, or about 15.9 thousand acre-feet. Most of the return flows are discharged near the Coast and are therefore not recapturable for reuse.

Current Ground-Water Development

Approximately 27.0 thousand acre-feet of ground water was used in 1980 in the Trinity-San Jacinto Coastal Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 27.0 thousand acre-feet of ground water used in the basin, about 14.4 thousand acre-feet or 53 percent was for irrigation purposes, and 11.7 thousand acre-feet or 43 percent was for municipal purposes.

Within the basin, an overdraft of ground water from the Gulf Coast Aquifer occurred in 1980 in Liberty County, due to excessive withdrawals for irrigation purposes.

Current Surface-Water Development

Cedar Bayou Reservoir is the only major reservoir in the Trinity-San Jacinto Coastal Basin. Cedar Bayou Reservoir is owned and operated by Houston Lighting and Power Company as a part of the cooling water facilities for the Cedar Bayou Steam-Electric Power Plant. Saline cooling water withdrawn from the lower reach of Cedar Bayou is discharged into Cedar Bayou Reservoir prior to being discharged into Trinity Bay.

In 1980, approximately 100.6 thousand acre-feet of surface water was used in the Trinity-San Jacinto Coastal Basin, 55.4 thousand acre-feet for manufacturing purposes and 30.6 thousand acre-feet for irrigation. About 47.1 thousand acre-feet of manufacturing water was supplied by the San Jacinto River Authority to industrial plants in the Baytown area. These raw-water supplies are diverted directly from Lake Houston through agreements between the Authority and the City of Houston.

The remaining 8.3 thousand acre-feet of manufacturing water used in the basin was supplied from the Trinity River Basin through the Coastal Industrial Water Authority (CIWA) canal system. Of the 30.6 thousand acre-feet of irrigation water supplied from surface-water sources, 2.6 thousand acre-feet was diverted directly from Cedar Bayou, 8.3 thousand acre-feet was supplied by the San Jacinto River Authority from Lake Houston in the San Jacinto River Basin, and about 19.7 thousand acre-feet was delivered from the Trinity River Basin through the CIWA canal system.

Water Rights

A total of 25,476 acre-feet of surface water was authorized or claimed for diversion and use in the Trinity-San Jacinto Coastal Basin as of December 31, 1983 (Table III-9-1). Diversions for irrigation use accounted for 24,854 or almost 98 percent of the total amount of water authorized or claimed in the basin (Table III-9-2).

Water Quality

Localized dissolved-oxygen problems occur periodically in the immediate vicinity of a number of individual point-source discharges into the Galveston Bay System. The estuary is closely monitored by the Texas Department of Water Resources for signs of eutrophication which would necessitate reduction of nutrient inflows. Urban, industrial, and agricultural runoff contribute to periodic water quality degradation.

Table III-9-1. Authorized or Claimed Amount of Water, by Type of Right, Trinity-San Jacinto Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	9	12,832
Claims	13	12,644
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	22	25,476

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include the authorized diversion of 3,620,000 acre-feet/year from saline sources. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-9-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Trinity-San Jacinto Coastal Basin

Type of Use	Number of Rights	Basin Total
Municipal	0	0
Industrial[1]	0	0
Irrigation	20	24,854
Recreation	2	622
Total	22	25,476

[1]Does not include the authorized diversion of 3,620,000 acre-feet/year for saline sources.

Flooding, Drainage, and Subsidence

As development and land subsidence continue, the flood potential approaches severe and hazardous levels. Heavy damages from flooding during Hurricane Carla in 1961 and the June flood in 1973 necessitated a Presidential disaster declaration. Federal disaster relief loans were made available to repair and rebuild the damaged communities.

Tropical Storm Claudette in July 1979, produced another disaster declaration for the basin with 676 thousand federal dollars spent for relief efforts. Heavy flooding in 1981 also produced significant damages in the Baytown, Chambers County areas. During the period 1979-1981, 663 flood insurance claims were filed for $3.8 million in flood damages.

Four basin cities designated as flood prone by the Federal Emergency Management Agency are participants in the National Flood Insurance Program. Flood insurance studies have been completed for the Cities of Baytown and Anahuac and studies are underway for Beach City, Mont Belvieu, and Chambers County. Chambers and Liberty Counties are participants in the Emergency Phase of the Program.

Heavy clay soils, inadequate natural outlets, flat topography, and rice cultural practices continue to necessitate installation of on-farm drainage improvements such as land leveling, field drains, and collection ditches. Lateral ditches to connect farm drainage systems to adequate main outlets are needed in some areas, and existing outlets are in need of improvement and maintenance.

Since 1906 within the Trinity-San Jacinto Coastal Basin, approximately one to more than nine feet of subsidence has occurred in Liberty, Chambers, and Harris Counties. The least amounts of subsidence have occurred in the northern and eastern portions of the basin. More than nine feet of subsidence has occurred in western Baytown due to clay compaction caused by ground-water withdrawals from the Gulf Coast Aquifer for industrial and municipal needs. In the area of the Goose Creek Oil Field, more than nine feet of subsidence has occurred due to petroleum and fresh to saline ground-water withdrawals. Fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages to roads and buildings caused by fault movement is very evident in Baytown and in western Chambers County. Subsidence and possibly faulting in and near the Brownwood Subdivision in western Baytown has caused abandonment of many homes because of inundation of the subsided area by bay waters.

Recreation Resources

Freshwater recreation activities in the basin are locally restricted to shoreline activities along the Gulf and along streams and ponds in the basin. Studies by the Texas Department of Water Resources and the Texas Parks and Wildlife Department indicate an estimated 306 thousand sport fishing parties visited the Trinity-San Jacinto estuary during 1976-1977. This recreation use produced an estimated total economic impact of $13.4 million to regional and State economies.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Trinity-San Jacinto Coastal Basin is projected to more than double by 2030, from the present level of 80.2 thousand to 203.2 thousand (Table III-9-3). A 71 percent increase to 136.8 thousand is expected from 1980 to year 2000, and a lower growth rate of 49 percent is projected from 2000 through 2030. The Harris County population, primarily in Baytown, was almost 92 percent of the total basin population in 1980, and is projected to make up almost 87 percent by 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Trinity-San Jacinto Coastal Basin were 11.7 thousand acre-feet in 1980. Municipal freshwater requirements in 2000 are estimated to increase from 63 to 150 percent; low and high case, respectively. By 2030, water demands are projected to be from 26.0 to 43.7 thousand acre-feet for the two cases of future growth.

Industrial

Manufacturing water requirements in 1980 were 56.0 thousand acre-feet in the Trinity-San Jacinto Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water use in the Trinity-San Jacinto Coastal Basin is projected to more than double by the year 2030, from a 1980 level of 56 thousand acre-feet to a 2030 range of 96.4 to 115.8 thousand acre-feet. The rate of change projected for manufacturing freshwater use in the Trinity-San Jacinto Coastal Basin is substantially less than the State average (72-107 percent for 1980-2030, compared to 178-230 percent for the State).

Most of basin manufacturing freshwater use was concentrated in Harris County, and is expected to continue through 2030. Principal manufacturing water users in Harris County are petroleum refineries.

Steam-Electric Power Generation

In 1980, approximately one thousand acre-feet was used for power generation in the Trinity-San Jacinto Coastal Basin. By 2030, 15.0 thousand acre-feet (high case) could be required to meet increased demands for electricity. From 1980 to 2010, energy water demand increases slowly to 2.5 and 5.7 thousand acre-feet, low and high cases, respectively. From 2010 to 2030, demands increase from 164 to 236 percent; low and high case, respectively.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Trinity-San Jacinto Coastal Basin are projected to increase from the 1980 level of 45.0 thousand acre-feet by a projected maximum 8 and 11 percent by the year 2000 in the high and low cases, respectively. In the year 2030, water requirements in the basin are projected to be about 44.2 thousand acre-feet annually in the high case to irrigate about 15.5 thousand acres.

Table III-9-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Trinity-San Jacinto Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Trinity-San Jacinto Basin																		
Population			80.2			111.2			136.8			153.6			174.2			203.2
Municipal	11.7	0.0	11.7	3.4	20.1	23.5	4.4	24.9	29.3	5.2	27.8	33.0	5.9	31.5	37.4	6.4	37.3	43.7
Manufacturing	0.6	55.4	56.0	2.0	67.0	69.0	2.0	77.4	79.4	2.0	85.9	87.9	2.0	98.3	100.3	2.0	113.8	115.8
Steam Electric	0.1	0.9	1.0	0.2	0.8	1.0	0.2	0.8	1.0	0.2	5.5	5.7	.2	10.1	10.3	0.2	14.8	15.0
Mining	0.1	13.6	13.7	0.1	13.6	13.7	0.1	13.7	13.8	0.1	14.4	14.5	.1	15.0	15.1	0.0	15.8	15.8
Irrigation	14.4	30.6	45.0	4.3	47.9	52.2	4.3	44.3	48.6	4.3	42.5	46.8	4.3	41.1	45.4	4.3	39.9	44.2
Livestock	0.1	0.1	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2	0.2	.0	0.2	0.2	0.0	0.2	0.2
Basin Total Water	27.0	100.6	127.6	10.0	149.6	159.6	11.0	161.3	172.3	11.8	176.3	188.1	12.5	196.2	208.7	12.9	221.8	234.7

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

Livestock

Due to a small expected increase in cattle production within the basin, annual livestock freshwater requirements are projected at 0.2 thousand acre-feet by 2030.

Mining

Mining freshwater requirements in the Trinity-San Jacinto Coastal Basin are projected to increase from 13.7 thousand acre-feet in 1980 to 15.8 thousand acre-feet by 2030. The greatest expansion is expected to occur between 2000 and 2030 when mining water requirements will increase 15 percent (2 thousand acre-feet) as compared to only 0.01 percent (92 acre-feet) during the 1980-2000 period. The basin's share of total State mining freshwater requirements amounted to less than six percent in 1980 and is not expected to exceed five percent in 2030.

Only two industries in the mining sector in the Trinity-San Jacinto Coastal Basin depend on measurable quantities of freshwater for production, the nonmetal mining industry and the fuel mining industry. In 1980, nonmetal mining operations (crushed and broken limestone, sand and gravel, clay, and sulfur) utilized 5.8 thousand acre-feet of water; however, this is projected to increase to 12.7 thousand acre-feet by year 2030. Mining water used for injection in secondary recovery of crude petroleum and natural gas amounted to 7.9 thousand acre-feet in 1980 but is expected to only require 3.1 thousand acre-feet of the basin's mining water by 2030.

Navigation

There are no navigation facilities in the Trinity-San Jacinto Coastal Basin requiring the use of regulated freshwater supplies.

Hydroelectric Power

As there are no major reservoirs in the basin, there are no hydroelectric power generating facilities in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Trinity-San Jacinto Coastal Basin through the year 2030 is 42.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation in the basin.

The projected annual ground-water use within the Trinity-San Jacinto Coastal Basin by decade from 1990 through 2030 is expected to be from 10.0 to 12.9 thousand acre-feet per year (Table III-9-3). The approximate average annual projected ground-water use within the basin is expected to be about 11.6 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

Water importation from the Trinity River Basin is projected to provide sufficient supplies to meet anticipated surface-water needs in the Trinity-San Jacinto Coastal Basin through the year 2030 (Table III-9-4, Figure III-9-2). Approximately 215.6 thousand acre-feet of surface water is estimated to be imported through existing water diversion facilities to meet the projected requirements in 2030.

The limited drainage area and flat topography preclude the development of major reservoir projects in the basin. Projected surface-water needs in the basin through the year 2030 will be met through water importation under existing water rights and contracts from the Trinity River Basin.

Water Quality Protection

A water quality management plan for the Trinity-San Jacinto Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Greater Houston metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $28.2 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Trinity-San Jacinto Coastal Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with projects costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Table III-9-4. Water Resources of the Trinity-San Jacinto River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	10.0	—	—	—	10.0	10.0	—	—	10.0	.0	.0	.0
Surface Water	.0	—	.0	143.4	143.4	143.4	—	.0	143.4	.0	.0	.0
Total	10.0	—	.0	143.4	153.4	153.4	—	.0	153.4	.0	.0	.0
2000												
Ground Water	11.0	—	—	—	11.0	11.0	—	—	11.0	.0	.0	.0
Surface Water	.0	—	.0	155.1	155.1	155.1	—	.0	155.1	.0	.0	.0
Total	11.0	—	.0	155.1	166.1	166.1	—	.0	166.1	.0	.0	.0
2010												
Ground Water	11.8	—	—	—	11.8	11.8	—	—	11.8	.0	.0	.0
Surface Water	.0	—	.0	170.1	170.1	170.1	—	.0	170.1	.0	.0	.0
Total	11.8	—	.0	170.1	181.9	181.9	—	.0	181.9	.0	.0	.0
2020												
Ground Water	12.5	—	—	—	12.5	12.5	—	—	12.5	.0	.0	.0
Surface Water	.0	—	.0	190.0	190.0	190.0	—	.0	190.0	.0	.0	.0
Total	12.5	—	.0	190.0	202.5	202.5	—	.0	202.5	.0	.0	.0
2030												
Ground Water	12.9	—	—	—	12.9	12.9	—	—	12.9	.0	.0	.0
Surface Water	.0	—	.0	215.6	215.6	215.6	—	.0	215.6	.0	.0	.0
Total	12.9	—	.0	215.6	228.5	228.5	—	.0	228.5	.0	.0	.0

[1] Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
- Intra-Basin: A transfer of water among zones within a river basin.
- Import: A transfer of water from another river basin.
- Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
- Export: A transfer of water to another river basin.

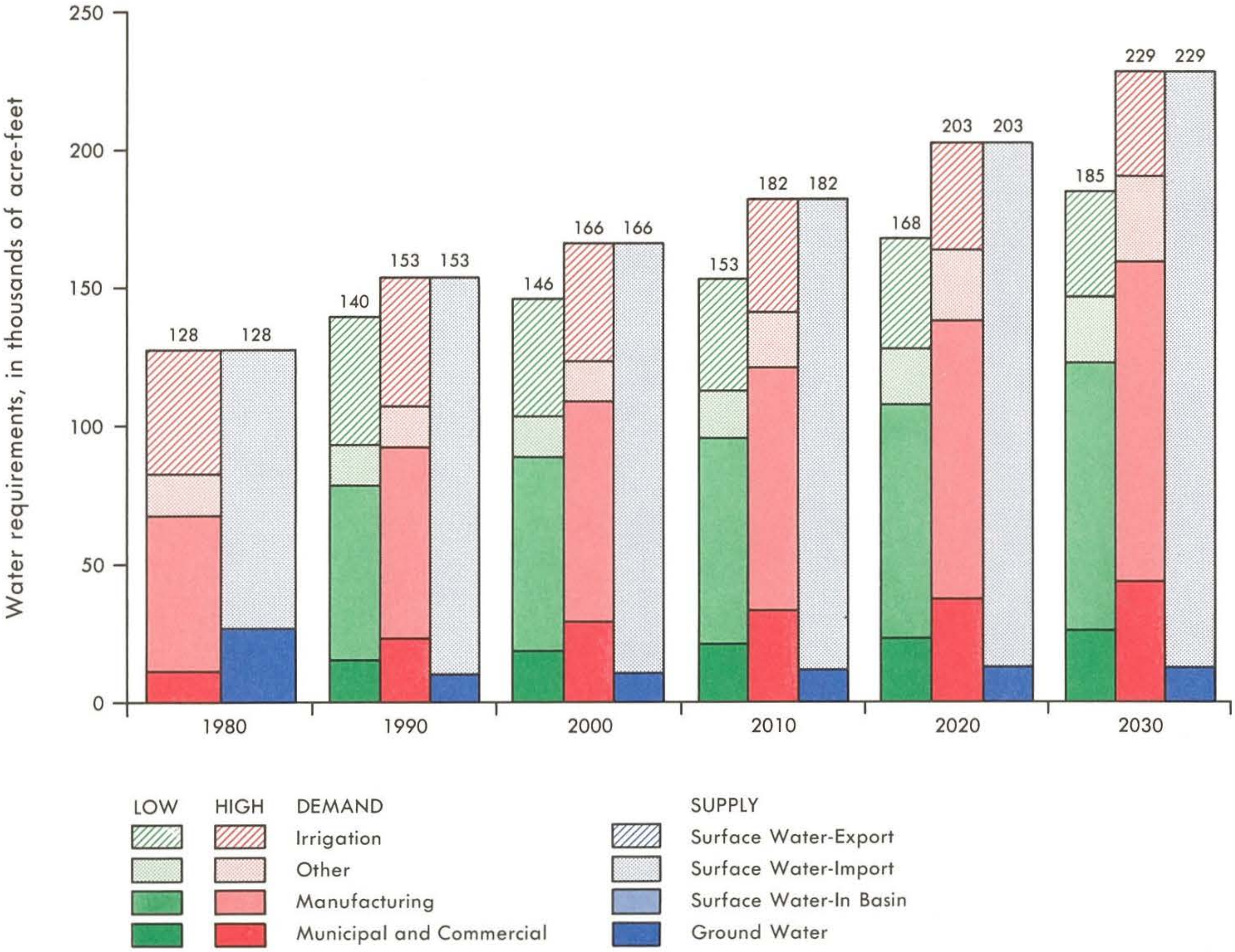


Figure III-9-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Trinity-San Jacinto Coastal Basin, 1980-2030

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

There are no existing flood-control reservoirs in the basin and none are planned through the year 2000. Present flood-control measures are limited to local levee works, channel improvements, and such nonstructural measures as flood-proofing, structural elevation, and flood-plain zoning. Another nonstructural alternative to control flood losses is evacuation of seriously flood-prone areas. Federal funds have been appropriated to the U.S. Army Corps of Engineers to accomplish detailed planning for the evacuation and relocation of structures in the Baytown area which have become increasingly flood prone due to land-surface subsidence.

Evacuation and relocation in association with flood-plain management construction standards will be widely used for future flood protection. The Corps of Engineers has additional studies underway in the Burnett, Crystal, and Scott Bays area to consider improvements for relief from flooding and drainage problems created by general land subsidence of the area. Future studies by the Corps of Engineers will include the Cedar Bayou area to consider possible improvements for flood control in the vicinity of Baytown, Texas.

10. SAN JACINTO RIVER BASIN

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10. SAN JACINTO RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The San Jacinto River Basin is bounded on the north and east by the Trinity River Basin and the Trinity-San Jacinto Coastal Basin, on the west by the Brazos River Basin, and on the south by the San Jacinto-Brazos Coastal Basin. Total basin drainage area is 5,600 square miles. Principal drainage systems in the basin are the San Jacinto River and Buffalo Bayou which drain into Galveston Bay through the Houston Ship Channel. Drainage area of the San Jacinto River above the confluence of the East and West Forks is 2,800 square miles, of which 1,750 square miles is in the West Fork drainage area and 1,050 square miles is in the East Fork drainage area. Originating at an elevation of 44 feet, Buffalo Bayou has a drainage area of 1,034 square miles. For planning purposes, the basin is treated as a single hydrologic unit (Figure III-10-1).

Surface Water

Average runoff for the period 1941 through 1970 in the basin was about 440 acre-feet per square mile. The lowest consecutive annual flows in the eastern part of the basin during the 1941-70 period occurred during 1954-56 and 1962-63. The average runoff was 125 acre-feet per square mile during 1954-56 and 224 acre-feet per square mile during 1962-63. The lowest runoff rate occurred in 1956 and averaged 70 acre-feet per square mile.

The San Jacinto River Basin is subject to intense rainstorms in every season of the year, with many of the most severe storms coming in the late summer and early autumn when tropical weather disturbances move inland out of the Gulf of Mexico.

Flooding is not confined to the San Jacinto River. Many of its principal tributaries are sources of massive flood problems. Buffalo Bayou, Brays Bayou, Sims Bayou, and Clear Creek are tributaries which are frequently sources of extensive damage to urban developments. Continued land subsidence aggravates this flood problem and increases the limits of flooding.

Urban development has increased the intensity of surface runoff to the point that many existing drainage systems are no longer capable of conveying flood waters from flooded areas. When bayous overflow in the Houston area, extensive damage results.

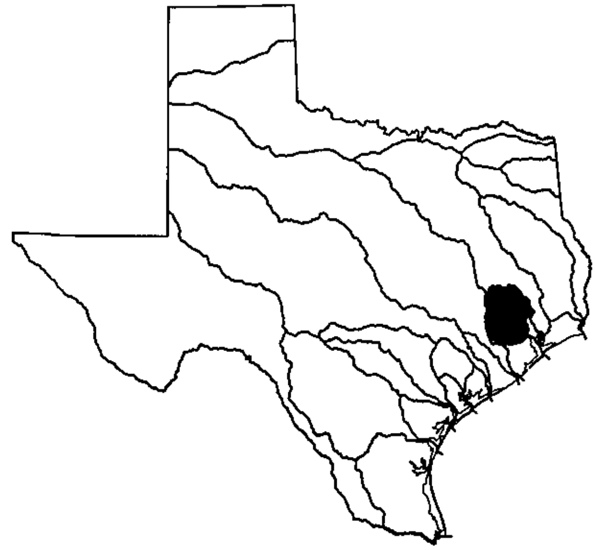
The San Jacinto River Basin exhibits wide variations in water quality. The upper part of the West Fork San Jacinto River flows into Lake Conroe, which supplies high-quality water to the area and also serves as a recreational resource. Occasional elevated levels of nutrients and bacteria have been noted in recent data from the West Fork San Jacinto River. The East Fork San Jacinto River, along with Peach Creek and Caney Creek, contribute consistently good-quality water to Lake Houston, which currently serves as the City of Houston's primary surface-water supply. Lake Houston also receives inflows from Cypress Creek and Spring Creek, which contain significant amounts of return flows. As the Houston metroplex has expanded toward the north, a proliferation of small sewage treatment plants has increased the nutrient loadings to Cypress Creek and Spring Creek and has caused localized dissolved-oxygen deficiencies. Although Lake Houston has a high nutrient concentration, the high turbidity level precludes the development of an intensive phytoplankton community.

The San Jacinto River flows approximately 20 miles from Lake Houston to its confluence with the upper portion of the Houston Ship Channel. The river then flows another 10 miles into Galveston Bay at Morgan's Point. Discharges from industries and municipalities, including the City of Houston's Northside and Sims Bayou sewage treatment plants, impact the quality of the lower San Jacinto River-Houston Ship Channel system. The upper part of the Houston Ship Channel is suitable for navigation and industrial water supply, but the water quality improves markedly below the San Jacinto River confluence and is adequate for most intended purposes, including fishing and recreation.

Ground Water

The Gulf Coast Aquifer underlies the entire San Jacinto River Basin. The aquifer extends to a maximum depth of about 3,000 feet. Yields of large-capacity wells average about 1,800 gallons per minute (gpm), but locally wells produce up to 2,900 gpm. The water in the aquifer generally contains less than 500 milligrams per liter (mg/l) total dissolved solids.

Importation of water from the Trinity River has decreased significantly the potential for additional land-surface subsidence and saline-water encroachment into



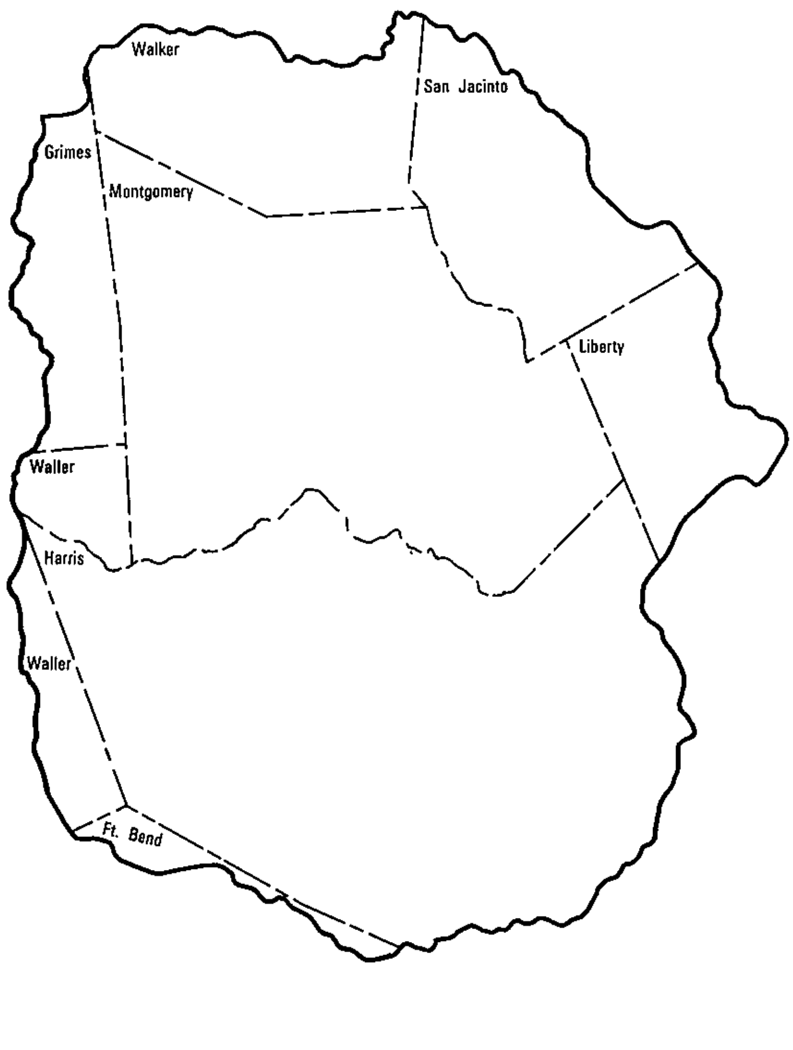


Figure III-10-1. San Jacinto River Basin

the Gulf Coast Aquifer in the eastern Houston and Pasadena areas along the Houston Ship Channel.

Population and Economic Development

The population of the San Jacinto River Basin was reported at 2.4 million in 1980. At present, 92 percent of the basin population resides in Harris County. Houston is the largest city, with over 1.5 million of its population within the San Jacinto River Basin. Other principal cities in the basin include Pasadena and Bellaire in Harris County, and Conroe in Montgomery County. The San Jacinto River Basin ranks much higher than the statewide average in percent urban and population density.

The economy of the basin is based on chemical and petrochemical manufacturing, oil production, diversified manufacturing, agribusiness, and shipping activities associated with the Port of Houston complex, the third largest port in the nation. The City of Houston is a leading center of banking and financial activity and wholesale and retail trade. Recreation, tourism, and convention business round out the highly diversified economy of the basin.

Water Use

Municipal freshwater use in the San Jacinto River Basin totaled 476.8 thousand acre-feet in 1980, and approximately 93 percent of total municipal use occurred in Harris County. An estimated 65 percent of total basin municipal water use in 1980 was supplied from ground water.

In 1980, freshwater use by manufacturing industries in the San Jacinto River Basin amounted to 227.6 thousand acre-feet. This represents about 15 percent of total manufacturing water use in the State in 1980. A significant part of this use occurred in, and adjacent to, the City of Houston, which has the largest number of manufacturing establishments of any city in Texas. Almost 79 percent, or 176.5 thousand acre-feet of the total 1980 manufacturing use, was derived from surface-water sources, while 51.1 thousand acre-feet was obtained from ground-water sources. Manufacturing industries in the basin which use significant quantities of freshwater include paper and allied products, chemicals, petroleum refining, and primary metals.

In 1980, there was 1,996 megawatts of installed steam-electric power generating capacity in the San Jacinto River Basin, which used 15.9 thousand acre-feet of ground water and 7.0 thousand acre-feet of fresh surface water. In addition large volumes of saline water was used for cooling.

In 1980, about 35.3 thousand acres was irrigated with 86.7 thousand acre-feet of water in the basin. About 96 percent was irrigated with ground water from the Gulf Coast Aquifer. The major crop irrigated was rice. Some soybeans and grain sorghum are grown as dryland crops. Urban and industrial development have significantly encroached upon agricultural lands in Harris and Montgomery Counties utilizing some of the best agricultural land for homesites, subdivisions, and industrial developments.

Mining water use in the San Jacinto River Basin was estimated at 5.5 thousand acre-feet in 1980. The most intensive use of water is concentrated in nonmetal mining industries, primarily Frasch sulfur production.

Livestock water requirements in 1980 amounted to about 2,400 acre-feet in the San Jacinto River Basin, principally in the production of cattle. About 1,100 acre-feet of the water used was supplied by surface-water sources.

The portion of the Houston Ship Channel which occupies the San Jacinto River and Buffalo Bayou is located in the San Jacinto River Basin. This marine navigation facility has no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the San Jacinto River Basin exceeded 315 thousand acre-feet and 162 thousand acre-feet, respectively. Over 97 percent of these return flows originated in the heavily populated and industrialized areas of Harris County.

Irrigation return flows in 1980 were estimated to total 34.5 thousand acre-feet. These return flows represent 35 to 40 percent of the water used in irrigation of rice land. Most return flows are not recoverable for reuse since they are discharged into saline waters near the Coast.

Current Ground-Water Development

Approximately 466.5 thousand acre-feet of ground water was used in 1980 in the San Jacinto River Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 466.5 thousand acre-feet of ground water used in the basin, about 309.8 thousand acre-feet or 66 percent was for municipal purposes, 82.9 thousand acre-feet or 18 percent was for irrigation purposes, and 51.1 thousand acre-feet or 11 percent was for manufacturing purposes.

Within the basin, an extremely large overdraft of ground water from the Gulf Coast Aquifer occurred in

1980 due primarily to excessive withdrawals for municipal purposes generally in central and western Harris County. This extremely large overdraft has caused significant water level declines, compaction of clays within the Gulf Coast Aquifer, and consequently, an increase in the rate of land-surface subsidence and probably fault movement in the western and southwestern portion of Harris County. Within the basin, a significant overdraft of ground water from the Gulf Coast Aquifer occurred in 1980 in Waller County, due to excessive withdrawals for irrigation purposes.

Current Surface-Water Development

Major reservoirs and impoundments in the San Jacinto River Basin include Lakes Conroe and Houston, Lewis Creek and Sheldon Reservoirs, and Addicks and Barker flood control dams. Lake Conroe, owned and operated by the San Jacinto River Authority, presently provides municipal and manufacturing water supplies for the City of Houston through releases to Lake Houston. The City of Houston has rights to two-thirds of the storage in Lake Conroe. Water is also diverted from Lake Conroe to Lewis Creek Reservoir, owned by Gulf States Utilities Co., to provide make-up water for consumptive use due to operation of the Lewis Creek steam-electric power plant.

Lake Houston is owned and operated by the City of Houston. The San Jacinto River Authority, which holds prior water rights to the low flows of the main-stem San Jacinto River, diverts raw water directly from Lake Houston, through an agreement with the City of Houston, to industrial plants in the Baytown area in the Trinity-San Jacinto Coastal Basin and for irrigation. Highlands Reservoir, owned by the San Jacinto River Authority, is used for regulation of these deliveries, which totaled about 47 thousand acre-feet for industrial use and 8 thousand acre-feet for irrigation purposes in 1980. Raw water is also conveyed from Lake Houston to a number of industries in Harris County and to the Galveston County Water Authority in Galveston County through contractual agreements with the City of Houston. Treated water from Lake Houston is utilized by the City of Houston and its present customers, which include the City of Galveston, Galveston County Water Authority, and the City of Pasadena. In 1980, in addition to the 246.1 thousand acre-feet of ground water pumped by the City of Houston from its well fields completed in the Gulf Coast Aquifer, 195.8 thousand acre-feet of water was diverted from Lake Houston by the city. A large portion of this amount was conveyed directly to industrial users, including a large paper mill and Houston Lighting and Power Company. The remainder was treated at the city's Federal Road Water Treatment Plant prior to use by the city and its customers.

Sheldon Reservoir is owned and operated by the Texas Parks and Wildlife Department for purposes of recreation, wildlife management, and as a fish hatchery. Addicks Dam and Barker Dam were constructed by the U.S. Army Corps of Engineers and are operated for flood control. These projects have no conservation storage pools.

The Coastal Industrial Water Authority (CIWA) pumping and conveyance system, designed to deliver water from the Trinity River Basin to the major industrial areas of the San Jacinto River Basin, is nearing completion. The CIWA Main Canal System (22 miles long) to the principal regulating reservoir, Lynchburg Reservoir, and much of the distribution system which will serve industrial complexes in the Houston Ship Channel, Bayport, La Porte, Clear Lake, Pasadena, and Galena Park areas, as well as future municipal needs, have been completed.

The CIWA System delivers part of the City of Houston share of the yield of Lake Livingston and the supplies provided under prior water rights associated with the former Southern Canal Company, into the Trinity-San Jacinto Coastal Basin, the San Jacinto River Basin, and the San Jacinto-Brazos Coastal Basin. The CIWA System, when fully completed, will have the capability of delivering an average of about 1.39 million acre-feet annually from the pumping station on the Trinity River, of which about 235 million gallons per day (263.2 thousand acre-feet per year) will be delivered through the Cedar Point Lateral System (formerly the Southern Canal Company canal system) to industrial users and irrigated areas in the Trinity-San Jacinto Coastal Basin.

Water Rights

A total of 691,961 acre-feet of surface water was authorized or claimed for diversion and use in the San Jacinto River Basin as of December 31, 1983 (Table III-10-1). Authorized and claimed diversions for municipal use accounted for 231,000 acre-feet or about 33 percent of the total amount of water authorized or claimed in the basin (Table III-10-2).

Water Quality

The Houston metropolitan area is drained almost entirely by Buffalo Bayou, which has been channelized to form the Houston Ship Channel in its lower reach. The channel now receives heavy pollution loadings of both municipal and industrial wastes. These heavy waste loads, together with the sluggish flow characteristics of the waterway and tidal action, have overloaded the natural waste-assimilative capacity of the channel.

Table III-10-1. Authorized or Claimed Amount of Water, by Type of Right, San Jacinto River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	76	686,574
Claims	16	5,387
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	92	691,961

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include 9 authorized diversions of saline water amounting to 2,734,931 acre-feet/year. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Certain areas within the basin experience periodic algal blooms as a result of high nutrient concentrations. This is partly a response to natural conditions, but is aggravated by municipal and industrial point source nutrients. Several areas in the basin experience water quality problems resulting from natural runoff of largely uncontrollable nonpoint sources of pollutants. The high turbidity and coloration of the waters of Lake Houston and slightly depressed dissolved-oxygen levels in the East Fork flows are considered to be largely attributed to point source discharges into the tributaries of the lake, especially Cypress Creek and Spring Creek.

Table III-10-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, San Jacinto River Basin

Type of Use	Number of Rights	Basin Total
Municipal	3	231,000
Industrial[2]	11	427,112
Irrigation	35	20,835
Mining	1	5,500
Recreation	47	7,514
Total	92[1]	691,961

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include 9 authorized diversions of saline water amounting to 2,734,931 acre-feet/year.

Flooding, Drainage, and Subsidence

Due to extensive use of flood plains for high value developments, flood damages have been extremely severe in the basin. Hurricane Carla (1961) caused in excess of $21 million in damages to nonagricultural properties in Harris County. In 1972, a heavy rainstorm in the City of Houston caused an estimated $5 million in damages to urban development. A flood in June 1973, was so severe that an area including Galveston, Harris, Liberty, Montgomery, and San Jacinto Counties was declared a disaster area by the President.

In June 1975, an intense thunderstorm centered over Sims Bayou in the southern part of Houston resulting in damages estimated at $8.8 million. One month later, a similar flood, again centered in Sims Bayou, caused an additional $2.6 million in damages. A year later, a thunderstorm dropped 14 inches of rain, causing extensive flooding along Sims and Brays Bayous and produced total flood damages estimated near $20 million. Ponded floodwaters damaged areas which were previously unharmed by flooding. The huge medical complex in the southern part of Houston suffered an estimated $15 million in damages when ponded water poured into basement storage areas. Flood-proofing of the complex was undertaken to prevent recurrence of this flooding.

The year 1979 will go down in history as one of the most disastrous flood years in the basin. Floods in April 1979, Tropical Storm Claudette in July 1979, and floods in September 1979 resulted in three Presidential disaster declarations for the basin. More than $2.1 million was spent by various federal agencies for flood relief. In 1979, 6,093 flood insurance claims were filed for $64.4 million in flood damages. Flooding in 1981 produced 3,665 flood insurance claims for $28.2 million in flood damages. Less serious flooding in 1977, 1978, and 1980 produced an additional 426 flood insurance claims for $1.9 million in flood damages.

Forty-one cities in the basin have been designated by the Federal Emergency Management Agency as having one or more flood-prone areas. Thirty-three of these cities have adopted flood-plain management controls and are participating in the National Flood Insurance Program. Nineteen flood insurance rate studies have been completed in the basin and additional studies are in progress to convert most of the remaining cities to the Regular Program.

Rapidly changing land use has brought about many complicated drainage problems. Much land area is characterized by low permeability and the lack of well-defined drainage channels for rapid discharge of floodwaters. Urban developments require extensive planning for adequate drainage systems. Development in some areas has created or aggravated downstream drainage problems, and in many cases has created new wetland areas. Increased surface runoff from urbanization has overtaxed major drain outlets, resulting in flooding of land previously free from inundation. An example is the recent flood and drainage problems experienced along Sims and Brays Bayous in Harris County.

Since 1906, land subsidence ranging from approximately six inches to more than nine feet, has occurred in Harris, Montgomery, and Liberty Counties. Subsidence is least in the central and northern portions of the basin. More than nine feet of subsidence has occurred in Pasadena along the Houston Ship Channel due to clay compaction caused by ground-water withdrawals from the Gulf Coast Aquifer for industrial needs. Fault activation and movement are associated with subsidence within the basin. In Harris County, rates of vertical displacement along active faults have been observed to be from 0.012 to 0.111 foot per year. In urban and industrialized areas of the basin, active faults have caused severe damage to buildings, streets, highways, airport runways, railroads, and various pipeline systems. Along 95 miles of active faults in the Houston area, the total cost of damage to homes in the early 1970's was estimated to be over $2.6 million. Also in the Houston area, repair of damage to highways, railroads, pipelines, and storm and sanitary sewers was estimated to cost about $140 thousand annually. Subsidence and faulting within the basin are also caused by withdrawals of petroleum and saline ground water. To stop subsidence and faulting due to ground-water withdrawals, large supplies of surface water are being conveyed from the Trinity River and Lake Houston to eastern Harris County. However, significant rises of the land surface will not occur, since ground water cannot reenter the compacted clays.

There are indications that ground-water pumpage is increasing in the southwestern portion of the basin because of westward growth of the City of Houston. At this time there are no facilities to distribute surface waters to this area. For example, during the 1970's, pumpage in eastern Harris County decreased 47 percent, while pumpage in western Harris, northern Fort Bend, and eastern Waller Counties increased 26 percent. Municipal pumpage in the southwestern portion of the basin increased 730 percent during the 1970's. If this trend continues, subsidence and active faulting are expected to increase in the southwestern portion of the San Jacinto River Basin. For example, the area had about 1.4 feet of subsidence between 1943 and 1978. Between 1973 and 1978, about 0.50 foot or 36 percent of the 1.4 feet of subsidence occurred.

Recreation Resources

In addition to the San Jacinto River, major freshwater recreation resources in the basin include Lake Houston (12.2 thousand surface acres), Sheldon Reservoir (1.7 thousand surface acres), Lake Conroe (21 thousand surface acres), and Buffalo Bayou.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the San Jacinto River Basin is projected to grow 153 percent by 2030, from the present 2.4 million, which is 17 percent of the State population, to 6 million, 18 percent of the State population (Table III-10-3). A 56 percent increase to 3.7 million is expected from 1980 to the year 2000, and an even larger growth of 62 percent is anticipated from 2000 to 2030.

Harris County contains 92 percent of the basin population. From 1980 to 2030, the Harris County in-basin population is projected to increase 130 percent, but Harris County's percentage of basin population is expected to decline to 83 percent. Montgomery County population is expected to increase sixfold to 794.2 thousand by 2030, thereby increasing its percentage of basin population from 5.4 percent to 13.1 percent.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the San Jacinto River Basin were 476.8 thousand acre-feet in 1980.

Municipal requirements are projected to reach from 609.4 to 887.8 thousand acre-feet by year 2000. From 2000 to 2030, water needs are projected to increase 45-63 percent. The year 2000 and 2030 estimates are about 17 percent of total statewide municipal water requirement.

Table III-10-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]/
San Jacinto River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
San Jacinto Basin																		
Population			2,369.2			3,080.6			3,687.8			4,293.7			5,029.1			5,987.1
Municipal	309.8	167.0	476.8	202.0	531.4	733.4	214.4	673.4	887.8	221.5	813.9	1,035.4	227.1	987.0	1,214.1	234.3	1,211.5	1,445.8
Manufacturing	51.1	176.5	227.6	28.9	277.5	306.4	28.8	357.0	385.8	27.0	413.0	440.0	27.0	517.1	544.1	27.0	651.0	678.0
Steam Electric	15.9	7.0	22.9	16.9	6.0	22.9	16.9	17.0	33.9	16.9	22.4	39.3	16.9	27.7	44.6	16.9	33.1	50.0
Mining	5.5	0.0	5.5	5.8	.0	5.8	5.6	.4	6.0	5.8	0.4	6.2	6.1	0.3	6.4	6.4	0.2	6.6
Irrigation	82.9	3.8	86.7	46.3	21.5	67.8	39.4	21.5	60.9	33.8	21.5	55.3	29.2	21.5	50.7	25.3	21.6	46.9
Livestock	1.3	1.1	2.4	.4	2.3	2.7	.4	2.6	3.0	0.4	2.6	3.0	0.4	2.6	3.0	0.4	2.6	3.0
Basin Total Water	466.5	355.4	821.9	300.3	838.7	1,139.0	305.5	1,071.9	1,377.4	305.4	1,273.8	1,579.2	306.7	1,556.2	1,862.9	310.3	1,920.0	2,230.3

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

Industrial

Manufacturing water requirements in 1980 were 227.6 thousand acre-feet in the San Jacinto River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the San Jacinto River Basin are expected to almost double by the year 2030 to a potential high of 678 thousand acre-feet by 2030.

Approximately 15 percent of the statewide manufacturing water requirements in 1980 is centered in the San Jacinto River Basin, and this percentage is expected to be 13 percent by 2030. In 1980, almost all of the manufacturing water requirements in the San Jacinto River Basin was in Harris County, and this trend is expected to continue.

Major water users in the Harris County portion of the basin are petroleum refineries, industrial organic chemical producers, plastic materials and synthetics plants, and agricultural chemical manufacturers.

Steam-Electric Power Generation

Water requirements for steam-electric power generation will expand rapidly in the San Jacinto River Basin, with a projected significant increase in the use of saline water. Combined annual ground-water withdrawals could reach 50 thousand acre-feet annually in 2030, plus saline-water consumption for steam-electric power plant cooling (Table III-10-3).

Current efforts to reduce ground-water pumpage in the Houston area to avoid increasing land subsidence will affect future ground-water use by steam-electric power plants. The result will be an even more rapid shift from from ground-water sources to saline and fresh surface-water sources. If saline surface-water sources are chosen, it is also probable that future plants will be located in coastal basins rather than in the San Jacinto River Basin.

Technological innovations and concerted water-conservation efforts may alter this case; however, the use of saline water for cooling will still be the most effective means of conserving freshwater. Despite innovation and conservation, some freshwater will be needed at electrical generating plants to provide for boiler feedwater makeup and sanitary and maintenance uses. These freshwater requirements are very small when compared to cooling water requirements; however, if the plant is a coal- or lignite-fired power plant, freshwater requirements for dust control and especially stackgas scrubbing for sulfur dioxide control could be signficant.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the San Jacinto River Basin are projected to decrease a maximum of 30 percent from the 1980 level of 86.7 thousand acre-feet to 60.7 thousand by the year 2000 in the high and low cases. By 2030, water requirements in the basin are projected to be about 46.9 thousand acre-feet annually in the low and high cases to irrigate about 18.9 thousand acres.

Livestock

Small increases in livestock production are expected to develop in the basin. The projected annual livestock water requirement in 2030 is almost 3 thousand acre-feet. From the 1980 level of 2.4 thousand acre-feet, livestock water requirements are expected to gradually increase by 25 percent by 2030.

Mining

Between 1980 and 2030, mining water use in the San Jacinto River Basin is projected to increase from 5.5 thousand acre-feet to 6.6 thousand acre-feet. The basin share of total State mining water requirements is two percent in 1980 and is projected to maintain this percentage to the year 2030.

Water requirements by fuel mining industries engaged in secondary recovery of petroleum and natural gas are projected to account for 16 percent of the total increase in San Jacinto River Basin mining water requirements in 2030. Nonmetal mining water use is expected to increase from 3 thousand acre-feet in 1980 to 5.6 thousand acre-feet in 2030.

Navigation

No provisions are required for water supply to serve navigation in the San Jacinto River Basin. All navigation is in the coastal waters of the Houston Ship Channel, which has no freshwater lockage requirements.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the San Jacinto River Basin.

Estuarine Freshwater Inflows

The San Jacinto River discharges into the Trinity-San Jacinto estuary. An estimated 1.44 million acre-feet per year of gaged inflow from the San Jacinto River Basin, plus 666 thousand acre-feet of inflow from ungaged areas of the basin, to the Galveston Bay portion of this estuarine system is needed to sustain desired salinity limits for the Subsistence Alternative (Table III-10-4). Estimated gaged river inflows of 1.7 million acre-feet per year are needed from the San Jacinto River Basin, in addition to 693 thousand acre-feet annually of ungaged inflow from the basin, to meet salinity needs and maintain annual commercial fisheries harvests at no less than average historic levels for the 1962-1976 period (Harvest Maintenance Alternative) (Table III-10-4). The estimated gaged freshwater inflows needed from the San Jacinto River Basin for meeting the Fisheries Harvest Enhancement Alternative of maximizing shrimp production in the adjacent offshore area (Gulf Area No. 18) equals the annual inflow limit set at the average (1941-1976) annual gaged basin inflow. This inflow volume is slightly less than 1.6 million acre-feet (Table III-10-4). Ungaged inflows from the basin for this alternative are estimated at 693 thousand acre-feet. An estimated 398 thousand acre-feet per year of gaged inflow from the San Jacinto River Basin is needed for the Biotic Species Viability Alternative to maintain the monthly salinity limits (Table III-10-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the San Jacinto River Basin through the year 2030 is 337 thousand acre-feet. This supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the San Jacinto River Basin by decades from 1990 through 2030 is expected to be from 300.3 to 310.3 thousand acre-feet per year (Table III-10-3). The average ground-water use within the basin is expected to be about 305.6 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

Based only on existing water supply sources, shortages are expected in the San Jacinto River Basin beginning around the year 2010. However, under the proposed development for surface-water supplies to meet these anticipated shortages, the San Jacinto River Basin will have a net surplus of surface water in all decades through the year 2030 (Table III-10-5, Figure III-10-2). The projected annual surplus for all purposes amounts to 201.2 thousand acre-feet in 2000 and 95.4 thousand acre-feet in 2030. Yet, due to local limitations on ground water, irrigation water will be in short supply by about 17.9 thousand acre-feet in 2030. To meet all needs, water would have to be imported annually into the basin at the rate of 868.1 thousand acre-feet in 2000 and 1.57 million acre-feet by 2030.

The population growth of the Houston metropolitan area will necessitate additional water supplies for meeting the manufacturing and municipal needs of the basin by the year 2010. Anticipated needs up to the year 2010 can be met through the development of the Luce Bayou diversion project which will convey water from below Lake Livingston on the Trinity River to Lake Houston in the San Jacinto River Basin for the City of Houston and adjacent suburban areas.

Table III-10-4. Gaged River Inflow Needs of the Trinity-San Jacinto Estuary From the San Jacinto River Basin Under Four Alternative Levels of Fisheries Productivity[1]

	San Jacinto River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Shrimp Harvest Enhancement	Biotic Species Viability
January	181.5	181.5	181.5	24.4
February	153.0	153.0	153.0	10.6
March	110.6	110.6	110.6	18.2
April	154.5	154.5	154.5	55.2
May	197.0	197.0	197.0	49.3
June	124.1	124.1	124.1	30.9
July	85.4	85.4	182.5	37.1
August	84.4	84.4	117.5	24.8
September	98.0	98.0	98.0	59.0
October	57.0	57.0	57.0	42.4
November	52.9	230.5	52.9	19.3
December	139.0	224.4	139.0	26.8
Annual	1,437.4	1,700.4	1,570.6	398.0

[1]All inflows are mean monthly values in thousand acre-feet.
[2]San Jacinto River Basin inflow represents spills from Lake Houston plus downstream contributions from gaged bayous.

The permitted Luce Bayou diversion project, currently in the advanced planning and design stage by the City of Houston, will provide when completed, the capability for delivery of the remainder of the city's share of the Lake Livingston water supply. The project, as presently designed, will consist of a pumping station on the main stem of the Trinity River approximately 10 miles north of Liberty in Liberty County, a combined 96-inch diameter pipeline and 14 thousand-foot long open canal system extending across the Trinity-San Jacinto River Basin divide to the headwaters of Luce Bayou in the San Jacinto River Basin, and the bed and banks of Luce Bayou which flows into Lake Houston. The Luce Bayou diversion project will be capable of delivering up to 450 thousand acre-feet of water annually into Lake Houston—400 thousand acre-feet for municipal use and 50 thousand acre-feet for industrial purposes. The project is needed before 1990.

A significant portion of the projected manufacturing water needs in the Houston Ship Channel area could be satisfied in an economical manner through the reuse of municipal effluent from the City of Houston. Cost studies have indicated that 100 thousand acre-feet per year of municipal wastewater could be provided, at prices comparable to existing manufacturing water delivery systems, to major manufacturing water users along the Houston Ship Channel by the year 2000. This reuse would likely occur after full utilization of supplies provided by the Luce Bayou project and the Coastal Industrial Water Authority Canal.

By the year 2010, water will be needed from additional sources to avoid shortages in the San Jacinto River Basin. Several potential reservoir sites exist in the basin, and extensive studies of the feasibility and yields of these potential projects have been performed. Projects previously given serious consideration include the Lake Creek, Lower East Fork, and Cleveland Reservoir sites. However, urban and industrial development, the attendant escalating land costs associated with such development, and structural problems present at one site present serious difficulties for the economical development of these sites. The U.S. Bureau of Reclamation is currently studying the water resources of the basin to determine any viable major reservoir sites that could increase the basin's water supply storage.

Additional firm supplies are potentially available from the Trinity River Basin should the authorized Tennessee Colony Reservoir project be constructed. Agreements would have to be reached with local sponsors of this project and appropriate contracts consummated with the Corps of Engineers for acquisition of the conservation storage in this project. The incremental yield of the Tennessee Colony Reservoir project would satisfy only a part of the ultimate 2030 requirements in the San Jacinto River Basin, however.

Additional sources of water include the Neches and Sabine River Basins in East Texas. Existing reservoirs in those basins could meet anticipated in-basin needs, as well

Table III-10-5. Water Resources of the San Jacinto River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	300.3	—	—	—	300.3	300.3	—	—	300.3	.0	.0	.0
Surface Water	258.2	—	43.1	866.2	1167.5	832.6	—	.0	832.6	352.6	(17.7)	334.9
Total	558.5	—	43.1	866.2	1467.8	1132.9	—	.0	1132.9	352.6	(17.7)	334.9
2000												
Ground Water	305.5	—	—	—	305.5	305.5	—	—	305.5	.0	.0	.0
Surface Water	242.8	—	155.8	868.1	1266.7	1065.5	—	.0	1065.5	218.9	(17.7)	201.2
Total	548.3	—	155.8	868.1	1572.2	1371.0	—	.0	1371.0	218.9	(17.7)	201.2
2010												
Ground Water	305.4	—	—	—	305.4	305.4	—	—	305.4	.0	.0	.0
Surface Water	237.6	—	173.1	912.0	1322.7	1267.4	—	.0	1267.4	73.0	(17.7)	55.3
Total	543.0	—	173.1	912.0	1628.1	1572.8	—	.0	1572.8	73.0	(17.7)	55.3
2020												
Ground Water	306.7	—	—	—	306.7	306.7	—	—	306.7	.0	.0	.0
Surface Water	232.3	—	192.5	1199.8	1624.6	1549.8	—	.0	1549.8	92.5	(17.7)	74.8
Total	539.0	—	192.5	1199.8	1931.3	1856.5	—	.0	1856.5	92.5	(17.7)	74.8
2030												
Ground Water	310.3	—	—	—	310.3	310.3	—	—	310.3	.0	.0	.0
Surface Water	227.1	—	213.2	1568.7	2009.0	1913.6	—	.0	1913.6	113.3	(17.9)	95.4
Total	537.4	—	213.2	1568.7	2319.3	2223.9	—	.0	2223.9	113.3	(17.9)	95.4

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

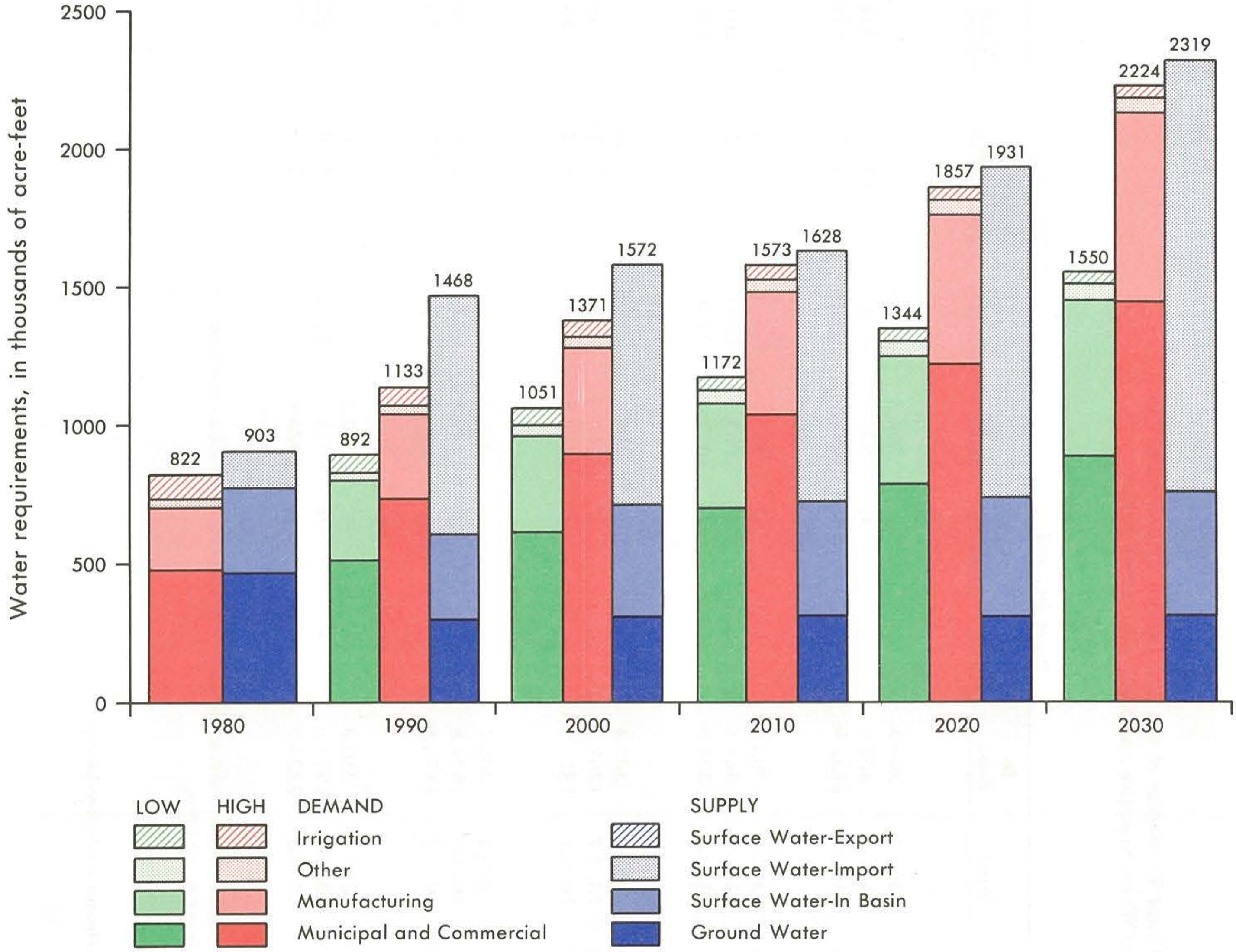


Figure III-10-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Jacinto River Basin, 1980-2030

as provide water to the Houston area through the year 2030 if Rockland Reservoir in the Neches River Basin is constructed by the year 2020 and Bon Weir Reservoir is completed in the Sabine by the year 2030. Additional conveyance facilities would be required to move surplus surface waters from the Neches and Sabine River Basins into the San Jacinto River Basin.

The feasibility and costs of conveying supplemental water from the lower Sabine and/or Neches River Basins into the Trinity River Basin, thence into the San Jacinto River Basin, have been given serious study in the past. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

Water Quality Protection

A water quality management plan for the San Jacinto River Basin has been developed pursuant to the requirements of the federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the greater Houston metropolitan area. These plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste-treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $1,037.2 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire San Jacinto River Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Existing water supply reservoirs in the San Jacinto River Basin have no provisions for flood-control storage. Dams on the Buffalo Bayou watershed, Addicks and Barker, were constructed by the Corps of Engineers in the 1940's for flood-control purposes. They provide a total storage capacity of 411.5 thousand acre-feet. Impounded waters are stored only until releases can be made without damaging property in downstream areas.

To date, flood-control measures implemented in the San Jacinto River Basin have been limited to local entities acting alone and the Corps of Engineers in cooperation with local entities. The Corps of Engineers has three authorized projects in the San Jacinto River Basin. The Buffalo Bayou and tributaries flood-control project has been underway for many years and, if funded, will ultimately result in a comprehensive plan for the control of flooding throughout the watershed. An interim feasibility report has been completed on Sims Bayou and has been forwarded to the Secretary of the Army with a favorable recommendation. There is a separately authorized project for channel improvement of Vince and Little Vince Bayous, which are also tributary to Buffalo Bayou. Construction is underway and is scheduled for completion in December 1986. Planning and engineering studies are underway on Upper White Oak Bayou and tributaries and are scheduled for completion in September 1985.

The authorized San Jacinto River and Tributaries project provides for a flood-control study of the San Jacinto River watershed including consideration of both structural and nonstructural measures. A survey report is due to be completed in September 1989.

The plan for the San Jacinto River Basin provides for coordination of local flood-control and flood-protection measures with planned projects and studies by the Corps of Engineers.

11. SAN JACINTO-BRAZOS COASTAL BASIN

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11. SAN JACINTO-BRAZOS COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The San Jacinto-Brazos Coastal Basin is bounded on the north by the San Jacinto River Basin, on the east by Galveston Bay and the Trinity-San Jacinto Coastal Basin, and on the west by the Brazos River Basin. Maximum elevation in the basin is about 100 feet, although most of the basin area has an elevation of less than 50 feet. The small streams which drain into Galveston Bay include Clear Creek, and Dickinson, Mustang, Chocolate, and Bastrop Bayous. Total basin drainage area is 1,440 square miles. For planning purposes, the basin is treated as a single hydrologic unit (Figure III-11-1).

Surface Water

Average annual runoff during the 1947-70 period was 802 acre-feet per square mile within the northern and central parts of the basin above the tidal-affected regions of the basin. The lowest runoff rates during the 1947-70 period occurred during 1954-56 and averaged 284 acre-feet per square mile. Lowest runoff occurred in 1956, with 137 acre-feet per square mile.

The majority of floods that strike this coastal basin result from torrential and persistent rainfall produced by tropical weather disturbances that migrate from the Gulf of Mexico inland across Texas' coastal plain. Some serious flooding occurs every few years in the spring as a result of bands of thunderstorms triggered by slow-moving cold fronts. The flood of 1957, which helped erase a long-standing, extreme drought, was one of the most memorable floods not related to a tropical cyclone. The basin sustained other disastrous floods in 1900, 1915, 1959, 1961, 1979, and 1981.

Nontidal reaches of streams in the San Jacinto-Brazos Coastal Basin generally have low concentrations of dissolved solids, commonly less than 400 milligrams per liter (mg/l). In tidal reaches, salinity increases markedly. Clear Lake varies widely in salinity, commonly containing from more than 12,000 to less than 400 mg/l total dissolved solids.

Ground Water

The Gulf Coast Aquifer underlies the entire San Jacinto-Brazos Coastal Basin. The aquifer extends to a maximum depth of about 2,600 feet in the northwest part of the basin. Yields of large-capacity wells average about 1,500 gallons per minute (gpm), but locally wells produce up to 3,200 gpm. The quality of water in the aquifer ranges from fresh to slightly saline. Over much of the area, total dissolved solids are less than 500 mg/l.

In the past, well fields for the Cities of Galveston and Freeport have had to be located further inland because of saline-water encroachment. Importation of surface water from the Trinity and Brazos Rivers to replace or supplement municipal and industrial ground-water pumpage should decrease the potential for saline-water encroachment. Within the basin, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great but can be controlled by proper well location, completion, and pumpage.

Population and Economic Development

The population of the San Jacinto-Brazos Coastal Basin was reported at 536.8 thousand in 1980. About 36 percent of the basin population resides in Galveston County, with another 29 percent and 25 percent living in portions of Harris and Brazoria Counties, respectively. Galveston, with a population over 61.9 thousand, is the largest city in the basin. It is followed by Texas City with a population over 41.4 thousand and Lake Jackson with an in-basin population of 18.1 thousand.

The economy of the area is based on oil production, petrochemical and other chemical manufacturing, agriculture, agribusiness, commercial fishing, and shipping activities associated with the Ports of Galveston, Freeport, and Texas City. Convention and recreation business round out the diversified basin economy.

Water Use

Municipal freshwater use in the San Jacinto-Brazos Coastal Basin totaled 86.8 thousand acre-feet in 1980, over 67 percent of which was supplied by ground water.

Figure III-11-1. San Jacinto-Brazos Coastal Basin

Twenty percent, or 17.3 thousand acre-feet, was used in Brazoria County, 39 percent (34.1 thousand acre-feet) in Galveston County, and 29 percent (25.5 thousand acre-feet) in Harris County.

Manufacturing industries used almost 22 percent (114.2 thousand acre-feet) of the total basin freshwater use in 1980. Ninety-six percent (109.2 thousand acre-feet) of the total used by manufacturers was derived from surface-water sources, while the remaining four percent (5.0 thousand acre-feet) was obtained from ground-water sources. The chemicals and petroleum refinery industries accounted for the largest part of the water required by manufacturing industries in 1980.

There was 3,385 megawatts of installed steam-electric power generating capacity in the San Jacinto-Brazos Coastal Basin in 1980, all plants used saline water for cooling. Small amounts of fresh water were used for boiler feedwater makeup, employee sanitation, and grounds maintenance. Ground-water pumpage for these purposes was about 1.8 thousand acre-feet, and surface-water use totaled less than 200 acre-feet. Saline-water consumption totaled approximately 13.0 thousand acre-feet.

In 1980, over 73.2 thousand acres was irrigated, mostly using surface water diverted from the Brazos River and from streams in the basin. In 1980, a total of 325.7 thousand acre-feet of water was used for irrigation in the basin, principally for rice production. About 316.1 thousand acre-feet of this on-farm use was supplied from surface-water diversions.

Estimated freshwater use by mining industries in the San Jacinto-Brazos Coastal Basin totaled 790 acre-feet in 1980. Nonmetal mining in Galveston County accounted for 57 percent of the total mining water used in the basin.

Livestock water use, predominantly for cattle production totaled about 1.1 thousand acre-feet in the basin in 1980. About 400 acre-feet was supplied from surface-water sources.

Navigation facilities in the San Jacinto-Brazos Coastal Basin include a portion of the Houston Ship Channel and Galveston Harbor and Channel, the Texas City Channel, Clear Creek and Clear Lake, Dickinson Bayou, and the Gulf Intracoastal Waterway and its tributary channels—Chocolate Bayou, Offatts Bayou, Bastrop Bayou, and Oyster Creek. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, total municipal and manufacturing return flows in the San Jacinto-Brazos Coastal Basin exceeded 131.8 thousand acre-feet.

Irrigation return flows in the San Jacinto-Brazos Coastal Basin in 1980 were estimated to total 74 thousand acre-feet, primarily from rice irrigation. Most of these return flows are discharged into estuarine waters.

Current Ground-Water Development

Approximately 76.2 thousand acre-feet of ground water was used in 1980 in the San Jacinto-Brazos Coastal Basin. Approximately 99 percent of this ground-water use was from the Gulf Coast Aquifer. The remaining small use was from the Brazos River Alluvium Aquifer.

Of the 76.2 thousand acre-feet of ground water used in the basin, 58.3 thousand acre-feet or 77 percent was for municipal purposes, and 9.6 thousand acre-feet or 13 percent was for irrigation purposes.

Within the basin, a significant overdraft of ground water from the Gulf Coast Aquifer occurred in 1980 in Galveston County due to excessive withdrawals for municipal, manufacturing, and steam-electric power generation purposes.

Current Surface-Water Development

There are no major reservoirs with conservation storage in the San Jacinto-Brazos Coastal Basin. However, two major diversion systems, the Canal A and Canal B systems owned and operated by the Brazos River Authority, serve as conveyance facilities to bring water from the Brazos River Basin to the irrigated areas and to the rapidly expanding industrial areas in the basin. The Chocolate Bayou Company and Dow Chemical also operate major diversion systems. Water is conveyed for irrigation and industrial purposes in Fort Bend and Brazoria Counties. Dow Chemical Company operates a Brazos River diversion in connection with an off-channel reservoir, Harris Reservoir in Brazoria County. Releases from this reservoir are conveyed downstream via Oyster Creek to the Dow Canal System. The water is used for industrial purposes and as a municipal water supply for the City of Freeport.

In the eastern part of the basin, the Galveston County Water Authority operates a 12.5 thousand acre-feet capacity off-channel reservoir which stores and regulates water diverted from the Brazos River through the Canal B system for municipal and manufacturing uses.

In 1980, approximately 454.4 thousand acre-feet of surface water was used within the San Jacinto-Brazos Coastal Basin. Of this total, 28.5 thousand acre-feet was used for municipal purposes, 109.2 thousand acre-feet was used by manufacturing industries, and 316.1 thousand acre-feet was used for irrigation. Diversions from the Brazos River Basin under existing permits supplied 394.2 thousand acre-feet of raw water through the Canal A and Canal B systems, while 28.0 thousand acre-feet was supplied from the San Jacinto River Basin through sales of treated water by the City of Houston to the Cities of Pasadena and Galveston, and an additional 31.1 thousand acre-feet supplied from the Trinity River Basin through the Coastal Industrial Water Authority System.

Water Rights

A total of 204,426 acre-feet of surface water was authorized or claimed for diversion and use in the San Jacinto-Brazos Coastal Basin as of December 31, 1983 (Table III-11-1). Authorized and claimed diversions for municipal use amounted to 12,000 acre-feet, or almost six percent of the total amount of water authorized or claimed in the basin (Table III-11-2).

Water Quality

Most of the segments in this basin are small coastal streams, bayous, and bays which receive various amounts of treated sewage, industrial discharges, and agricultural, urban, and industrial runoff. Nutrients, especially phosphorus, are consistently high throughout most of the basin. Phytoplankton standing crops are also high throughout most of the basin, resulting in wide dissolved-oxygen fluctuations due to algal photosynthesis and respiration. Total and fecal coliform bacterial levels are also elevated in many segments.

The Clear Lake basin experiences the most eutrophication-related problems, probably because the population density in the basin is high and the water quality in the adjacent portion of Galveston Bay is relatively poor. Bastrop, Christmas, and Drum Bays characteristically have good water quality because they are located in a sparsely populated area and receive no direct wastewater discharges. Lower Oyster Creek also exhibits problems with low dissolved oxygen levels and elevated levels of nutrients and bacteria.

Table III-11-1. Authorized or Claimed Amount of Water, by Type of Right, San Jacinto-Brazos Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	23	168,733
Claims	40	27,103
Certified Filings	4	8,590
Certificates of Adjudication	0	0
Total Authorizations and Claims	67	204,426

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include 10 authorized diversions of saline water amounting to 9,407,385 acre-feet/year. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Flooding, Drainage, and Subsidence

As a result of Hurricane Carla in 1961, Brazoria and Galveston Counties recorded flood damages to agriculture

Table III-11-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, San Jacinto-Brazos Coastal Basin

Type of Use	Number of Rights	Basin Total
Municipal	1	12,000
Industrial[2]	7	95,669
Irrigation	58	94,037
Recreation	7	2,720
Total	67[1]	204,426

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include 10 authorized diversions of saline water amounting to 9,407,385 acre-feet/year.

of $4.25 million and nonagricultural flood damages of $96.5 million. Tropical Storm Claudette in July 1979 produced record rainfall and record flood damages. As a result of a federal disaster declaration, over $4.1 million was spent in flood relief and 9,737 flood insurance claims were filed for $138.7 million in flood damages. Additional heavy rainfall in September 1979 resulted in another disaster declaration for the basin and an additional $574 thousand in flood relief. Massive flooding in 1981 in the Galveston-La Marque-Texas City area produced 2,464 flood insurance claims for $11.5 million in flood damages. During the years 1977, 1978, and 1980, less serious flooding produced 570 flood insurance claims for $2.5 million in flood damages.

Unincorporated areas of Brazoria, Galveston, and Harris Counties are participating in the Regular Phase of the National Flood Insurance Program, and have 100-year base flood elevation data. Fort Bend County has not as yet entered the program. Within the basin, a total of 31 cities are in the Regular Phase and 7 cities are in the Emergency Phase. Efforts are underway to establish 100-year flood elevations throughout the basin.

As urbanization has increased so have drainage problems. Improvement of major drainage outlets is required if drainage systems are to keep pace with urbanization. This is evident in the Clear Creek area where increased urban runoff frequently exceeds channel capacities. In cultivated areas, drainage improvements are necessary to enhance crop yields. These improvements may consist of land levelling or more elaborate installations of subsurface drainage and collection ditches. Work is necessary in most areas to improve the shallow, natural drainage systems; however, care must be taken to avoid damaging wetland habitats.

Since 1906 within the San Jacinto-Brazos Coastal Basin, subsidence, ranging from approximately 0.5 foot to more than eight feet, has occurred in Galveston, Harris, Brazoria, and Fort Bend Counties. The least amounts of subsidence are in south-central Brazoria County. More than six feet of subsidence has occurred in Texas City. The subsidence is due to clay compaction caused by ground-water withdrawals from the Gulf Coast Aquifer for industrial needs. More than two feet of subsidence has occurred at Freeport due to ground-water withdrawals. The most subsidence within the basin was about eight feet in Deer Park in the northern part of the basin southwest of the San Jacinto Monument. This area is part of the subsidence "bowl" caused mainly by the concentrated historical ground-water withdrawals in the Houston Ship Channel area in the San Jacinto River Basin. Fault activation and movement are associated with subsidence within the San Jacinto-Brazos Coastal Basin. Active faults have been identified in Harris and Galveston Counties within the basin. In urban and industrialized areas in Harris and Galveston Counties, active faults have caused severe damage to buildings, streets, highways, airport runways, railroads, and various pipeline systems. Subsidence and faulting has caused inundation by bay waters of part of the San Jacinto Monument State Park in eastern Harris County within the basin. Subsidence and faulting are also caused by withdrawals of petroleum and associated saline ground-water within the basin. To stop subsidence and faulting due to ground-water withdrawals, large supplies of surface water are being conveyed from the Brazos and Trinity Rivers to Harris and Galveston Counties within the basin.

Recreation Resources

Similar to other coastal basins in the State, water-oriented recreation resources available in the San Jacinto-Brazos Coastal Basin are directed primarily toward meeting the needs of the marine recreationist. An estimated 306 thousand sport fishing parties visited the Trinity-San Jacinto estuary during 1976-1977. The Trinity-San Jacinto estuary extends into the San Jacinto-Brazos Coastal Basin. The recreation use by the sport fishermen produced an estimated total economic impact of $13.4 million to regional and State economies. There are no major reservoir facilities located in the basin and the limited amount of freshwater recreation resources available in the area are restricted to shoreline activities along streams and ponds.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the San Jacinto-Brazos Coastal Basin is projected to more than double by 2030, from the present 536.8 thousand to 1.4 million (Table III-11-3). A 73 percent increase is projected from 1980 to the year 2000, yielding a population of 926.9 thousand. A slightly smaller growth of 55 percent is anticipated from 2000 to 2030.

Galveston County population is expected to grow 106 percent by 2030, compared to 142 percent for the State. However, the county percentage of basin population is expected to decline from 36.2 percent in 1980 to 28.3 percent in 2030. In comparison, the Fort Bend County in-basin population is predicted to grow the fastest, 396.4 percent from 1980 to 2030, and as a result its percentage of basin population is projected to increase from 9.9 percent to 18.7 percent by 2030. Harris County, with a 1980 to 2030 growth of 163.5 percent, is expected to maintain its in-basin population percentage of 29 percent.

Table III-11-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
San Jacinto-Brazos Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
San Jacinto-Brazos Basin																		
Population			536.8			738.9			926.9			1,077.5			1,242.1			1,434.1
Municipal	58.3	28.5	86.8	63.5	99.4	162.9	82.5	126.2	208.7	88.3	154.6	242.9	92.3	188.0	280.3	97.7	226.2	323.9
Manufacturing	5.0	109.2	114.2	0.0	168.4	168.4	0.0	224.3	224.3	0.0	287.1	287.1	0.0	362.0	362.0	0.0	458.4	458.4
Steam Electric	1.8	0.2	2.0	2.0	0.0	2.0	2.0	0.0	2.0	2.0	0.0	2.0	2.0	0.0	2.0	2.0	0.0	2.0
Mining	0.8	0.0	0.8	0.9	0.0	0.9	1.1	0.0	1.1	1.1	0.0	1.1	1.1	0.0	1.1	1.0	0.0	1.0
Irrigation	9.6	316.1	325.7	9.4	217.1	226.5	6.3	205.8	212.1	6.3	205.1	211.4	3.3	208.2	211.5	2.3	208.9	211.2
Livestock	0.7	0.4	1.1	0.5	0.8	1.3	0.5	0.9	1.4	0.5	0.9	1.4	0.5	0.9	1.4	0.5	0.9	1.4
Basin Total Water	76.2	454.4	530.6	76.3	485.7	562.0	92.4	557.2	649.6	98.2	647.7	745.9	99.2	759.1	858.3	103.5	894.4	997.9

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the San Jacinto-Brazos Coastal Basin are projected to increase from the 1980 level of 86.8 thousand acre-feet by a projected maximum of 140 percent by the year 2000. By 2030, water requirements range from 194.9 to 323.9 thousand acre-feet low and high case, respectively.

Industrial

Manufacturing water requirements in 1980 were 114.2 thousand acre-feet in the San Jacinto-Brazos Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the San Jacinto-Brazos Coastal Basin are projected to increase more than three times by the year 2030, to a potential high of 458.4 thousand acre-feet by 2030 (high case). Galveston County accounts for most of the basin use in the production of industrial organic chemicals and petroleum refining.

Steam-Electric Power Generation

In 1980, almost two thousand acre-feet was used for power generation in the San Jacinto-Brazos Coastal Basin. Little increase is projected in consumption of fresh water in this basin. From 1980 to 2030 steam-electric generating water requirements are projected to increase only one percent. Plants using saline water for cooling require small amounts of fresh water for boiler feedwater makeup, employee use, sanitation, and other applications such as grounds maintenance. These freshwater consumption requirements will probably not exceed several hundred acre-feet, although total freshwater withdrawal requirements will be higher. Significant amounts of fresh water, however, will be required if expanded or new plants are coal- or lignite-fueled and are required to use stackgas scrubbers.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of future change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the San Jacinto-Brazos Coastal Basin are projected to decrease from the 1980 level of 325.7 thousand acre-feet by a projected maximum 35 percent by the year 2000 in the high case. In the year 2030, water requirements in the basin are projected to be about 211.2 thousand acre-feet annually in the low and high cases to irrigate about 71.0 thousand acres.

Livestock

Cattle production in the San Jacinto-Brazos Coastal Basin is expected to increase livestock water use to 1.4 thousand acre-feet annually by the year 2030. From 1980 to 2030, livestock water requirements are predicted to increase by 27 percent.

Mining

Mining water use in the San Jacinto-Brazos Coastal Basin is projected to only increase 25 percent from 1980 to 2030 (0.8 thousand to 1.0 thousand acre-feet). Nonmetal mining operations required 62 percent of the basin mining water use in 1980; by 2030, nonmetal mining is projected to be 85 percent or 0.9 thousand acre-feet annually. By the year 2030, water used in the secondary recovery of petroleum and natural gas is expected to account for 0.1 thousand acre-feet primarily in Brazoria and Harris Counties.

Navigation

There is no anticipated regulated freshwater requirement for navigation in the basin through the year 2030.

Hydroelectric Power

No hydroelectric power generation facilities are planned in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the San Jacinto-Brazos Coastal Basin through the year 2030 is 110.5 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the San Jacinto-Brazos Coastal Basin by decade from 1990 through 2030 is expected to be from 76.3 to 103.5 thousand acre-feet per year (Table III-11-3). The approximate average annual projected ground-water use within the basin is expected to be about 93.7 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

The San Jacinto-Brazos Coastal Basin is projected to experience water shortages by 1990 if only the existing water supply sources are available to supply the anticipated needs. However, based on the proposed development, the projected surface-water requirements in the basin can be met with only minor irrigation shortages through the year 2030 (Table III-11-4, Figure III-11-2). Supplies to the basin provided from the Brazos River Basin and proposed interbasin surface-water transfers from the Neches and Sabine River Basins are projected to be 545.3 thousand acre-feet annually in 2000 and 881.7 thousand acre-feet by 2030. The irrigation shortages are forecast to occur due to localized limited ground-water availability.

There are no major reservoirs proposed for the basin. Off-channel reservoirs for holding excess flows pumped from the Brazos River Basin may be developed to augment existing surface-water resources and to abate the effects of high salinity conditions. Projected surface-water needs are anticipated to be partially met through existing water rights and contracts with the Brazos River Authority for water from the Brazos River Basin. Additional surface-water supplies will be needed by the year 1990 above those currently available from the Brazos River Basin. The development of the proposed South Bend Reservoir in the Brazos River Basin by 1990 would supply additional projected water needs until 2000. An alternative for providing surface water needed by 2000 and beyond to year 2030 is the construction of water conveyance canals and pipelines from the Neches and Sabine River Basins in East Texas. Sufficient supplies presently exist in those basins to meet anticipated increases in surface-water needs in this basin until the year 2020 when Rockland Reservoir or alternative water supply projects are projected to be needed in the Neches River Basin. By the year 2030, projected increases in surface-water needs in this basin will require the construction of an additional major reservoir in the Sabine or Neches River Basins if water shortages are to be avoided. Additional studies will have to be done by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such major interbasin transfers of water. Bon Wier Reservoir in the Sabine River Basin is an alternative project to meet this need.

Water Quality Protection

A water quality management plan for the San Jacinto-Brazos Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the greater Houston metropolitan area. These plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $158.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire San Jacinto-Brazos Coastal Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Table III-11-4. Water Resources of the San Jacinto-Brazos Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	76.3	—	—	—	76.3	76.3	—	—	76.3	.0	.0	.0
Surface Water	.0	—	.0	474.0	474.0	474.0	—	.0	474.0	.0	.0	.0
Total	76.3	—	.0	474.0	550.3	550.3	—	.0	550.3	.0	.0	.0
2000												
Ground Water	92.4	—	—	—	92.4	92.4	—	—	92.4	.0	.0	.0
Surface Water	.0	—	.0	545.3	545.3	545.3	—	.0	545.3	.0	.0	.0
Total	92.4	—	.0	545.3	637.7	637.7	—	.0	637.7	.0	.0	.0
2010												
Ground Water	98.2	—	—	—	98.2	98.2	—	—	98.2	.0	.0	.0
Surface Water	.0	—	.0	634.0	634.0	635.8	—	.0	635.8	.0	(1.8)	(1.8)
Total	98.2	—	.0	634.0	732.2	734.0	—	.0	734.0	.0	(1.8)	(1.8)
2020												
Ground Water	99.2	—	—	—	99.2	99.2	—	—	99.2	.0	.0	.0
Surface Water	.0	—	.0	745.9	745.9	747.2	—	.0	747.2	.0	(1.3)	(1.3)
Total	99.2	—	.0	745.9	845.1	846.4	—	.0	846.4	.0	(1.3)	(1.3)
2030												
Ground Water	103.5	—	—	—	103.5	103.5	—	—	103.5	.0	.0	.0
Surface Water	.0	—	.0	881.7	881.7	882.5	—	.0	882.5	.0	(.8)	(.8)
Total	103.5	—	.0	881.7	985.2	986.0	—	.0	986.0	.0	(.8)	(.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

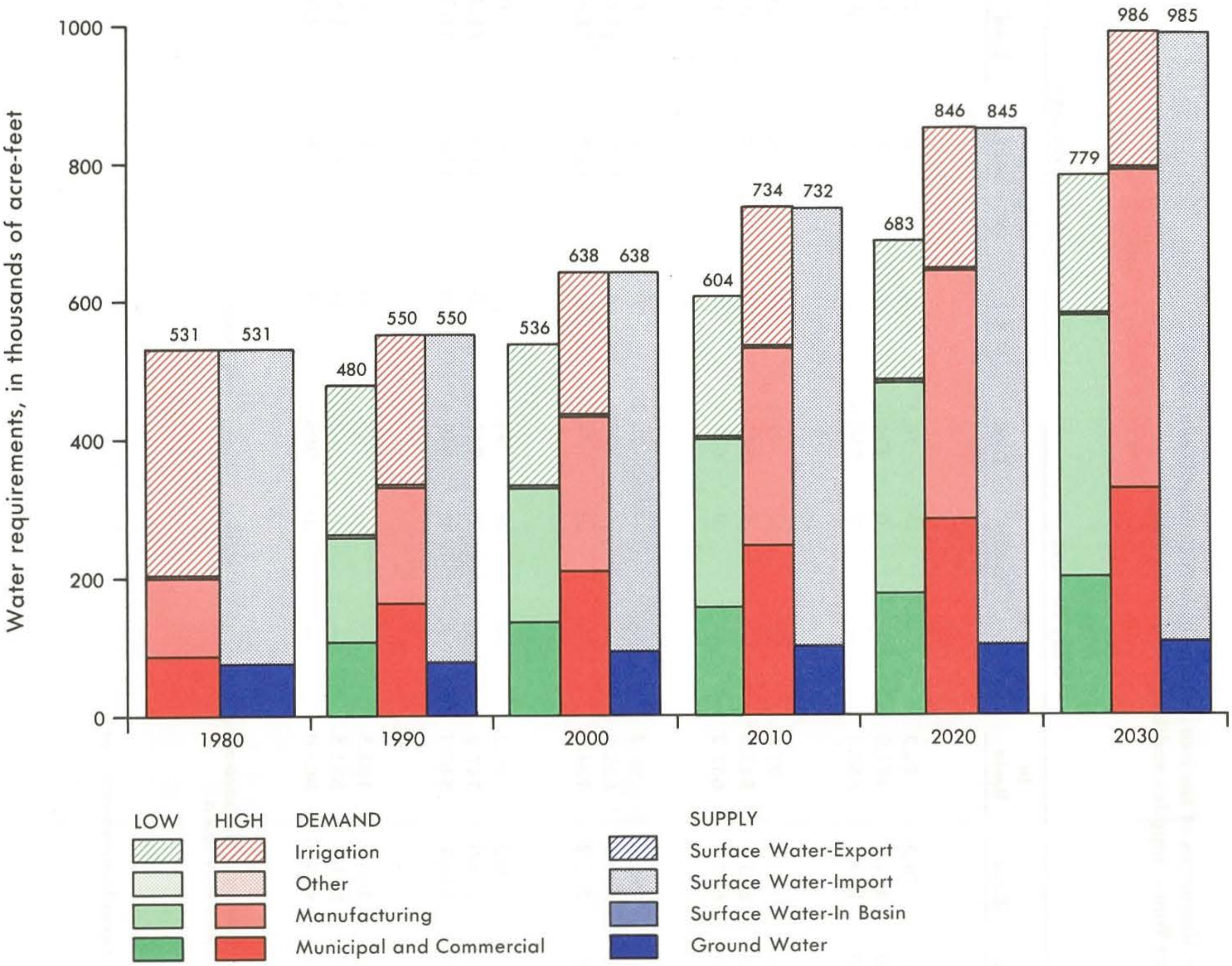

Figure III-11-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Jacinto-Brazos Coastal Basin, 1980-2030

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

There are no existing flood-control reservoirs in the San Jacinto-Brazos Coastal Basin. Present flood-control measures include channel improvements, levees, floodproofing, flood-plain zoning, and elevation of structures. The Texas City Hurricane-Flood Protection project, authorized in 1958, provides hurricane and tidal flood protection to Texas City. The project consists of approximately 17 miles of levees and sea walls.

The Flood Control Act of 1968 authorized the U.S. Army Corps of Engineers to enlarge and rectify the natural channel of Clear Creek. The project is awaiting appropriations from Congress for construction. The project will eliminate most damages from floods having an expected recurrence interval of 100 years or less in the active growth areas of Harris and Galveston Counties.

Construction of the Highland Bayou Flood Protection project was begun by the Corps of Engineers in August 1974. The project, consisting of channel improvements and a diversion channel, will provide flood protection to La Marque and Hitchcock.

The Galveston Seawall provides some protection to downtown Galveston from tidal flooding, and additional studies are underway by the Corps of Engineers to determine feasibility of providing hurricane flood protection to low-lying areas.

The Freeport Hurricane Flood Protection project, begun by the Corps of Engineers in 1965, has been completed. The project, which provides protection from hurricane flooding to Freeport and vicinity, includes 38 miles of improved levees, 2 miles of new levees, drainage structures, pumping plants, and a tide-control structure.

The Corps has a flood damage prevention study underway on Dickinson Bayou. This study is scheduled for completion in April 1987.

12. BRAZOS RIVER BASIN

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12. BRAZOS RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Brazos River Basin is bounded on the north by the Red River Basin, on the east by the Trinity and San Jacinto River Basins and the San Jacinto-Brazos Coastal Basin, and on the south and west by the Colorado River Basin and the Brazos-Colorado Coastal Basin. Elevation ranges from about 4,700 feet near Plainview on the High Plains to sea level at the mouth of the Brazos River near Freeport. Total basin drainage area is 45,573 square miles, of which about 43,000 square miles is in Texas and the remainder in New Mexico. Approximately 9,566 square miles of drainage area in the basin, mostly in the High Plains, is noncontributing. The Brazos River Basin varies in width from about 70 miles in the High Plains to approximately 110 miles in the vicinity of Waco, then decreases gradually in width to approximately 10 miles near Richmond. Headwaters of the White River form near Floydada (Floyd County), southeast of Plainview. Headwaters of the Salt Fork form in northwestern Garza County at an elevation of approximately 2,400 feet. The White River joins the Salt Fork Brazos River in northwestern Kent County, and the confluence of the Salt Fork and Double Mountain Forks of the Brazos River is located in eastern Stonewall County. Principal tributaries of the Brazos River downstream from this confluence include the Clear Fork Brazos River, Bosque River, Little River (formed by the confluence of the Leon and Lampasas Rivers) Yegua Creek, and the Navasota River. For planning purposes, the basin is divided into six zones (Figure III-12-1).

Surface Water

The average annual runoff in the Brazos River Basin for the period 1941 through 1970 was 156 acre-feet per square mile of contributing area. The average annual runoff ranged from about 530 acre-feet per square mile near the mouth to less than 50 acre-feet per square mile near the escarpment of the High Plains.

The lowest runoff for consecutive years during the period 1941 through 1970 occurred during the years 1951 through 1956 and 1962 through 1964. During the period 1951 through 1956, annual runoff averaged 39 acre-feet per square mile, and for the period 1962 through 1964 annual runoff averaged 45 acre-feet per square mile. The two lowest annual runoff rates occurred in 1951 and 1956, when annual runoff was 20 and 22 acre-feet per square mile, respectively.

The flat terrain of the High Plains portion of the Brazos River Basin produces shallow or sheet flooding due to the slow movement of water over the surface. Flooding is almost exclusively confined to the warmer half of the year (April-September); during this time gigantic thunderstorms will unleash very heavy rainfall in short periods of time. These short-term deluges can fill a dry streambed in a matter of a few hours—if not minutes—and the resultant overflow inundates bridges, overpasses, and low-lying residential areas. Normally, most of the water flows into playa lakes where it forms ponds and causes local, minor flooding.

The coastal regions of the Brazos River Basin experience flooding from frontal-type storms, hurricanes, and thunderstorms. The two most devasting storms and resulting floods occurred in 1913 and 1957. These floods were the result of prolonged, torrential rains.

Sources of saline water, primarily of natural origin, in the upper Brazos River Basin partially degrade the chemical quality of the river throughout its entire length. Flows of the Salt Fork, parts of the Double Mountain Fork, and the mainstream of the Brazos River above Possum Kingdom Reservoir are too saline for most beneficial uses. As a result of this natural salt pollution in the upper basin, waters in the three mainstream reservoirs, Possum Kingdom, Granbury, and Whitney, are unsuitable for municipal water supply without special and costly treatment processes. The principal sources of natural salt (sodium chloride) in the upper basin are springs and seepages in the drainage area of the Salt Fork. The major salt contributing tributaries include Croton, Salt Croton, and North Croton Creeks in Stonewall County; Salt Creek in Kent County; and McDonald Creek in Northern Garza County. In addition, large quantities of calcium and sulfate are contributed from the solution of gypsum-bearing formations which are widespread in the upper Brazos Basin. The daily loads of dissolved solids to the Salt Fork Brazos River are estimated to be 1,760 tons per day.

The quality of the river improves significantly in the lower basin as the salinity decreases because of the substantial dilution by good quality water from tributaries below Whitney Reservoir. The contributions of water from tributaries such as the Paluxy River, Little River, and the Navasota River decrease the extreme variations in mineral concentrations and thus provide water of a uniform quality in the lower basin. However, during periods of decreased

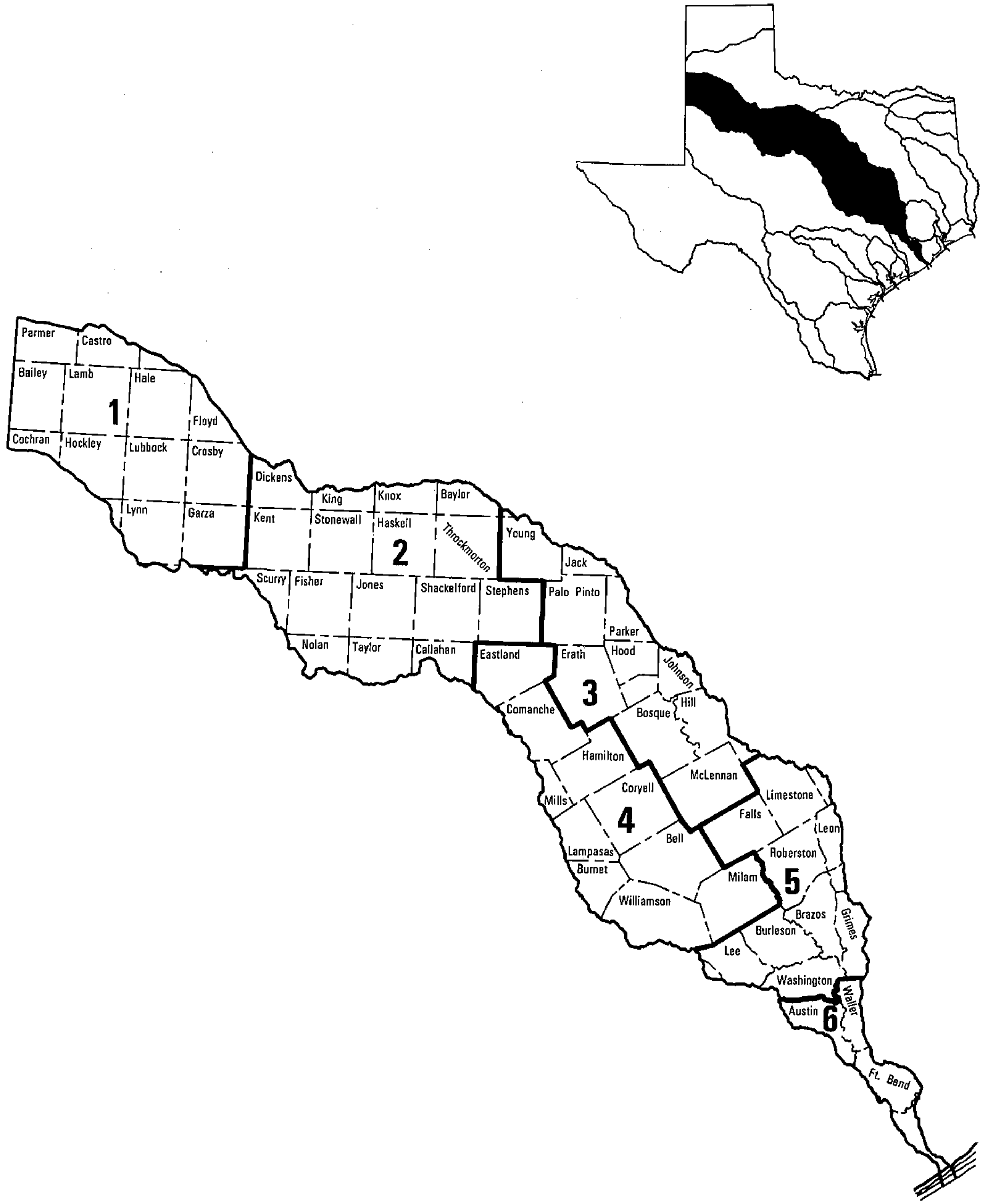

Figure III-12-1. Brazos River Basin and Zones

streamflow in the lower basin, the total dissolved-solids concentrations in the mainstem nearer Richmond in Fort Bend County have exceeded 500 milligrams per liter (mg/l).

Highly saline waters resulting from oil and gas exploration and production continue to degrade the chemical quality of many streams in the basin, particularly within the drainage areas of the Clear Fork Brazos River and the Navasota River; however, the quality of the rivers has improved significantly in recent years. Regulation of streamflow by Possum Kingdom Lake and Lake Whitney on the main stem, and contributions of good quality water from most downstream tributaries such as the Paluxy River, Little River, Navasota River, and San Gabriel River, decrease extreme variations in mineral concentrations and thus provide water of a more uniform quality in the lower basin. Nevertheless, chloride and sulfate concentrations and the excessive hardness of flows of the main stem have severely limited full potential use of the surface-water resources of the basin.

Ground Water

The Trinity Group Aquifer produces water in the central part of the Brazos River Basin. Total thickness ranges from about 230 to 1,200 feet. Yields of large-capacity wells average 200 gallons per minute (gpm), although locally wells produce up to 1,000 gpm. The ground water is fresh through much of the aquifer, but quality deteriorates gradually downdip.

The Edwards (Balcones Fault Zone) Aquifer extends into Williamson and southern Bell Counties in the central part of the basin. The aquifer is approximately 250 feet thick. Yields of high-capacity wells range up to 2,000 gpm. Ground water produced from the aquifer is relatively hard, but in most areas contains less than 500 mg/l total dissolved solids.

The Carrizo-Wilcox Aquifer occurs in the central part of the basin, and includes the Wilcox Group and the Carrizo Formation of the Claiborne Group. Total thickness of the aquifer ranges from less than 100 to more than 2,200 feet. Yields of large-capacity wells range between 300 and 3,000 gpm. The water generally contains less than 1,000 mg/l total dissolved solids, but quality deteriorates rapidly downdip.

The Gulf Coast Aquifer occurs in the lower part of the basin and extends to a maximum depth of about 3,000 feet. Yields of large-capacity wells average 1,500 gpm, ranging up to 3,400 gpm. Ground water produced from the Gulf Coast Aquifer is generally fresh, but quality deteriorates with depth, particularly near the Coast.

The High Plains (Ogallala) Aquifer underlies a large portion of the upper Brazos River Basin. In 1980, the saturated thickness of the High Plains Aquifer within the basin ranged from about 20 to 260 feet. Yields of large-capacity wells average about 550 gpm; although locally wells produce up to 1,000 gpm. Generally, the water has less than 1,000 mg/l total dissolved solids. However, in some areas of the basin ground water of the High Plains (Ogallala) Aquifer has fluoride concentrations which exceed Environmental Protection Agency-Texas Department of Health primary standards for fluoride.

The Alluvium Aquifer within the Brazos River Basin includes the Seymour Formation and the Brazos River Alluvium. The Seymour Formation constitutes an important aquifer in isolated areas within the west-central part of the basin. The total thickness ranges up to 165 feet. Yields of large-capacity wells average 280 gpm, but locally wells produce up to 1,300 gpm. The quality of the water ranges from 500 to more than 3,000 mg/l total dissolved solids.

The Brazos River Alluvium Aquifer occurs in a narrow band along the course of the Brazos River from McLennan County to Fort Bend County. The total thickness ranges from approximately 15 to 200 feet. Yields of large-capacity wells average 500 gpm, but locally wells produce as much as 1,350 gpm. Most of the water in the aquifer contains less than 1,000 mg/l total dissolved solids, but locally the ground water contains as much as 2,700 mg/l total dissolved solids.

The Santa Rosa Aquifer occurs in the western part of the Brazos River Basin, primarily in Scurry County. The total thickness is approximately 300 feet. Well yields range from about 50 to 100 gpm. The water is generally fresh, containing less than 500 mg/l total dissolved solids.

The Woodbine Aquifer produces water in a small area in Hill and Johnson Counties in the central part of the basin. The total thickness is less than 500 feet, with 40 to 50 percent net sand. Yields of high-capacity wells average less than 200 gpm. Water in the aquifer is fresh to slightly saline, with quality deteriorating downdip and to the south where the sand facies of the Woodbine Formation pinches out.

The Queen City Aquifer occurs in the lower part of the Brazos River Basin. Total thickness ranges up to about 500 feet, with 50 to 60 percent sand. Yields of most wells are relatively low, few exceeding 250 gpm. The water generally contains less than 500 mg/l total dissolved solids, but quality deteriorates downdip.

The Sparta Aquifer occurs in the lower part of the Brazos River Basin. Total thickness reaches a maximum of approximately 300 feet. Yields of large-capacity wells average about 325 gpm although locally wells produce as much as 500 gpm. Total dissolved solids of water in the aquifer is generally less than 1,000 mg/l, but water quality deteriorates downdip.

Within the Brazos River Basin, the Nacatoch Sand Aquifer occurs only in a small part of Limestone County. Total thickness ranges up to about 350 to 400 feet. No large-capacity wells are known to produce from this aquifer in the basin. The water ranges from fresh to slightly saline.

The Hickory Sandstone Aquifer occurs in a narrow strip in the central part of the basin. The thickness ranges from 300 to 450 feet. Few wells have been completed in the Hickory Sandstone in the Brazos River Basin, but high-capacity wells produce from 200 to 500 gpm in the adjoining Colorado River Basin. The quality of water in the Hickory Sandstone in the Brazos River Basin is slightly saline, as only the downdip portion of the aquifer is present in the basin.

The Ellenburger-San Saba Aquifer also occurs in a narrow strip in the central part of the Brazos River Basin. The total thickness ranges up to about 1,000 feet in the basin. Wells producing from the aquifer in the adjoining Colorado River Basin yield as much as 1,000 gpm.

The Marble Falls Limestone Aquifer occurs only in two isolated areas in Lampasas and Burnet Counties. The unit reaches a maximum thickness of approximately 600 feet. Wells completed in the aquifer in the Colorado River Basin yield as much as 2,000 gpm.

The Edwards-Trinity (High Plains) Aquifer occurs in the far western part of the Brazos River Basin. Total thickness ranges up to 300 feet. Well yields are generally low except in local areas where the limestone portion of the aquifer is saturated. The quality of the water ranges from slightly to moderately saline.

Highly mineralized ground water occurs locally in Quaternary, Cretaceous, Triassic, Permian, and Pennslyvanian rocks within the upper part of the Brazos River Basin. Where these rocks are in contact locally with saturated deposits of the High Plains (Ogallala), Alluvium, Santa Rosa, and Trinity Group Aquifers, the potential for saline-water encroachment is great. In these local areas depletion of storage within these aquifers will cause highly mineralized ground water to invade the depleted fresh to slightly saline water deposits. In the High Plains area within the Brazos River Basin, brine occurs in and beneath saline lakes. Some of the water in some of the lakes and in the Quaternary and Cretaceous deposits beneath the lakes have total dissolved solids in excess of 100,000 mg/l. In most cases, the water in the lakes and the ground water beneath the lakes are hydraulically connected to the High Plains (Ogallala) Aquifer. Mining of usable quality ground water from the High Plains (Ogallala) Aquifer in areas adjacent to these saline lakes and their associated saline water-bearing deposits, particularly near the southeastern flanks of the lakes, can cause saline-water encroachment. Saline lakes with associated saline water-bearing deposits are known to occur in Bailey, Lamb, Hockley, Terry, and Lynn Counties within the Brazos River Basin.

Potential saline-water encroachment problems due to reductions in artesian pressures exist in the Trinity Group Aquifer in Hill, McLennan, Falls, and Bell Counties, and in the Gulf Coast Aquifer in Brazoria County. If the reduction in artesian pressure continues, saline water which is under high artesian pressure will move into the depressured fresh-water zones.

Population and Economic Development

The population of the Brazos River Basin was reported at 1.53 million in 1980. Lubbock is the largest city in the basin with a 1980 population of 174.0 thousand or 11.4 percent of the basin total. It is followed in size by Waco, Abilene, Bryan-College Station, Killeen, and Temple, all of which have populations of 25.0 thousand or more.

The overall economy of the basin is based principally on agriculture, agribusiness, varied manufacturing, and mineral production and processing. Lubbock, in the High Plains, is the location of the world's largest cottonseed processing center. Agricultural production throughout the basin is varied and extensive. Principal crops include cotton, sorghums, vegetables, soybeans, and peanuts. Livestock production includes cattle, poultry, hogs, sheep, goats, and turkeys.

The diverse manufacturing activities in the basin include processing of oilseed, manufacture of earth-moving and farm equipment, mobile homes, food containers, glass products, tires, furniture, clothing, and rocket fuel. Mineral activities include oil, gas, stone, cement, sand, gravel, clay, salt, and sulphur production. Federal government expenditures and extensive recreation round out the basin economy.

Water Use

Municipal water use in the Brazos River Basin totaled 290.4 thousand acre-feet in 1980. Ground-water sources supplied over 42 percent of the total municipal water needs in 1980.

The City of Lubbock used almost 12 percent of the total municipal water used in the basin in 1980, the City of

Abilene used almost 8 percent, and the City of Waco over 10 percent.

Manufacturing industries in the basin rely heavily upon surface-water supplies. In 1980, about 95 percent of the total manufacturing water use (209.5 thousand acre-feet) was supplied from surface-water sources. About 87 percent (182.4 thousand acre-feet) of the total 1980 water use occurred in Zone 6.

In 1980, there was 8,861 megawatts of steam-electric power generation capacity operating in the Brazos River Basin. About 5.3 thousand acre-feet of ground water was withdrawn and over 50.1 thousand acre-feet of surface water was evaporated by steam-electric power plants in the basin during 1980. This includes 17.2 thousand acre-feet of estimated net adjusted evaporation for cooling reservoirs. In addition, 10.0 thousand acre-feet of water was used to fill Comanche Peak Reservoir, an off-stream cooling reservoir, and 4.2 thousand acre-feet of treated municipal effluent was used for power plant cooling. Much of the electric power generated in the basin is distributed to other areas of the State.

In 1980, about 2.6 million acres was irrigated in the Brazos River Basin requiring 3.4 million acre-feet of water. Of this amount, 3.3 million acre-feet of ground water was used while 123.7 thousand acre-feet of surface water was used for irrigation in the basin.

In 1980, there was 2.3 million acres irrigated in Zone 1, using 3.1 million acre-feet of water supplied primarily from ground-water sources.

In 1980, 130.9 thousand acres was irrigated in Zone 2 using about 119.1 thousand acre-feet of water. The Seymour Aquifer and other alluvial aquifers supplied 109.8 thousand acre-feet of ground water for irrigation of about 123.8 thousand acres in Zone 2. In 1980, almost 7.0 thousand acres was irrigated with 9.3 thousand acre-feet of surface water in Zone 2.

Irrigation in Zone 3 is concentrated in the peanut-producing area in Erath County, scattered areas along the Bosque River and Brazos River above and below Lake Whitney, and small areas in McLennan County. About 26.9 thousand acres was irrigated in 1980 using 31.2 thousand acre-feet of water. There was 10.6 thousand acre-feet of ground water and 20.6 thousand acre-feet of surface water used in Zone 3 for irrigation.

In Zone 4, about 47.3 thousand acres was irrigated in 1980, using 48.9 thousand acre-feet of water. Of this total, 20.0 thousand acre-feet of ground water, and 28.9 thousand acre-feet of surface water was used in Zone 4. The irrigated acreage occurs along the Little, Leon, and San Gabriel Rivers, and in the peanut-producing areas in Comanche and Eastland Counties.

In 1980, about 41.4 thousand acres was irrigated in Zone 5, using 39.6 thousand acre-feet of water. Of this total, 29.4 thousand acre-feet of ground water and 10.2 thousand acre-feet of surface water was used in Zone 5.

Almost 24.2 thousand acres was irrigated with 72.9 thousand acre-feet of water in 1980 in Zone 6. About 33.2 thousand acre-feet of ground water, and 39.7 thousand acre-feet of surface water was used for irrigation in Zone 6.

Mining industries in the Brazos River Basin used an estimated total of 27.1 thousand acre-feet of fresh water, of which 19.4 thousand acre-feet was used for secondary oil recovery and production operations in 1980. Most of the mining water was used for petroleum and natural gas production, particularly in Hockley County (9.2 thousand acre-feet) and Stephens County (4.7 thousand acre-feet).

Livestock water use in 1980 in the Brazos River Basin totaled about 52.0 thousand acre-feet, of which 28.7 thousand acre-feet was surface water and 23.3 thousand acre-feet was ground water. The High Plains portion of the basin (Zone 1) used the most ground water (10.0 thousand acre-feet) and the least surface water (1.1 thousand acre-feet) for a total of 11.1 thousand acre-feet. Livestock water use in Zones 2 through 6 was 40.9 thousand acre-feet, with all but 13.3 thousand acre-feet supplied by surface water.

Navigation facilities in the Brazos River Basin include the Gulf Intracoastal Waterway and Freeport Harbor. These marine navigation facilities have no regulated fresh-water requirements.

Hydroelectric power generating facilities are installed at both Possum Kingdom Lake (22.5 megawatts) and Lake Whitney (30 megawatts).

Return Flows

In 1980, over 224.1 thousand acre-feet of municipal and manufacturing return flows was discharged in the Brazos River Basin, primarily from municipal water use in the Lubbock, Waco and Temple-Belton, and Bryan-College Station areas.

Irrigation in the Brazos Basin is practiced under widely diverse conditions which produce diverse patterns of irrigation return flows. In Zone 1, irrigation activities use large quantities of water. However, the physiography of the High Plains area results in negligible quantities of irrigation return flows. Part of the irrigation water applied percolates back into the aquifer from which irrigation water is obtained; at the present time there are no reliable estimates of the total quantity of water recycled to the aquifer.

In Zones 2 through 5 of the basin, ground-water irrigation contributes negligible return flows to local streams. It is estimated that about 20 percent of direct diversions of surface waters for irrigation reenters streams as return flow. Irrigation return flows in 1980 were estimated at 1,000 acre-feet in Zone 2, about 2.3 thousand acre-feet in Zone 3, 3.3 thousand acre-feet in Zone 4, and 1.3 thousand acre-feet in Zone 5. These flows enter streams at many locations but represent only a small contribution to streamflow.

Zone 6 of the basin is mainly an irrigated rice production area. Return flows are estimated to be 35 and 40 percent of diversions from ground- and surface-water sources, respectively. Return flows in Zone 6 were estimated to total about 23 thousand acre-feet in 1980. Much of these return flows reenters streams below points of potential reuse.

Current Ground-Water Development

In 1980, approximately 3,439.5 thousand acre-feet of ground water was used in the Brazos River Basin. Of this amount, 3,111.6 thousand acre-feet was used in Zone 1, 117.9 thousand acre-feet in Zone 2, 41.7 thousand acre-feet in Zone 3, 50.2 thousand acre-feet in Zone 4, 65.9 thousand acre-feet in Zone 5, and 52.2 thousand acre-feet in Zone 6. Practically all of the ground water used in Zone 1 was from the High Plains (Ogallala) Aquifer. In Zone 2, 87 percent of the ground water used was from the Seymour Alluvium Aquifer. Ninety-five percent of the ground water used in Zone 3 was from the Trinity Group Aquifer. In Zone 4, 78 percent of the ground water used was from the Trinity Group Aquifer, and 14 percent of the use was from the Edwards (Balcones Fault Zone) Aquifer. Of the total ground water used in Zone 5 in 1980, 42 percent was from the Carrizo-Wilcox Aquifer, 41 percent was from the Brazos River Alluvium Aquifer, 5 percent was from the Gulf Coast Aquifer, and 3 percent was from the Queen City Aquifer. Practically all of the ground water used in Zone 6 of the basin was from the Gulf Coast Aquifer.

Of the 3,439.5 thousand acre-feet of ground water used in the basin, approximately 3,260.0 thousand acre-feet or 95 percent was used for irrigation purposes, and 4 percent for municipal purposes.

Withdrawals of ground water in 1980 in Zone 1 from the High Plains Aquifer are estimated at about 35 times the aquifer's annual natural recharge. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage which has caused significant water level declines within Zone 1 of the basin.

In Zone 2 in 1980, large overdrafts of ground water from the Seymour Alluvium Aquifer for irrigation purposes occurred in Haskell and Knox Counties. Also significant overdrafts of ground water from the Santa Rosa Aquifer primarily for irrigation purposes occurred in Nolan and Scurry Counties within Zone 2.

Large overdrafts of ground water primarily for municipal purposes from the Trinity Group Aquifer occurred in 1980 in Erath, Hill, Hood, Johnson, and McLennan Counties within Zone 3 of the basin.

Within Zone 4 in 1980, withdrawals of ground water for irrigation purposes caused large overdrafts from the Trinity Group Aquifer in Comanche and Eastland Counties. Large overdrafts from the same aquifer due to withdrawals for municipal purposes occurred in Coryell and Williamson Counties. Also, a significant overdraft from the Edwards (Balcones Fault Zone) Aquifer due to withdrawals for municipal purposes occurred in Williamson County.

Within Zone 5, withdrawals of ground water for municipal purposes caused a significant overdraft in Brazos County. The Trinity Group Aquifer was overdrafted in Falls County due to withdrawals for municipal purposes. Large irrigation withdrawals of ground water from the Brazos River Alluvium Aquifer in Robertson County caused a large overdraft in 1980.

Significant overdrafts of ground water from the Gulf Coast Aquifer primarily for municipal purposes occurred in 1980 in Brazoria and Fort Bend Counties within Zone 6 of the Brazos River Basin.

Current Surface-Water Development

There are 40 existing major reservoirs in the Brazos River Basin. Lakes Whitney, Proctor, Waco, Stillhouse Hollow, Belton, Somerville, Granger, Georgetown, and Aquilla are multipurpose projects constructed by the U.S. Army Corps of Engineers as part of a basinwide plan for flood control. By entering into contracts with the United States to pay the costs associated with the inclusion of conservation storage space in these lakes, the Brazos River Authority has acquired the authorization to use these projects as part of its basinwide water supply system, along with Lakes Possum Kingdom, Granbury, and Limestone, which are owned and operated by the Authority itself. The remaining 28 major reservoirs within the basin include water supply lakes owned and operated by municipalities, special-purpose districts, and private interests, and special-purpose projects such as cooling lakes for steam-electric power plants.

White River Reservoir is the only major reservoir in Zone 1. This project, owned and operated by the White River Municipal Water District, currently serves the Cities of Post, Crosbyton, Ralls, and Spur. The Canadian River Municipal Water Authority's Aqueduct from Lake Meredith in the Canadian River Basin provides raw water supplies to the Cities of Plainview, Lubbock, Levelland, Slaton, and Tahoka in Zone 1.

In Zone 2, existing major reservoirs include Sweetwater, Abilene, Kirby, Fort Phantom Hill, Hubbard Creek, Daniel, Davis, Stamford, and Millers Creek. Lakes Abilene, Kirby, and Fort Phantom Hill are owned by the City of Abilene. The yield of Lake Fort Phantom Hill is supplemented by diversions into the reservoir from the Clear Fork Brazos River under permit provisions which stipulate maximum allowable diversion rates under specific high-flow conditions. Lake Sweetwater is owned and operated by the City of Sweetwater; however, the city presently is supplied by diversions from Oak Creek Reservoir, which it owns and which is located in the adjacent Colorado River Basin. Hubbard Creek Reservoir is owned by the West Central Texas Municipal Water District, whose member cities include Abilene, Breckenridge, Anson, and Albany. Lake Stamford, constructed for the principal purpose of providing cooling water for steam-electric power plant operation, also provides municipal supplies for the Cities of Stamford and Hamlin. Millers Creek Reservoir, owned by the North Central Texas Municipal Water District, provides water for its member cities, Seymour, Haskell, Knox City, Aspermont, Rule, and Munday. Lake Daniel is owned by the City of Breckenridge. Lake Davis, owned and operated by the League Ranch, consists of two lakes with a combined capacity of 7,479 acre-feet and is used for irrigation purposes. Other small reservoirs with capacities of less than 5.0 thousand acre-feet which provide municipal supplies in Zone 2 include Lakes Trammel (Sweetwater), Baird, McCarty, and Throckmorton. Surface-water supplies are also delivered to several cities and communities in Zone 2 from water systems in the Colorado River Basin (supplied from Lake J.B. Thomas).

Lake Whitney and Lake Waco, in Zone 3, are multipurpose projects constructed by the Corps of Engineers. Lake Waco provides water supply and flood control and Lake Whitney flood control, water supply, and hydroelectric power generation. The conservation storage in Lake Waco is owned by the Brazos River Authority (BRA) but assigned to the City of Waco. The BRA also has rights to use conservation storage in Lake Whitney for water supply purposes. Further, water released from the power pool in Lake Whitney to generate power marketed by the Southwestern Power Administration contributes to main stem flows diverted from the lower part of the basin for municipal, industrial, and irrigation purposes. Possum Kingdom Reservoir is owned and operated by the Brazos River Authority for hydroelectric power generation and water supply purposes. Under water supply contracts with users, water from Possum Kingdom is supplied to users who make direct diversion from storage and, through releases from storage, to users who divert the water at downstream locations. Lake Graham provides the municipal water needs of the City of Graham. Lake Graham also provides cooling water for steam-electric power generation. Lake Mineral Wells and Lake Palo Pinto, through the Palo Pinto County Municipal Water District No. 1, serve the City of Mineral Wells and its customers which include numerous small water districts and water supply corporations in the area. The City of Cleburne and its customers are supplied from Lake Pat Cleburne and from Lake Whitney under a contract with the BRA. Lake Granbury is owned and operated by the BRA for water supply purposes. Water is delivered from Lake Granbury to Squaw Creek Reservoir to provide cooling water for the Comanche Peak Nuclear Power Plant currently under construction in Somerville County. Tradinghouse Creek and Lake Creek Reservoirs are owned and operated by utility companies for steam-electric power plant cooling. Make-up water to maintain constant operating levels in these lakes is provided from Lake Granbury and Possum Kingdom, as needed, under contracts with the BRA. The City of Olney in northern Young County is supplied from two small reservoirs in the Red River Basin.

A desalting water treatment plant is under construction to treat 0.5 million gpd from Lake Granbury to serve the City of Granbury to supplement the ground-water supply.

There are six existing reservoirs in Zone 4. Lake Cisco is owned and operated by the City of Cisco for municipal water supply. Lake Leon is owned and operated by the Eastland County Water Supply District and provides municipal water supplies to the Cities of Ranger, Olden, and Eastland. Alcoa Reservoir, located in the lower part of the zone, is owned and operated by the Aluminum Company of America and supplies water for manufacturing and for cooling of a steam-electric power plant. Lake levels are maintained at desired operation levels through supplemental diversions by pumping facilities located on the Little River. The remaining reservoirs within the zone are Proctor, Belton, and Stillhouse Hollow Lakes. These projects were constructed by the Corps of Engineers for flood-control and water supply purposes, with conservation storage owned by the BRA.

The Upper Leon River Municipal Water District has contracted with the BRA for purchase of water to supply the Cities of Comanche, Dublin, DeLeon, and Gorman. The City of Dublin is located in Zone 3.

The Bell County Water Control and Improvement District No. 1 is supplied water from Lake Belton through a contract with the BRA. The District supplies water to Killeen, Copperas Cove, Belton, Harker Heights, and Nolanville as well as a number of local individual systems. The City of Temple and a number of water supply corporations, smaller water districts, and individual water users in the area are also supplied from Lake Belton through contracts with the BRA. The BRA also utilizes releases from Lake Belton in coordination with other reservoirs in its basinwide system to meet commitments under contracts with downstream users.

The Central Texas Water Supply Corporation, Kempner Water Supply Corporation, the City of Lampasas, and the Salado Water Supply Corporation have contracts with the BRA for water supplies from Stillhouse Hollow Reservoir. The remaining yield of Stillhouse Hollow is used by the BRA to meet downstream needs through coordinated releases with other reservoirs in its basinwide system.

Two reservoir projects, Georgetown and Granger, were constructed by the Corps of Engineers on the San Gabriel watershed for flood-control and water supply purposes. These projects, when water conveyance and treatment facilities are completed, will serve the water supply needs for local municipalities. The BRA has contracted with the Corps of Engineers for the conservation storage in both projects and has in turn contracted to supply water from them to the Cities of Round Rock, Georgetown, and Taylor, and to the Lake Granger Water Supply Corporation.

In Zone 5, existing major reservoirs include Somerville, Mexia, Camp Creek, Lake Limestone, Gibbons Creek, and Bryan Utilities Lake. Lake Somerville is a multipurpose flood-control and water supply reservoir constructed by the Corps of Engineers, with the BRA owning the conservation storage in the project. From Lake Somerville, the BRA supplies water for municipal purposes to the City of Brenham, and for diversions from the main stem downstream from Lake Somerville. Lake Limestone was constructed on the Navasota River by the BRA, uses the project to supply water for municipal and industrial purposes. Under contract with the BRA, Houston Lighting and Power Company will obtain make-up water from Lake Limestone for the off-channel cooling lake for the Limestone Electric Generating Station, currently under construction on the east shore of Lake Limestone. In the future, Lake Limestone will also supply make-up water to off-channel cooling lakes for the Oak Knoll and Twin Oak lignite-fueled steam-electric power plants soon to be constructed by Texas Power and Light on Steele and Duck Creeks in Limestone and Robertson Counties, respectively. The Twin Oak cooling lake is under construction at this time. Gibbons Creek Reservoir is owned and operated by Texas Municipal Power Agency and provides cooling water for a lignite-fueled steam-electric power plant. Supplemental waters to Gibbons Creek are delivered from Lake Limestone through contractural agreements with the BRA. Lake Mexia supplies the City of Mexia in the Brazos River Basin and other customers through the Bistone MWD. Camp Creek Lake is owned by the Camp Creek Water Co., and is used for recreation. Bryan Utilities Lake provides cooling water for a steam-electric power plant and is also used for recreation. Other small local municipally owned lakes in Zone 5 include Teague Lake, Marlin Town Lake, and Rosebud Lake.

In Zone 6, the principal impoundments include Brazoria, William Harris, Eagle Nest, Manor, and Smithers, all located on tributary streams. Smithers Lake provides cooling water for a steam-electric power plant. Brazoria and William Harris Reservoirs are operated by the Dow Chemical Company to provide off-channel storage and regulation of water diverted from the main stem and Oyster Creek, principally for manufacturing purposes at the industrial complex in southern Brazoria County. Eagle Nest and Manor are irrigation system storage and regulating facilities. Major diversion systems in Zone 6 include: the Canal A and Canal B systems, owned and operated by the Brazos River Authority; the Richmond Rice Grower's Association canal system; the Chocolate Bayou Water Company canal system; and the Dow Chemical complex in Brazoria County.

In Zone 6 of the Brazos River Basin, approximately 243.5 thousand acre-feet of surface water was used in 1980, primarily for manufacturing, irrigation, and steam-electric power plant cooling. Over 31.0 thousand acre-feet of water was diverted through the Richmond Rice Grower's Association canal system for irrigation and to supply Smithers Lake, a power plant cooling reservoir. The remaining surface-water use in Zone 6 of the Brazos River River Basin in 1980 was principally for manufacturing purposes by the Dow Chemical complex.

The Canal A and Canal B systems and the Chocolate Bayou Water Company system convey industrial and irrigation supplies into the San Jacinto-Brazos Coastal Basin. In 1980, these systems delivered approximately 394.2 thousand acre-feet of water to the San Jacinto-Brazos Coastal Basin. Of this total amount, about 78.1 thousand acre-feet was used by manufacturing industries and 316.1 thousand acre-feet was used for irrigation, primarily in Brazoria County. Approximately 44.3 thousand acre-feet of the manufacturing water was used by the Galveston County Water Authority system, with the remaining 33.8 thousand acre-feet used by industries in Fort Bend and Brazoria Counties.

Water Rights

A total of 4,662,554 acre-feet of surface water was authorized or claimed for diversion and use in the Brazos River Basin as of December 31, 1983 (Table III-12-1). Table III-12-2 indicates the distribution of authorized or claimed rights by use category. The total quantity of water authorized or claimed was greatest in Zone 3, followed closely by Zones 5, 6, and 4. Authorized and/or claimed diversions for municipal use amounted to 787,377 acre-feet or almost 17 percent of the total amount of water authorized or claimed in the basin. Hydroelectric power is generated by run-of-the-river water or water released from reservoir storage for other downstream uses. Hydroelectric use is nonconsumptive.

Water Quality

Overall water quality in the basin is relatively good with the exception of the salinity problems resulting from natural salt pollution previously described. Localized problem areas include Nolan Creek, which receives large volumes of treated municipal wastewater which frequently exceed the natural waste-assimilative capacity of the stream. This causes a depression of the stream's dissolved-oxygen concentration. However, Nolan Creek water quality has improved substantially as a result of new treatment facilities. The Clear Fork Brazos River is a nutrient-rich stream. This condition apparently results from several factors, including treated municipal effluents and high nitrogen levels in springs and seeps issuing from alluvial deposits in the upper part of the Clear Fork Brazos River. The Clear Fork is also affected by runoff from oil and gas producing areas and possible seepage from abandoned and improperly plugged oil and gas wells. Water quality degradation due to agricultural runoff occurs locally throughout the basin, particularly in the Bosque River and the Clear Fork Brazos River. The Bosque River, Nolan River, and Brushy Creek all experience depressed dissolved oxygen levels as a result of sewage treatment plant discharges.

Table III-12-1. Authorized or Claimed Amount of Water, by Type of Right, Brazos River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	570	4,435,468
Claims	882	14,185
Certified Filings	15	10,385
Certificates of Adjudication	216	75,616
Total Authorizations and Claims	1,683	4,662,554

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. These totals do not include 7 authorized diversions of saline water amounting to 1,019,653 acre-feet/year. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Although water stored in all reservoirs in the basin is presently in compliance with stream quality standards, Hubbard Creek Lake and Lake Fort Phantom Hill have exhibited progressive increases in salinity in recent years.

Ground water in the High Plains (Ogallala) and Alluvium Aquifers in the Brazos River Basin is generally fresh; however, in many areas fluoride and nitrate concentrations exceed the U.S. Environmental Protection Agency (EPA) Interim Primary Drinking Water Standards. Ground water in the Santa Rosa Aquifer is generally of poorer quality and, in some areas, also exceeds the EPA Interim Primary Drinking Water Standards. Water in the Trinity Group Aquifer is suitable for most uses; however, locally fluoride concentrations exceed the EPA Interim Primary Drinking Water Standards.

Flooding, Drainage, and Subsidence

Most of the flood damages in the High Plains region of the basin have been in the form of agricultural losses. The central and southern parts of the basin are much more urbanized, and are more susceptible to flooding due to changing patterns of runoff. One of the most devastating floods on record, in terms of economic losses, was the flood of 1957. Flood damages amounted to $44 million, with agricultural losses accounting for approximately two-thirds of this total. When Tropical Storm Amelia moved through North Central Texas in August 1978, many areas experienced record-breaking flood levels. This storm brought a Presidential disaster declaration to the basin and expenditure of $6.8 million in federal funds for flood relief. Many areas flooded in this storm were not covered by flood insurance as only 19 flood claims were filed for $72 thousand in damages. The Roscoe flood in 1980, and the October 1981 flooding in the mid-basin region brought two additional disaster declarations and more than $2.3 million in federal relief. Flooding in 1979, 1980, and 1981 produced 350 flood insurance claims for $2.8 million in flood damages.

Table III-12-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Brazos River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Total
Municipal	101	10,216	120,700	142,863	350,146	135,228	28,244	787,377
Industrial	69	6,680	15,536	145,625	62,083	1,073,045	414,411	1,717,380
Irrigation	1,437	27,310	16,846	73,114	62,608	70,921	270,392	521,191
Mining	35	6,470	30,860	1,621	2,115	1,140	52,000	94,206
Hydroelectric	1	0	0	1,500,000	0	0		1,500,000
Recreation	92	6,051	5,135	6,551	1,658	18,687	4,318	42,400
Other	1	0	0	0	0	0	0	0
TOTAL	1,683[1]	56,727	189,077	1,869,774	478,610	1,299,021	769,345	4,662,554

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

The Federal Emergency Management Agency has designated 191 cities within the Brazos River Basin as having one or more potential flood-prone areas within their respective boundaries. Identification and mapping of these designated areas continues at a rapid pace with the Federal Insurance Administration striving to complete 100-year flood elevation and insurance rate studies for the more critical areas of the State by 1985.

To date, 69 designated cities are participating in the Emergency Phase of the National Flood Insurance Program, and 42 cities are now participating in the Regular Phase of the Program. As more communities enter the Program, a comprehensive basinwide standard for flood-plain management will emerge to combat flood damages through nonstructural alternatives.

More than one-half of the inadequately drained acreage in the Brazos River Basin lies in the bottomlands and flood-plain terraces along the main stem from Waco to the Gulf of Mexico. The remaining drainage problem areas occur primarily in the coastal prairie in the lower part of the basin.

In the bottomland areas, drainage problems are aggravated by infrequent major flooding of the Brazos River and more frequent minor flooding of principal tributaries. The principal problem results from lack of adequate drainage for isolated depressions and traces of former river channels. Removal of excess water through shallow, vegetation-choked channels is retarded by backwater effects during high flows of the main stream.

Except for the area of the Gulf Coast Aquifer, land subsidence due to clay compaction caused by withdrawals of ground water is not a problem within the Brazos River Basin. However, the potential for locally significant subsidence exists within the upper part of the basin in the outcrop of Permian rocks. Due to compaction of clays caused by ground-water withdrawals from the Gulf Coast Aquifer, additional subsidence is a potential problem in the Freeport area of Brazoria County where from 1906 to 1978 subsidence between 2.0 and 2.5 feet occurred. Land-surface subsidence increases the potential for flood damages and intensifies drainage problems in the low-lying flat terrain of the Coastal Plain. Also, fault activation and movement associated with subsidence can cause considerable damage to property. Damage caused by fault movement is very evident in urban areas of the Gulf Coastal Plain. Subsidence and fault movement also are caused locally by petroleum withdrawals and extractions of sulfur and other minerals in the Gulf Coastal Plain.

Recreation Resources

The 34 reservoirs in the Brazos River Basin with capacities of 5 thousand acre-feet or more provide about 158.0 thousand surface acres for flat-water recreation purposes. Nearly 45 percent of the total surface area is located in Zone 3 of the basin, serving the recreational needs of the Central Texas area. Zone 1, in the High Plains, and Zone 6, in the Gulf Coast area, contain only 1 percent and 4 percent, respectively, while Zone 5 accounts for 10 percent of the surface area. The remaining water surface area available for flat-water recreation is divided about equally between Zone 2 and Zone 4. The largest recorded recreation use of any reservoir operated by the Corps of Engineers in the Brazos River Basin occurred at Lake Waco, with more than 3.3 million visits by recreationists during 1980. Recreation visitation at the remaining five reservoirs operated by the Corps of Engineers totaled 8.9 million visits during 1980.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Brazos River Basin is projected to grow 146 percent by 2030, from the present 1.5 million (11 percent of the State population) to almost 3.8 million (11 percent of the State population). A 47 percent increase, to 2.2 million, is forecast from 1980 to the year 2000, and a growth of 68 percent is anticipated during the period 2000-2030 (Table III-12-3). Williamson County's percentage of in-basin population is projected to increase from 5 percent to 14 percent, and Bell County's percentage from 10 percent to 15 percent by the year 2030.

From 1980 to 2030, Lubbock County is projected to increase in population by 96 percent (211.7 thousand to 415.7 thousand), causing its percentage of in-basin population to decrease from 14 percent to 11 percent. Brazos County is projected to grow 135 percent during this period (a total increase in population of 126.0 thousand), while Fort Bend County is projected to grow 170 percent (an increase in population of 119.4 thousand).

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per

Table III-12-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030a/
Brazos River Basin

River Basin Zone & Category of Use	1980			1990			2000			2010			2020			2030		
	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total
Zone 1																		
Population			346.6			392.2			443.5			501.0			573.3			672.1
Municipal	25.5	39.1	64.6	46.9	48.4	95.3	44.9	65.3	110.2	44.5	80.0	124.5	56.2	86.3	142.5	79.4	87.8	167.2
Manufacturing	4.3	1.8	6.1	5.1	3.7	8.8	6.9	5.4	12.3	8.8	7.2	16.0	14.0	6.8	20.8	19.1	7.2	26.3
Steam Electric	4.3	4.4	8.7	17.3	13.2	30.5	17.3	13.2	30.5	19.6	13.2	32.8	22.0	13.2	35.2	24.3	13.2	37.5
Mining	10.5	0.7	11.2	7.1	0.0	7.1	3.5	0.0	3.5	2.4	0.0	2.4	1.4	0.0	1.4	0.4	0.0	0.4
Irrigation	3,057.0	15.0	3,072.0	3,129.7	15.0	3,144.7	3,557.9	15.0	3,572.9	3,726.7	15.0	3,741.7	3,885.9	15.1	3,901.0	2,944.7	15.0	2,959.7
Livestock	10.0	1.1	11.1	11.2	1.9	13.1	13.2	2.0	15.2	11.9	3.3	15.2	8.8	6.4	15.2	6.6	8.6	15.2
Zone Total Water	3,111.6	62.1	3,173.7	3,217.3	82.2	3,299.5	3,643.7	100.9	3,744.6	3,813.9	118.7	3,932.6	3,988.3	127.8	4,116.1	3,074.6	131.7	3,206.3
Zone 2																		
Population			194.6			214.8			228.1			248.6			284.0			328.9
Municipal	5.4	38.3	43.7	5.1	45.3	50.4	5.7	48.8	54.5	6.3	53.0	59.3	6.7	61.2	67.9	7.0	71.6	78.6
Manufacturing	0.1	2.8	2.9	0.0	4.2	4.2	0.1	5.7	5.8	0.1	7.5	7.6	0.1	9.6	9.7	0.1	12.2	12.3
Steam Electric	0.0	3.3	3.3	0.0	3.3	3.3	0.0	3.3	3.3	0.0	5.5	5.5	0.0	7.8	7.8	0.0	10.0	10.0
Mining	1.0	7.0	8.0	0.8	4.2	5.0	0.3	1.7	2.0	0.2	1.3	1.5	0.2	0.7	0.9	0.1	0.3	0.4
Irrigation	109.8	9.3	119.1	82.7	75.2	157.9	140.0	78.5	218.5	120.6	164.8	285.4	174.6	107.0	281.6	163.7	129.4	293.1
Livestock	1.6	5.9	7.5	3.4	5.5	8.9	3.5	6.8	10.3	3.5	6.8	10.3	3.5	6.8	10.3	3.2	7.1	10.3
Zone Total Water	117.9	66.6	184.5	92.0	137.7	229.7	149.6	144.8	294.4	130.7	238.9	369.6	185.1	193.1	378.2	174.1	230.6	404.7
Zone 3																		
Population			332.5			404.5			451.5			508.7			572.2			646.3
Municipal	24.8	44.0	68.8	9.6	86.8	96.4	9.8	98.6	108.4	9.7	111.4	121.1	10.4	125.2	135.6	9.3	143.2	152.5
Manufacturing	2.2	3.3	5.5	1.0	7.9	8.9	0.8	12.2	13.0	0.7	16.8	17.5	0.6	22.4	23.0	0.4	29.0	29.4
Steam Electric	0.4	21.9	22.3	0.0	46.3	46.3	0.0	59.8	59.8	0.0	65.0	65.0	0.0	70.2	70.2	0.0	75.4	75.4
Mining	0.3	1.8	2.1	0.2	2.4	2.6	0.1	3.1	3.2	0.1	3.6	3.7	0.0	4.1	4.1	0.0	4.6	4.6
Irrigation	10.6	20.6	31.2	0.7	40.5	41.2	0.7	40.6	41.3	0.7	40.7	41.4	0.7	40.7	41.4	0.6	40.8	41.4
Livestock	3.4	6.1	9.5	2.3	8.9	11.2	2.3	10.6	12.9	2.3	10.6	12.9	2.3	10.6	12.9	2.0	10.9	12.9
Zone Total Water	41.7	97.7	139.4	13.8	192.8	206.6	13.7	224.9	238.6	13.5	248.1	261.6	14.0	273.2	287.2	12.3	303.9	316.2
Zone 4																		
Population			368.8			476.8			642.7			836.5			1,062.8			1,412.8
Municipal	23.4	40.6	64.0	16.0	90.6	106.6	17.2	128.2	145.4	18.2	169.2	187.8	19.4	217.9	237.3	18.7	295.1	313.8
Manufacturing	1.8	9.6	11.4	0.9	11.6	12.5	0.9	12.9	13.8	0.9	14.2	15.1	0.9	15.8	16.7	0.9	17.8	18.7
Steam Electric	0.0	0.0	0.0	0.0	4.0	4.0	7.1	20.7	27.8	6.9	25.6	32.5	6.7	30.6	37.3	6.4	35.6	42.0
Mining	1.3	0.3	1.6	0.2	1.8	2.0	0.2	2.2	2.4	0.3	2.5	2.8	0.3	2.9	3.2	0.3	3.3	3.6
Irrigation	20.0	28.9	48.9	1.8	101.5	103.3	1.8	101.2	103.0	1.8	101.2	103.0	1.8	101.2	103.0	1.3	101.7	103.0
Livestock	3.7	6.5	10.2	3.8	8.3	12.1	3.6	10.3	13.9	3.6	10.3	13.9	3.6	10.3	13.9	3.0	10.9	13.9
Zone Total Water	50.2	85.9	136.1	22.7	217.8	240.5	30.8	275.5	306.3	31.7	323.4	355.1	362.7	378.7	411.4	30.6	464.4	495.0
Zone 5																		
Population			200.5			273.0			313.6			348.5			375.9			403.4
Municipal	30.5	5.4	35.9	20.9	41.6	68.5	29.5	52.0	81.5	31.9	58.6	90.5	34.7	62.8	97.5	37.0	67.6	104.6
Manufacturing	0.9	0.4	1.3	0.7	1.2	1.9	0.9	1.7	2.6	1.2	2.2	3.4	1.4	3.0	4.4	1.7	3.8	5.5
Steam Electric	0.0	3.0	3.0	9.4	27.6	37.0	33.6	44.5	78.1	40.4	44.5	84.9	45.2	46.5	91.7	50.4	48.1	98.5
Mining	1.6	0.3	1.9	2.2	0.0	2.2	2.8	0.0	2.8	11.9	4.1	16.0	20.9	8.3	29.2	26.2	16.2	42.4
Irrigation	29.4	10.2	39.6	20.3	15.3	35.6	20.6	15.5	36.1	20.8	15.8	36.6	20.4	16.2	36.6	18.8	17.8	36.6
Livestock	3.5	7.7	11.2	2.1	11.2	13.3	2.2	13.2	15.4	2.2	13.2	15.4	2.0	13.4	15.4	1.7	13.7	15.4
Zone Total Water	65.9	27.0	92.9	61.6	96.9	158.5	89.6	126.9	216.5	108.4	138.4	246.8	124.6	150.2	274.8	135.8	167.2	303.0
Zone 6																		
Population			86.9			126.2			163.5			210.5			258.7			304.0
Municipal	12.8	0.6	13.4	15.3	12.3	27.6	18.8	17.8	36.6	22.4	24.5	46.9	26.1	31.4	57.5	29.3	38.1	67.4
Manufacturing	2.2	180.1	182.4	0.2	301.7	301.9	0.2	429.5	429.7	0.3	576.5	576.8	0.3	752.1	752.4	0.4	971.3	971.7
Steam Electric	0.6	21.7	22.3	0.0	34.3	34.3	11.0	34.3	45.3	22.9	34.3	57.2	34.8	34.3	69.1	46.7	34.3	81.0
Mining	2.3	0.0	2.3	3.3	0.0	3.3	4.4	0.0	4.4	4.8	0.0	4.8	5.2	0.0	5.2	5.6	0.0	5.6
Irrigation	33.2	39.7	72.9	49.8	18.9	68.7	45.8	18.9	64.7	42.6	19.0	61.6	39.8	19.0	58.8	35.4	20.8	56.2
Livestock	1.1	1.4	2.5	0.5	2.5	3.0	0.7	2.8	3.5	0.7	2.8	3.5	0.7	2.8	3.5	0.7	2.8	3.5
Zone Total Water	52.2	243.5	295.7	69.1	369.7	438.8	80.9	503.3	584.2	93.7	657.1	750.8	106.9	839.6	946.5	118.1	1,067.3	1,185.4
BASIN TOTALS																		
Population			1,529.9			1,887.5			2,242.9			2,653.8			3,126.9			3,767.5
Municipal	122.4	168.0	290.4	119.8	325.0	444.8	125.9	410.7	536.6	133.0	497.1	630.1	153.5	584.8	738.3	180.7	703.4	884.1
Manufacturing	11.5	198.0	209.5	7.9	330.3	338.2	9.8	467.4	477.2	12.0	624.4	636.4	17.3	809.7	827.0	22.6	1,.41.3	1,063.9
Steam Electric	5.3	54.3	59.6	26.7	128.7	155.4	69.0	175.8	244.8	89.8	188.1	277.9	108.7	202.6	311.3	127.8	216.6	344.4
Mining	17.0	10.1	27.1	13.8	8.4	22.2	11.3	7.0	18.3	19.7	11.5	31.2	28.0	16.0	44.0	32.6	24.4	57.0
Irrigation	3,260.0	123.7	3,383.7	3,285.0	266.4	3,551.4	3,766.8	269.7	4,036.5	3,913.2	356.5	4,269.7	4,123.2	299.2	4,422.4	3,164.5	325.5	3,490.0
Livestock	23.3	28.7	52.0	23.3	38.3	61.6	25.5	45.7	71.2	24.2	47.0	71.2	20.9	50.3	71.2	17.2	54.0	71.2
Basin Total Water	3,439.5	582.8	4,022.3	3,476.5	1,097.1	4,573.6	4,008.3	1,376.3	5,384.6	4,191.9	1,724.6	5,916.5	4,451.6	1,962.6	6,414.2	3,545.5	2,365.1	5,910.6

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

capita water use. Water requirements in the Brazos River Basin are projected to increase from the 1980 level of 290.4 thousand acre-feet by a projected maximum of 85 percent by the year 2000. In the year 2030, water requirements are projected to range from 517.3 to 884.1 thousand acre-feet. Zone 1 is projected to account for 21 to 22 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 19 to 20 percent of the total. Most of the water use in Zone 1 is in Lubbock County.

A range of 39.3 to 54.5 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000. Total municipal water requirements in Zone 3 are projected to range from 73.4 to 108.4 thousand acre-feet in the year 2000; by 2030, Zone 3 is projected to account for between 93.6 and 152.5 thousand acre-feet of the total basin municipal water requirements.

Municipal water requirements in Zone 4 are projected to increase from 22 percent of the 1980 total basin water demand to 35.5 percent in 2030.

Zone 5 required 35.9 thousand acre-feet in 1980. This water requirement is projected to range from 57.6 to 81.5 thousand acre-feet in 2000; and, by 2030 rise to 73.9 to 104.6 thousand acre-feet (low and high case, respectively).

Zone 6 consumed five percent of the total basin water requirement in 1980. By 2030, this portion is projected to rise to eight percent.

Industrial

Manufacturing water requirements in 1980 were 209.5 thousand acre-feet in the Brazos River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Brazos River Basin are projected to increase more than five times by the year 2030, to a potential high of 1,063.9 thousand acre-feet.

By the year 2030, it is projected that about 21 percent of manufacturing water use in Texas will be supplied from Brazos River Basin sources. Zone 6, which accounted for almost 87 percent of basin manufacturing water use in 1980, is expected to account for almost 91 percent of the 2030 manufacturing water requirements.

It is anticipated that the growth in manufacturing water requirements in Zone 6 of the basin will be centered in Brazoria County and will be concentrated in the production of industrial organic chemicals. These projections are based on national trends and are directly linked to national industrial organic chemical markets. If water is not available in the future to meet these demands in Brazoria County, changes in plant locations, especially in the case of large chemical complexes which use large quantities of water for processing, would result in a relocation of water demands. Plants now targeted for Brazoria County might locate in other Texas coastal counties where water supplies are available and are in suitable proximity to proposed new deepwater ports in the Gulf.

Steam-Electric Power Generation

Freshwater requirements for steam-electric power generation are projected to expand dramatically between 1980 and 2000 as extensive development of the basin's near-surface lignite reserves occurs. Large lignite deposits throughout Zone 5 and the lower part of Zone 4 should support rapid growth in these areas.

In 1980, 59.6 thousand acre-feet was used in steam-electric power generation. Future requirements were projected for two different levels of electricity demand. By 2000, total basin water requirements are projected to range from 205.2 to 244.8 thousand acre-feet. In 2030, this water requirement is projected to increase an additional 38 to 41 percent.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone.

Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Brazos River Basin are projected to increase from the 1980 level of 3.4 million acre-feet by a projected maximum 19 percent by the year 2000 in the high case, declining 26 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 2.9 to 3.5 million acre-feet annually, low and high case, respectively, to irrigate from 2.9 to 3.0 million acres.

Zone 1 is projected to account for about 89 percent of total basin irrigation requirements in 2000; in 2030, Zone 1 is projected to account for about 85 percent of the total in the high case and approximately the same in the low case. A range of 2.2 to 3.6 million acre-feet of irrigation requirements is projected in Zone 1 by 2000. By 2030, the range for this Zone is from 2.6 to 3.0 million acre-feet annually.

Irrigation water requirements in Zones 2, 3, 4, 5, and 6 are projected to be about 8, 1, 3, 2, and 1 percent respectively of the 2030 requirements in the high case.

Livestock

It is anticipated that annual livestock water requirements will be 71.2 thousand acre-feet by 2030. The High Plains region of the basin (Zone 1) is expected to use approximately 15.2 thousand acre-feet annually by 2030. It is estimated that ground water will primarily supply feedlot cattle and surface water will supply the remainder. Livestock water requirements in Zones 2 through 6 will be approximately 56.0 thousand acre-feet annually by year 2030.

Mining

Mining water use in the Brazos River Basin is projected to increase from 27.1 thousand acre-feet in 1980 to 57.0 thousand acre-feet in 2030, with fuel mining requirements reaching 39.5 thousand acre-feet by the end of the planning period.

Water use by nonmetal mining firms in the Brazos River Basin is projected to increase from 7.2 thousand acre-feet in 1980 to 16.3 thousand acre-feet in 2030.

Navigation

Although extensive studies of the feasibiity of navigation of the Brazos River have been conducted, upstream navigation is not considered economically feasible at the present time.

Hydroelectric Power

There is currently 52.5 megawatts of capacity at the existing hydroelectric facilities in the Brazos River Basin. There is significant potential for the development of additional hydroelectric generating capacity in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains Aquifer within the Brazos River Basin from 1990 through 2030 by decade: 2.62 million acre-feet in 1990, 2.44 million acre-feet in 2000, 2.39 million acre-feet in 2010, 1.85 million acre-feet in 2020, and 1.39 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 56 million acre-feet of ground water would be removed from recoverable storage, and that of the 10.9 million acre-feet remaining in recoverable storage in the year 2031 about 10.6 million acre-feet would remain in the "caprock" (tillable) area and about 0.3 million acre-feet would remain in the "breaks" (non-tillable) area of the basin. Within the Brazos River Basin, the High Plains Aquifer receives on an average annual basis about 88.9 thousand acre-feet of recharge.

The approximate annual ground-water yield to the year 2030 within the remaining portion of the Brazos River Basin is 500.9 thousand acre-feet with the following amounts annually available by aquifer: 132.5 thousand acre-feet from the Carrizo-Wilcox Aquifer, 124.7 thousand acre-feet from the Brazos River Alluvium Aquifer, 108.5 thousand acre-feet from the Seymour Alluvium Aquifers, 72.5 thousand acre-feet from the Gulf Coast Aquifer, 37.3 thousand acre-feet from the Trinity Group

Aquifer, 7.0 thousand acre-feet from the Sparta Aquifer, 6.3 thousand acre-feet from the Marble Falls Limestone Aquifer, 5.0 thousand acre-feet from the Edwards (Balcones Fault Zone) Aquifer, 3.4 thousand acre-feet from the Santa Rosa Aquifer, 2.7 thousand acre-feet from the Queen City Aquifer, and 1.0 thousand acre-feet from the Woodbine Aquifer. In the year 2030, the yields of the Carrizo-Wilcox, Brazos River Alluvium, Seymour Alluvium, and Trinity Group Aquifers within the basin were reduced to the average annual effective recharge of the aquifers which is 349.3 thousand acre-feet per year. These reductions decrease the total ground-water availability within the basin in 2030 to 447.2 thousand acre-feet (High Plains (Ogallala) Aquifer not included).

The projected annual ground-water use within the Brazos River Basin by decade from 1990 through 2030 is expected to be from 1.81 to 2.88 million acre-feet per year (Table III-12-3). The approximate average annual projected ground-water use within the basin is expected to be about 2.48 million acre-feet per year. Of the 2.48 million acre-feet of average annual projected use, about 87 percent is expected to be from the High Plains (Ogallala) Aquifer, about 4 percent from the Carrizo-Wilcox Aquifer, and about 3 percent from the Seymour Alluvium Aquifer.

Surface-Water Availability and Proposed Development

Surface-water supplies available in the Brazos River Basin are not sufficient to meet all projected water requirements through the year 2030 (Table III-12-4, Figure III-12-2). Shortages vary throughout the zones in the basin with the most significant shortages occurring in Zone 1 due to the declining ground-water resources of the High Plains (Ogallala) Aquifer.

Zone 1

Zone 1 of the Brazos River Basin has annual water shortages, essentially all for irrigated agriculture, projected to be about 1.2 million acre-feet in 2000 and 1.6 million acre-feet in 2030 (Table III-12-5, Figure III-12-3). Surface water use in 2030 in this zone is projected to be about 108 thousand acre-feet annually, with 50.2 thousand acre-feet per year provided from sources outside of the basin.

Municipal and manufacturing water requirements in Zone 1, which will total about 122.5 thousand acre-feet annually by the year 2000, will continue to be met through combined use of ground- and surface-water supplies. Deliveries of water from Lake Meredith through the Canadian River project Main Aqueduct can be increased as the cities served by this system gradually receive their full allotment under provisions of the water supply contracts for the project. The Lubbock area will need supplemental supplies before 1990, however, as the city's existing well fields and Canadian River supply will be capable of producing only about 47.5 thousand acre-feet annually as compared to a projected need of approximately 53.5 thousand acre-feet annually by 1990. This deficit could be met by construction of the permitted Post Reservoir, on the North Fork Double Mountain Fork Brazos River in Garza County, by the White River Municipal Water District, and acquisition of a portion of the project's estimated dependable yield of 10.6 thousand acre-feet by the City of Lubbock.

The Justiceburg Reservoir project, proposed by the City of Lubbock for construction on the South Fork Double Mountain Fork Brazos River, could provide an additional dependable yield of up to about 29.9 thousand acre-feet annually. The City of Lubbock applied to the Texas Water Commission in 1981 for a permit to construct Justiceburg Reservoir. After extensive public hearings on the project the Texas Water Commission issued a permit in August 1984 for diversion of 35.0 thousand acre-feet per year. Based on the need for additional surface water, it is proposed that Justiceburg Reservoir begin supplying Lubbock by 1990, with Post Reservoir water available by 2000. Acquisition by Lubbock of additional ground-water rights in adjacent counties will be necessary if the presently planned surface-water development is not carried out.

Even with the development of the Post and Justiceburg Reservoir sites, the City of Lubbock will experience water shortages by 2010 if additional sources are not provided. Large volumes of suitable quality ground-water from the High Plains (Ogallala) Aquifer are available in areas of the eastern Canadian River Basin in Texas. Preliminary engineering studies have determined that an extensive well field and conveyance pipeline could develop sufficient water to supply Lubbock's anticipated additional growth in water demand through 2030, with sufficient surplus to supply additional municipalities on the High Plains in the Canadian, Red, Brazos, and Colorado River Basins. In addition to serving Lubbock, the potential pipeline system could supply the Cities of Bovina, Sudan, Littlefield, Dimmitt, Plainview, Albernathy, Slaton, Tahoka, O'Donnell, and Shallowater in the Brazos River Basin with sufficient water to meet projected additional demands through 2030. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

Table III-12-4. Water Resources of the Brazos River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	2877.2	—	—	—	2877.2	3376.5	—	—	3376.5	.0	(599.3)	(599.3)
Surface Water	1186.4	—	196.3	54.6	1437.3	979.5	—	408.2	1387.7	216.4	(166.8)	49.6
Total	4063.6	—	196.3	54.6	4314.5	4456.0	—	408.2	4864.2	216.4	(766.1)	(549.7)
2000												
Ground Water	2738.0	—	—	—	2738.0	4008.3	—	—	4008.3	.0	(1270.3)	(1270.3)
Surface Water	1291.4	—	238.5	145.4	1675.3	1249.7	—	449.2	1698.9	147.9	(171.5)	(23.6)
Total	4029.4	—	238.5	145.4	4413.3	5258.0	—	449.2	5707.2	147.9	(1441.8)	(1293.9)
2010												
Ground Water	2740.9	—	—	—	2740.9	4192.3	—	—	4192.3	.0	(1451.4)	(1451.4)
Surface Water	1280.6	—	286.9	376.9	1944.4	1593.4	—	502.7	2096.1	106.7	(258.4)	(151.7)
Total	4021.5	—	286.9	376.9	4685.3	5785.7	—	502.7	6288.4	106.7	(1709.8)	(1603.1)
2020												
Ground Water	2245.4	—	—	—	2245.4	4451.5	—	—	4451.5	.0	(2206.1)	(2206.1)
Surface Water	1422.9	—	334.5	489.4	2246.8	1828.9	—	514.1	2343.0	105.0	(201.2)	(96.2)
Total	3668.3	—	334.5	489.4	4492.2	6280.4	—	514.1	6794.5	105.0	(2407.3)	(2302.3)
2030												
Ground Water	1810.3	—	—	—	1810.3	3545.4	—	—	3545.4	.0	(1735.1)	(1735.1)
Surface Water	1412.5	—	384.4	772.2	2569.1	2225.5	—	530.2	2755.7	41.4	(228.0)	(186.6)
Total	3222.8	—	384.4	772.2	4379.4	5770.9	—	530.2	6301.1	41.4	(1963.1)	(1921.7)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
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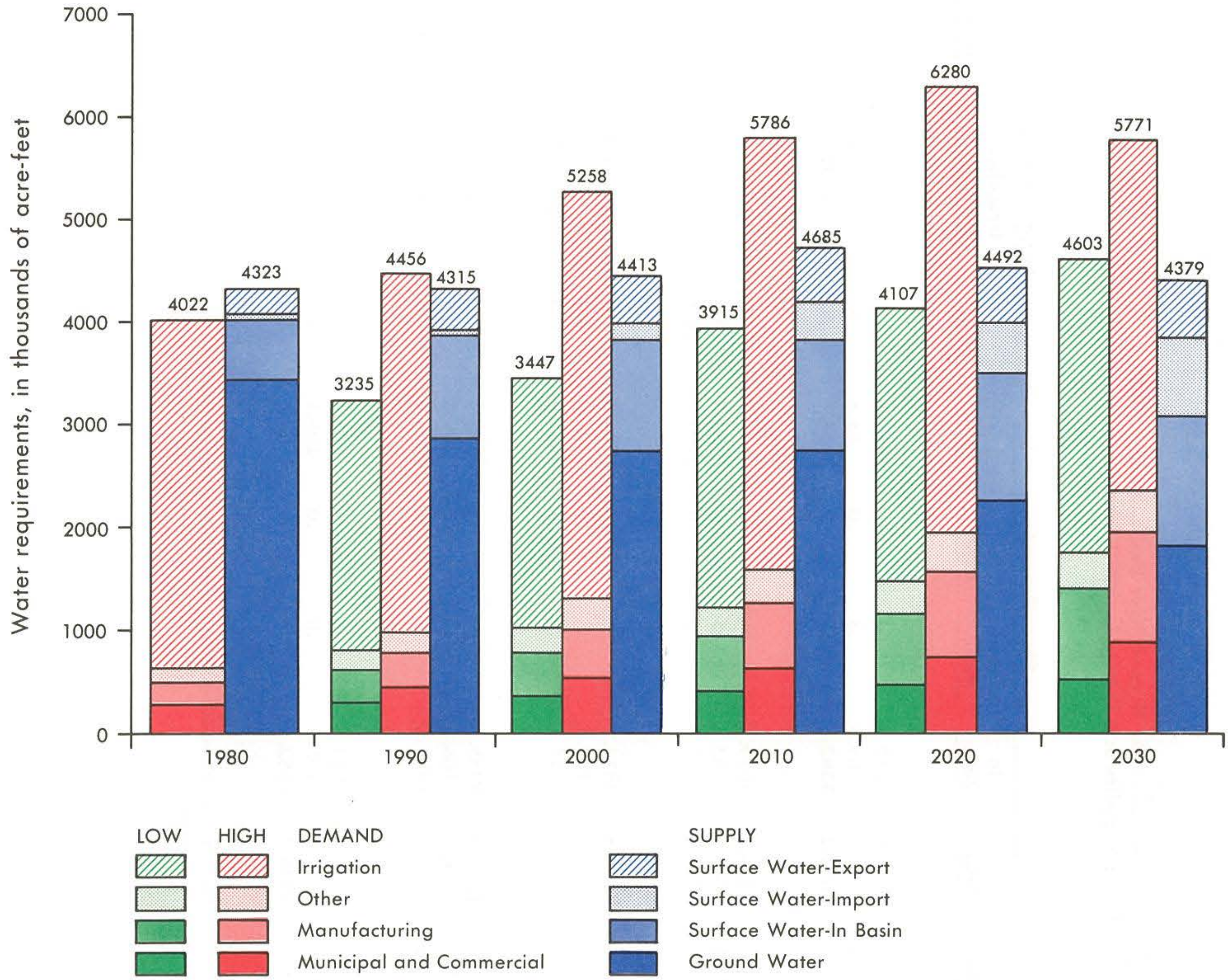

Figure III-12-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, 1980-2030

Zone 2

Existing water resources are not sufficient to meet projected water needs in Zone 2 from 1990 onward (Table III-12-6, Figure III-12-4). However, existing and proposed surface-water development is estimated to meet projected surface-water needs for municipal and industrial purposes in Zone 2 of the basin through the year 2030. Shortages are projected to occur, however, in the supply for irrigation water. The annual irrigation shortage is estimated to be 68.8 thousand acre-feet in year 1990, increasing to 213.1 thousand acre-feet in 2030. These shortages are the result of localized limited availability of ground water.

Existing surface-water supplies for municipal and manufacturing purposes are expected to be capable of meeting projected demands in Zone 2 through 2010. However, by 2020, additional firm supplies of 9.9 thousand acre-feet per year are estimated to be needed. Shortages of 23.0 thousand acre-feet annually are projected by 2030. Possible solution alternatives include (1) diversions from Possum Kingdom Lake and (2) construction of the

Table III-12-5. Water Resources of the Brazos River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	2620.1	—	—	—	2620.1	3217.8	—	—	3217.8	.0	(597.2)	(597.2)
Surface Water	14.8	.0	13.2	43.1	71.1	65.3	.5	.0	65.8	5.3	.0	5.3
Total	2634.9	.0	13.2	43.1	2691.2	3282.6	.5	.0	3283.1	5.3	(597.2)	(591.9)
2000												
Ground Water	2430.2	—	—	—	2430.2	3643.7	—	—	3643.7	.0	(1213.5)	(1213.5)
Surface Water	44.5	.0	13.2	45.7	103.4	83.8	.5	.0	84.3	19.1	.0	19.1
Total	2474.7	.0	13.2	45.7	2533.6	3727.5	.5	.0	3728.0	19.1	(1213.5)	(1194.4)
2010												
Ground Water	2396.8	—	—	—	2396.8	3814.3	—	—	3814.3	.0	(1417.5)	(1417.5)
Surface Water	44.4	.0	13.2	47.7	105.3	100.4	.6	.0	101.0	4.3	.0	4.3
Total	2441.2	.0	13.2	47.7	2502.1	3914.7	.6	.0	3915.3	4.3	(1417.5)	(1413.2)
2020												
Ground Water	1871.4	—	—	—	1871.4	3988.3	—	—	3988.3	.0	(2116.9)	(2116.9)
Surface Water	44.4	.0	13.2	49.1	106.7	106.3	.4	.0	106.7	.0	.0	.0
Total	1915.8	.0	13.2	49.1	1978.1	4094.6	.4	.0	4095.0	.0	(2116.9)	(2116.9)
2030												
Ground Water	1431.6	—	—	—	1431.6	3074.5	—	—	3074.5	.0	(1642.9)	(1642.9)
Surface Water	44.4	.0	13.2	50.2	107.8	108.1	.0	.0	108.1	(.3)	0	(.3)
Total	1476.0	.0	13.2	50.2	1539.4	3182.6	.0	.0	3182.6	(.3)	(1642.9)	(1643.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
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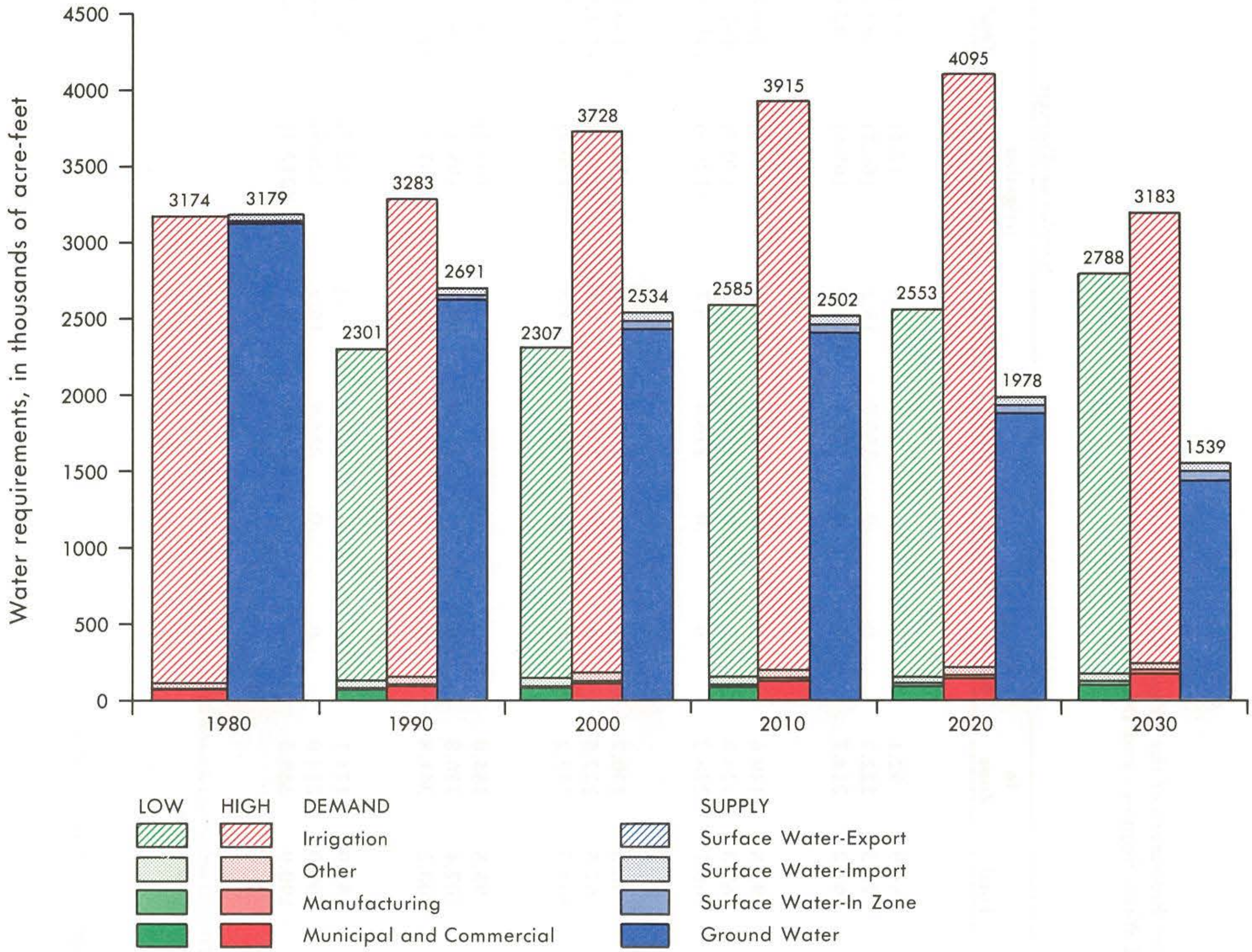

Figure III-12-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 1, 1980-2030

potential Breckenridge Reservoir on the Clear Fork Brazos River in southern Throckmorton County.

Use of water stored in Possum Kingdom Reservoir for municipal and many manufacturing purposes is severely limited because of its salinity. Congress has authorized the Corps of Engineers to construct a series of brine-retention lakes (Croton, Dove, and Kiowa Peak) and pumping and conveyance facilities to control the major natural salt-providing areas in the Brazos River Basin. Operation of this control system is projected to significantly improve salinity in Possum Kingdom Reservoir. The feasibility of this alternative for meeting the areas' future needs will depend to a large extent upon construction of the authorized salt control facilities, equitable allocation of the construction costs and annual operating costs for these projects, and realization of the anticipated benefits through improvement in the quality of the main stem Brazos River.

The construction of the Breckenridge Reservoir would provide an estimated 38.9 thousand acre-feet of firm annual yield. This supply would be more than sufficient to meet all municipal and manufacturing needs in Zone 2 through 2030. A detrimental impact of additional development of the Clear Fork Brazos River drainage system would be to diminish the beneficial effects of the authorized Brazos River Natural Salt Control project. Further, the salt control project would provide benefits to water users

Table III-12-6. Water Resources of the Brazos River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	89.9	—	—	—	89.9	92.1	—	—	92.1	.0	(2.1)	(2.1)
Surface Water	57.0	.6	7.8	5.9	71.3	122.7	.0	.0	122.7	15.2	(66.7)	(52.4)
Total	146.9	.6	7.8	5.9	161.2	214.7	.0	.0	214.7	15.2	(68.8)	(53.6)
2000												
Ground Water	92.8	—	—	—	92.8	149.6	—	—	149.6	.0	(56.8)	(56.8)
Surface Water	51.7	.5	8.8	6.3	67.3	128.6	.0	.0	128.6	8.7	(70.2)	(61.3)
Total	144.5	.5	8.8	6.3	160.1	278.2	.0	.0	278.2	8.7	(126.8)	(118.1)
2010												
Ground Water	96.8	—	—	—	96.8	130.7	—	—	130.7	.0	(33.9)	(33.9)
Surface Water	49.5	.6	9.9	7.5	67.5	222.5	.0	.0	222.5	1.3	(156.3)	(155.0)
Total	146.3	.6	9.9	7.5	164.3	353.2	.0	.0	353.2	1.3	(190.2)	(188.9)
2020												
Ground Water	95.8	—	—	—	95.8	185.0	—	—	185.0	.0	(89.2)	(89.2)
Surface Water	86.2	.4	11.6	9.2	107.4	176.8	.0	.0	176.8	29.0	(98.4)	(69.4)
Total	182.0	.4	11.6	9.2	203.2	361.8	.0	.0	361.8	29.0	(187.6)	(158.6)
2030												
Ground Water	81.9	—	—	—	81.9	174.1	—	—	174.1	.0	(92.2)	(92.2)
Surface Water	84.0	.0	13.8	11.2	109.0	214.0	.0	.0	214.0	15.9	(120.9)	(105.0)
Total	165.9	.0	13.8	11.2	190.9	388.1	.0	.0	388.1	15.9	(213.1)	(197.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
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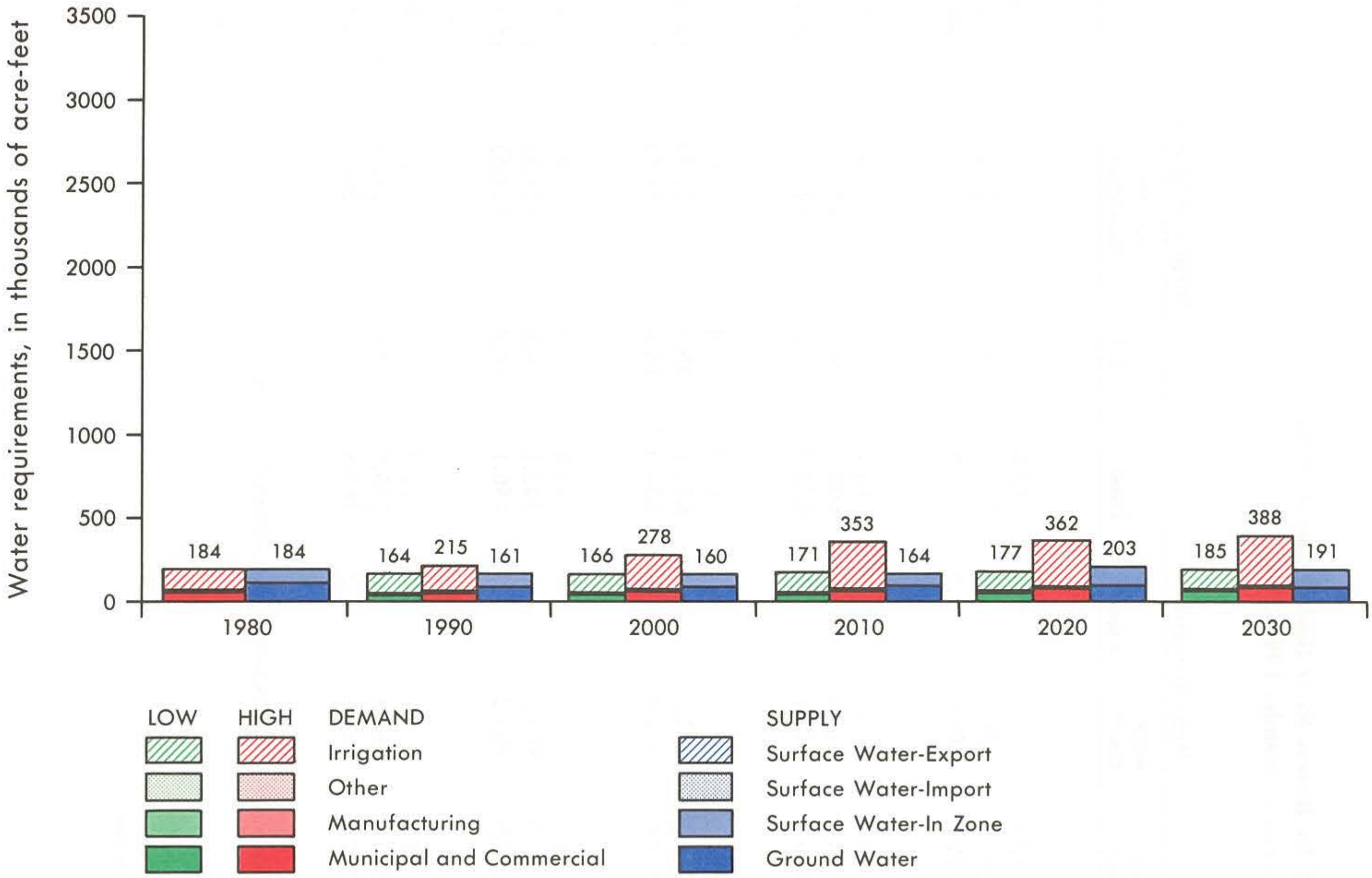

Figure III-12-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 2, 1980-2030

throughout the middle and lower Brazos Basin. It is therefore recommended that the Brazos River Natural Salt Control project be constructed as soon as practicable, with the Breckenridge Reservoir to be constructed by 2020 as an alternative if the salt control project proves impossible to accomplish.

Zone 3

Zone 3 of the Brazos River Basin has existing and proposed surface-water development sufficient to meet projected surface-water requirements for all purposes other than irrigated agriculture through the year 2030 (Table III-12-7, Figure III-12-5). A projected irrigation shortage of about 21.4 thousand acre-feet per year is estimated to occur beginning in the year 1990. This shortage is forecast as a result of insufficient ground-water resources. Surface-water supplies in this zone are projected to increase from 616.5 thousand acre-feet in year 1990 to 742.7 thousand acre-feet in year 2030 as a result of proposed project development and increased return flows.

Although most areas in Zone 3 have sufficient surface water to meet projected municipal and manufacturing needs through 2010, localized shortages are anticipated by 1990 largely due to severely limited availability from the Trinity Group Aquifer. The Cities of Stephenville and Glen Rose and areas in Erath and Hood Counties are projected to be supplied by the proposed Paluxy Reservoir. Local sponsors of the project have applied for a water rights permit for the reservoir. The permit application is currently under review by the Department.

Before the year 2020, additional municipal and industrial surface-water supplies will be needed for Johnson and Hill Counties in this zone. These needs as well as those in other areas of the basin could be met through the reallocation of storage from hydroelectric power genera-

Table III-12-7. Water Resources of the Brazos River Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	13.8	—	—	—	13.8	13.8	—	—	13.8	.0	.0	.0
Surface Water	586.8	.7	26.2	2.8	616.5	163.2	406.6	.0	569.8	68.1	(21.4)	46.7
Total	600.6	.7	26.2	2.8	630.3	177.0	406.6	.0	583.6	68.1	(21.4)	46.7
2000												
Ground Water	13.7	—	—	—	13.7	13.7	—	—	13.7	.0	.0	.0
Surface Water	578.8	.8	31.5	3.3	614.4	193.1	416.1	.0	609.2	26.7	(21.5)	5.2
Total	592.5	.8	31.5	3.3	628.1	206.8	416.1	.0	622.9	26.7	(21.5)	5.2
2010												
Ground Water	13.5	—	—	—	13.5	13.5	—	—	13.5	.0	.0	.0
Surface Water	575.9	.9	37.5	3.9	618.2	214.1	407.0	.0	621.1	18.6	(21.5)	(2.9)
Total	589.4	.9	37.5	3.9	631.7	227.6	407.0	.0	634.6	18.6	(21.5)	(2.9)
2020												
Ground Water	14.0	—	—	—	14.0	14.0	—	—	14.0	.0	.0	.0
Surface Water	686.9	.9	44.2	4.6	736.6	240.9	501.2	.0	742.1	16.0	(21.5)	(5.5)
Total	700.9	.9	44.2	4.6	750.6	254.9	501.2	.0	756.1	16.0	(21.5)	(5.5)
2030												
Ground Water	12.3	—	—	—	12.3	12.3	—	—	12.3	.0	.0	.0
Surface Water	684.0	1.0	52.4	5.3	742.7	270.5	484.8	.2	755.5	8.8	(21.6)	(12.8)
Total	696.3	1.0	52.4	5.3	755.0	282.8	484.8	.2	767.8	8.8	(21.6)	(12.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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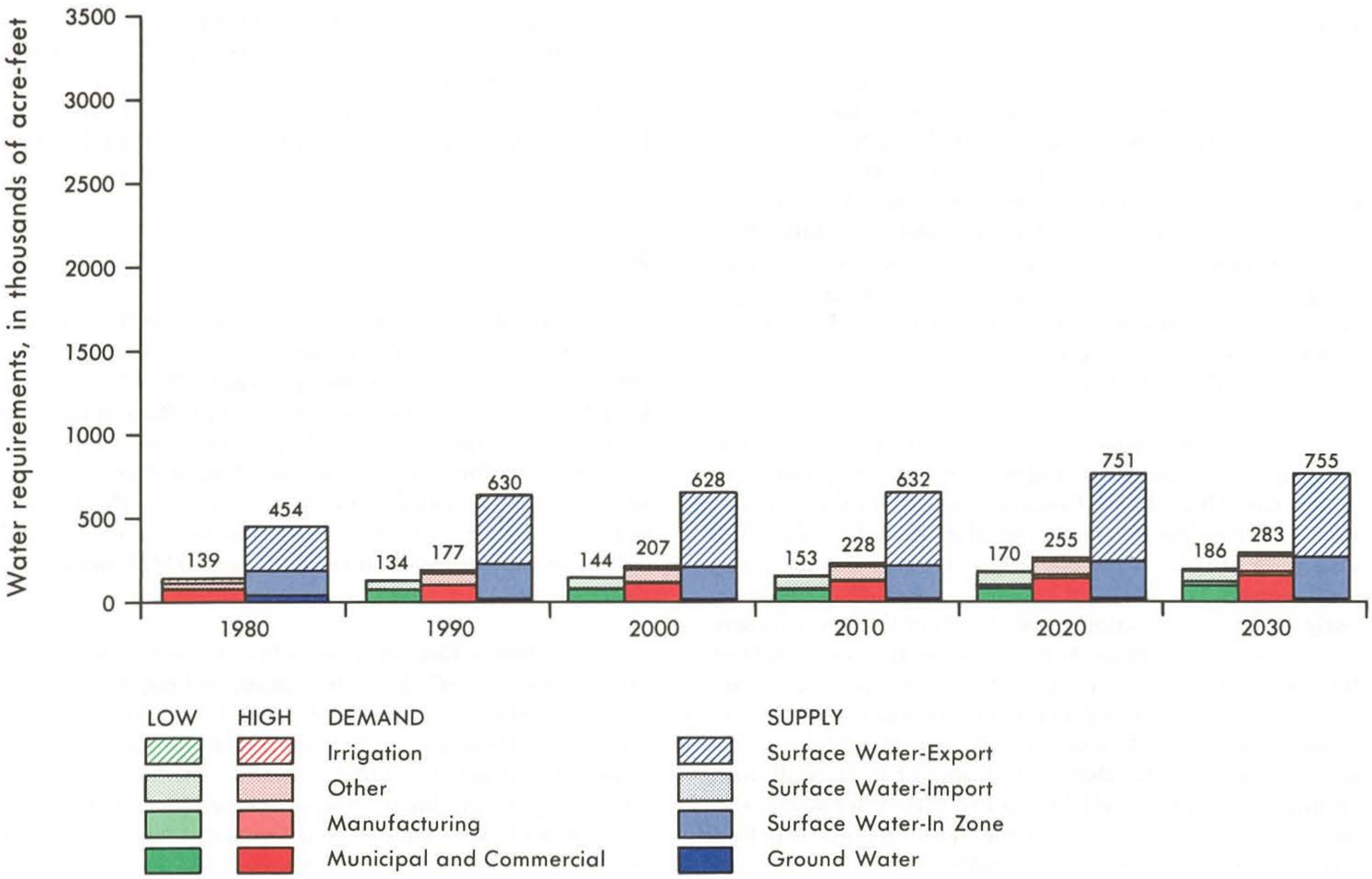

Figure III-12-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 3, 1980-2030

tion to water supply in Lake Whitney. Lake Whitney currently has a reserved power pool at a water-surface elevation of 523 feet above mean sea level. By removing this minimum storage pool, the firm annual yield of the reservoir would increase by 113.9 thousand acre-feet. Any conversion of storage in Lake Whitney will require Congressional authorization.

Additional surface-water supplies will also be required to meet municipal and industrial needs in McLennan and Bosque Counties. The proposed Bosque Watershed project is currently under study by the BRA. This two-stage project will consist of constructing Lake Bosque on the North Bosque River and raising the surface of the conservation pool in Lake Waco. The Bosque Watershed project will meet water supply needs for municipal and industrial use in the Waco metropolitan area of McLennan County. The potential Stephenville Reservoir on the North Bosque River is an alternative future project for this area.

Another surface-water project being planned for development in Zone 3 of the Brazos River Basin is the South Bend project on the Brazos River in Young County. The BRA is studying this project as a potential water supply, hydroelectric power generation, and flood-control project. Should this project prove to be feasible, the BRA proposes to have it operational by the mid-1990's to meet additional needs in Zone 3 and to free up water for use in Zone 4 of the Brazos River Basin.

Future water needs in Zone 3 for municipal and manufacturing purposes may be partially met through desalting slightly to moderately saline ground and surface waters. The City of Granbury is currently constructing a desalting plant to satisfy part of its water demands. Further studies are necessary to determine the engineering and economic feasibility of desalting to satisfy area water needs.

Zone 4

Projected surface-water requirements are estimated to exceed available surface-water supplies in Zone 4 of the Brazos River Basin by the year 1990 (Table III-12-8, Figure III-12-6). However, existing and proposed surface-water supplies for municipal and industrial purposes are sufficient to meet projected needs through 2030. Projected irrigation needs in this zone exceed available surface-water supplies by about 74 thousand acre-feet per year from the present through the year 2030. Surface-water supplies in this zone are estimated at 363.9 thousand acre-feet in the year 2030.

The rapidly expanding population and associated municipal and manufacturing surface-water requirements within Coryell and Bell Counties, including the requirements for Fort Hood, are projected to exceed the dependable yield of Lake Belton by 2010. Large portions of the yields of both Lakes Belton and Stillhouse Hollow are presently used to meet water supply needs in the lower Brazos Basin. The Brazos River Authority plans to use the yield of the proposed South Bend Reservoir to supply the downstream needs now being met from Lakes Belton and Stillhouse Hollow, thereby freeing up their total yields for use in Zone 4. All of Lake Belton and part of Lake Stillhouse Hollow will thus be available for use with other sources in the area to meet the municipal and industrial needs in Bell and Coryell Counties through 2030.

Rapidly increasing municipal and manufacturing water requirements in Burnet and Williamson Counties are expected to be met largely from surface-water sources. Rapidly declining ground-water levels and inferior quality of these supplies, particularly in Williamson County, dictate that future ground-water pumpage not exceed the present level. Existing supplies from Lakes Granger and Georgetown are projected to be fully utilized before 2000. The construction of the authorized Corps of Engineers South Fork Reservoir on the South Fork San Gabriel River could supply an additional 5.4 thousand acre-feet annually to Williamson County. The project is proposed for construction prior to 2000.

If South Fork Reservoir is built, it will meet anticipated shortages in Williamson County only until the year 2000. Utilizing all of Lake Stillhouse Hollow's yield not committed to Bell and Coryell Counties' use could add 42 thousand acre-feet per year to the supplies available to Williamson County for municipal and industrial uses. This would make it possible to meet the needs in Williamson County through the year 2020. Area needs through 2030 could be met from water made available from Lake Sommerville as a result of the construction of Caldwell Reservoir in Zone 5.

In cooperation with cities, water supply corporations, and districts in Williamson County, the Brazos River Authority is currently conducting studies to determine the feasibility and costs of delivering water from Stillhouse Hollow to Williamson County after it is freed up by construction of the proposed South Bend Reservoir.

Zone 5

Proposed and existing surface-water supplies are estimated to provide 258.6 thousand acre-feet in the year 2030 for Zone 5 of the basin (Table III-12-9, Figure III-12-7). Supplies of surface water are sufficient through year 2030 to meet industrial and manufacturing water requirements for the zone. Irrigated agriculture has projected shortages in all decades from the present through the year 2030, with shortages of 5.1 thousand acre-feet and 7.6 thousand acre-feet annually in years 1990 and 2030, respectively.

The Brazos County area, which includes the rapidly growing Bryan-College Station area, will require surface-water supplies to supplement available ground-water resources. Although a small part of these surface-water requirements could be met by Lake Limestone, the authorized Corps of Engineers system of reservoirs on the Navasota River (Lakes Millican and Navasota) will provide the major part of these requirements provided development of the Navasota River can be implemented in a timely manner. The Millican Reservoir project, authorized for construction first, is in the advanced engineering and design phase with the Phase I General Design Memorandum originally scheduled for completion at an early date. However, the existence of potentially commercial, near-surface lignite deposits in the reservoir area, part of which has been acquired by utilities, poses a significant conflict. The Corps of Engineers is currently reassessing the plan of development for the Navasota River, which includes examination of several alternatives and possible reformulation of the authorized plan of development of the Navasota River. It is recognized that the authorized Navasota Lake project could also provide additional supplies to meet area needs if further studies show economic feasibility. Currently estimated yields of these projects are subject to revision pending additional studies of the projects and the related impact of Lake Limestone.

An alternative surface-water supply in Zone 5 is the Caldwell Reservoir project, currently planned by the BRA. The preliminary site for the reservoir is on Cedar Creek in Burleson and Milam Counties, with an estimated project surface area of 8.0 thousand acres. The project will store water from Cedar Creek, as well as Brazos River floodwaters pumped to the reservoir through a planned pipeline. If

Table III-12-8. Water Resources of the Brazos River Basin, Zone 4, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	22.7	—	—	—	22.7	22.7	—	—	22.7	.0	.0	.0
Surface Water	258.7	.0	17.5	2.6	278.8	186.1	103.7	.0	289.8	61.0	(72.0)	(11.0)
Total	281.4	.0	17.5	2.6	301.5	208.8	103.7	.0	312.5	61.0	(72.0)	(11.0)
2000												
Ground Water	30.8	—	—	—	30.8	30.8	—	—	30.8	.0	.0	.0
Surface Water	254.2	4.7	20.0	3.7	282.6	240.7	114.9	.0	355.6	.0	(73.0)	(73.0)
Total	285.0	4.7	20.0	3.7	313.4	271.5	114.9	.0	386.4	.0	(73.0)	(73.0)
2010												
Ground Water	31.7	—	—	—	31.7	31.7	—	—	31.7	.0	.0	.0
Surface Water	249.7	16.7	25.6	5.2	297.2	287.6	83.0	.0	370.6	.0	(73.4)	(73.4)
Total	281.4	16.7	25.6	5.2	328.9	319.3	83.0	.0	402.3	.0	(73.4)	(73.4)
2020												
Ground Water	32.7	—	—	—	32.7	32.7	—	—	32.7	.0	.0	.0
Surface Water	245.3	38.0	31.3	6.4	321.0	341.9	52.8	.0	394.7	.0	(73.7)	(73.7)
Total	278.0	38.0	31.3	6.4	353.7	374.6	52.8	.0	427.4	.0	(73.7)	(73.7)
2030												
Ground Water	30.6	—	—	—	30.6	30.6	—	—	30.6	.0	.0	.0
Surface Water	241.0	77.5	37.0	8.4	363.9	425.6	12.7	.0	438.3	.0	(74.4)	(74.4)
Total	271.6	77.5	37.0	8.4	394.5	456.2	12.7	.0	468.9	.0	(74.4)	(74.4)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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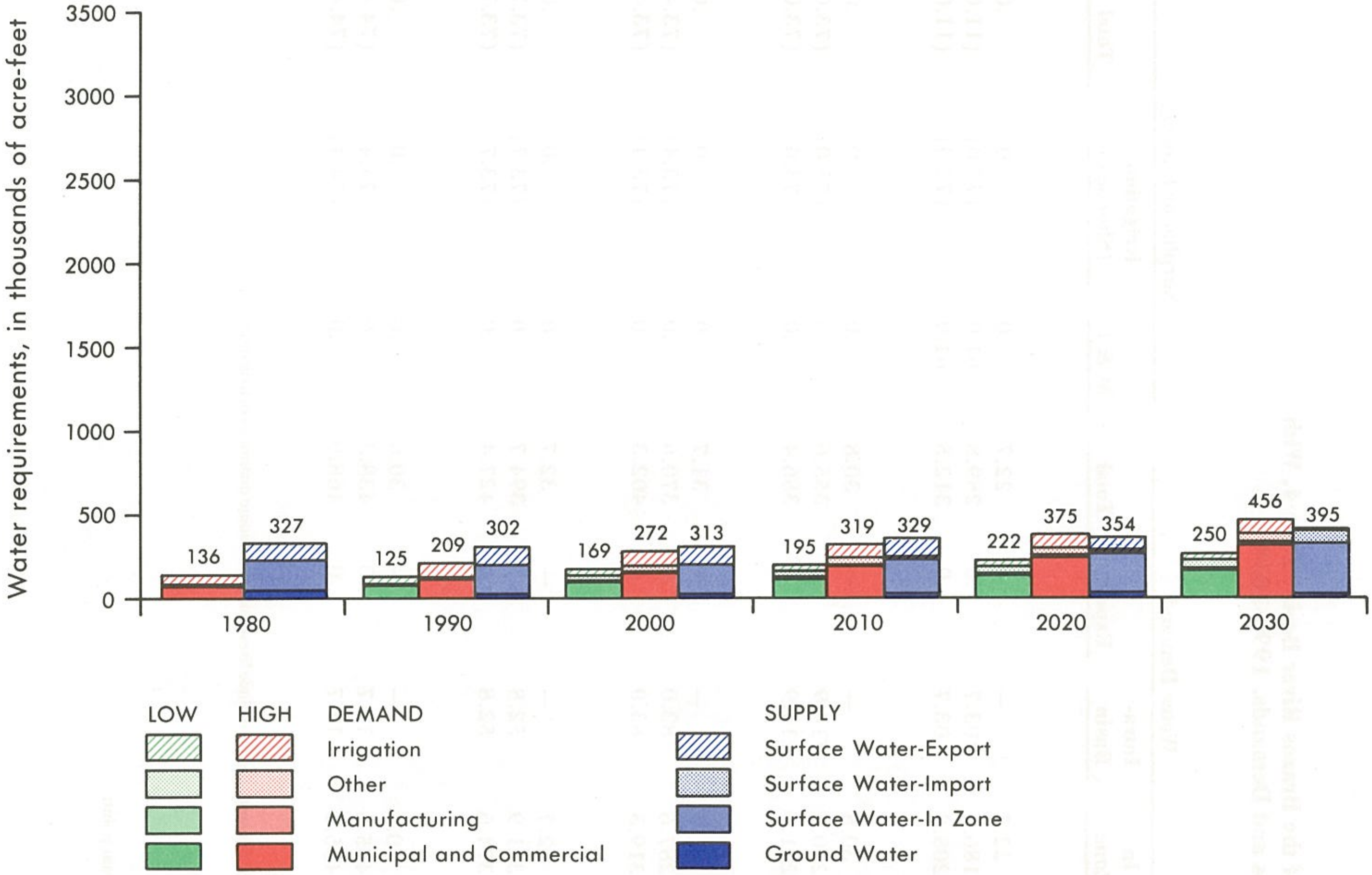

Figure III-12-6. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 4, 1980-2030

built, it is anticipated that this project will be used to supply water to lignite-burning power generation plants located in the general area. It is also considered to be an alternative for supplying lower basin customers currently served by Stillhouse Hollow Reservoir, thereby freeing Stillhouse Hollow water for use in Williamson, Bell, and adjacent counties if South Bend Reservoir cannot be built. BRA officials indicate that construction of the reservoir will take at least 10 years. Further detailed economic and engineering studies are being conducted by the BRA to determine the feasibility of the project. For current planning purposes, it has been assumed that Caldwell Reservoir will be constructed before 2000 to meet needs in the lower basin.

Zone 6

Projected surface-water needs can be satisfied through 2030 from existing and proposed surface-water development in Zone 6 of the Brazos River Basin and importation of water from basins to the east (Table III-12-10, Figure III-12-8). Slight irrigation shortages of from 1.6 thousand acre-feet in 1990 to 3.5 thousand acre-feet in 2030 are projected due to limited ground-water supplies. Shortages for municipal and industrial purposes are estimated to be much greater if proposed importation into the basin does not occur by the year 2000. Through the development of additional surface-water resources in the basin and importation from sources outside the basin, surface-water supplies for this zone are projected to increase from 773.1 thousand acre-feet in 1990 to 1.59 million acre-feet in the year 2030.

Municipal and manufacturing water requirements in Zone 6, which are anticipated to reach almost 466.3 thousand acre-feet annually by 2000 and 1.04 million acre-feet annually by 2030, will have to be supplied from dependable sources outside of the basin in addition to main-stream diversions of releases from upstream reservoirs, incremental river flows, and return flows. In addition

Table III-12-9. Water Resources of the Brazos River Basin, Zone 5, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	61.6	—	—	—	61.6	61.6	—	—	61.6	.0	.0	.0
Surface Water	118.1	3.6	31.1	.2	153.0	75.1	10.2	.6	85.9	72.2	(5.1)	67.1
Total	179.9	3.6	31.1	.2	214.6	136.7	10.2	.6	146.9	72.2	(5.1)	67.1
2000												
Ground Water	89.6	—	—	—	89.6	89.6	—	—	89.6	.0	.0	.0
Surface Water	211.2	3.6	37.0	.2	252.0	103.0	53.6	.6	157.2	100.2	(5.4)	94.8
Total	300.8	3.6	37.0	.2	341.6	192.6	53.6	.6	246.8	100.2	(5.4)	94.8
2010												
Ground Water	108.4	—	—	—	108.4	108.4	—	—	108.4	.0	.0	.0
Surface Water	210.1	4.6	41.0	.2	255.9	114.5	57.2	.7	172.4	89.1	(5.6)	83.5
Total	318.5	4.6	41.0	.2	364.3	222.9	57.2	.7	280.8	89.1	(5.6)	83.5
2020												
Ground Water	124.6	—	—	—	124.6	124.6	—	—	124.6	.0	.0	.0
Surface Water	209.1	3.1	43.9	.2	256.3	126.2	69.5	.7	195.7	66.6	(6.0)	60.6
Total	333.7	3.1	43.9	.2	380.9	250.8	69.5	.7	320.3	66.6	(6.0)	60.6
2030												
Ground Water	135.8	—	—	—	135.8	135.8	—	—	135.8	.0	.0	.0
Surface Water	208.1	3.3	47.0	.2	258.6	142.8	100.0	.7	242.8	23.4	(7.6)	15.8
Total	343.9	3.3	47.0	.2	394.4	278.6	100.0	.7	378.6	23.4	(7.6)	15.8

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
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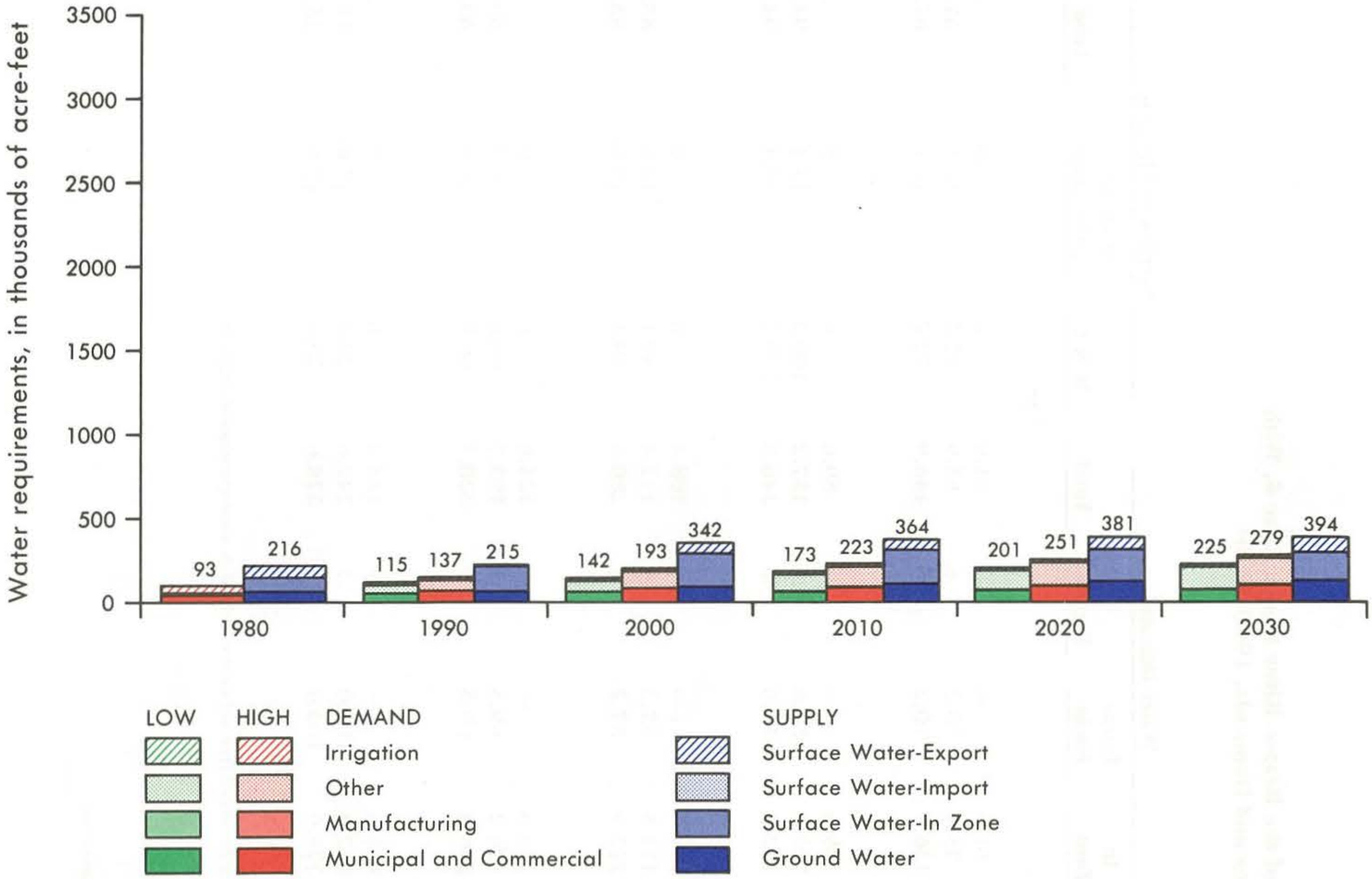

Figure III-12-7. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 5, 1980-2030

to requirements within the basin, part of the projected future needs in the San Jacinto-Brazos Coastal Basin (municipal, manufacturing, and irrigation) will continue to be met by diversions from the Brazos River through the canal systems under existing permits and contracts.

The projected 1990 surface-water needs in Zone 6 and adjacent areas of the San Jacinto-Brazos Coastal Basin exceed estimated available supplies from existing sources. The construction of South Bend Reservoir by 1990 would forestall the projected deficit until 2000. To provide water needed by 2000 and through the year 2030 for this area, water importation from the Neches and Sabine River Basins is a possible alternative. Existing reservoirs in those basins have a surplus of surface water which could be diverted through a system of pipelines and open channels to the lower Brazos River Basin and adjacent coastal areas. Such a conveyance system could also be used to provide water to meet municipal and manufacturing needs in the San Jacinto River Basin. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

Water Quality Protection

A water quality management plan for the Brazos River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Temple-Belton metropolitan area. These plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Table III-12-10. Water Resources of the Brazos River Basin, Zone 6, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	69.1	—	—	—	69.1	69.1	—	—	69.1	.0	.0	.0
Surface Water	151.0	521.6	100.5	.0	773.1	367.1	.0	407.6	774.7	.0	(1.6)	(1.6)
Total	220.1	521.6	100.5	.0	842.2	436.2	.0	407.6	843.8	.0	(1.6)	(1.6)
2000												
Ground Water	80.9	—	—	—	80.9	80.9	—	—	80.9	.0	.0	.0
Surface Water	151.0	582.3	128.0	86.2	947.5	500.5	.0	448.6	949.1	.0	(1.6)	(1.6)
Total	231.9	582.3	128.0	86.2	1028.4	581.4	.0	448.6	1030.0	.0	(1.6)	(1.6)
2010												
Ground Water	93.7	—	—	—	93.7	93.7	—	—	93.7	.0	.0	.0
Surface Water	151.0	531.6	159.7	312.4	1154.7	654.3	.0	502.0	1156.3	.0	(1.6)	(1.6)
Total	244.7	531.6	159.7	312.4	1248.4	748.0	.0	502.0	1250.0	.0	(1.6)	(1.6)
2020												
Ground Water	106.9	—	—	—	106.9	106.9	—	—	106.9	.0	.0	.0
Surface Water	151.0	587.4	190.3	419.9	1348.6	836.8	.0	513.4	1350.2	.0	(1.6)	(1.6)
Total	257.9	587.4	190.3	419.9	1455.5	943.7	.0	513.4	1457.1	.0	(1.6)	(1.6)
2030												
Ground Water	118.1	—	—	—	118.1	118.1	—	—	118.1	.0	.0	.0
Surface Water	151.0	521.4	221.0	696.9	1590.3	1064.5	.0	529.3	1593.8	.0	(3.5)	(3.5)
Total	269.1	521.4	221.0	696.9	1708.4	1182.6	.0	529.3	1711.9	.0	(3.5)	(3.5)

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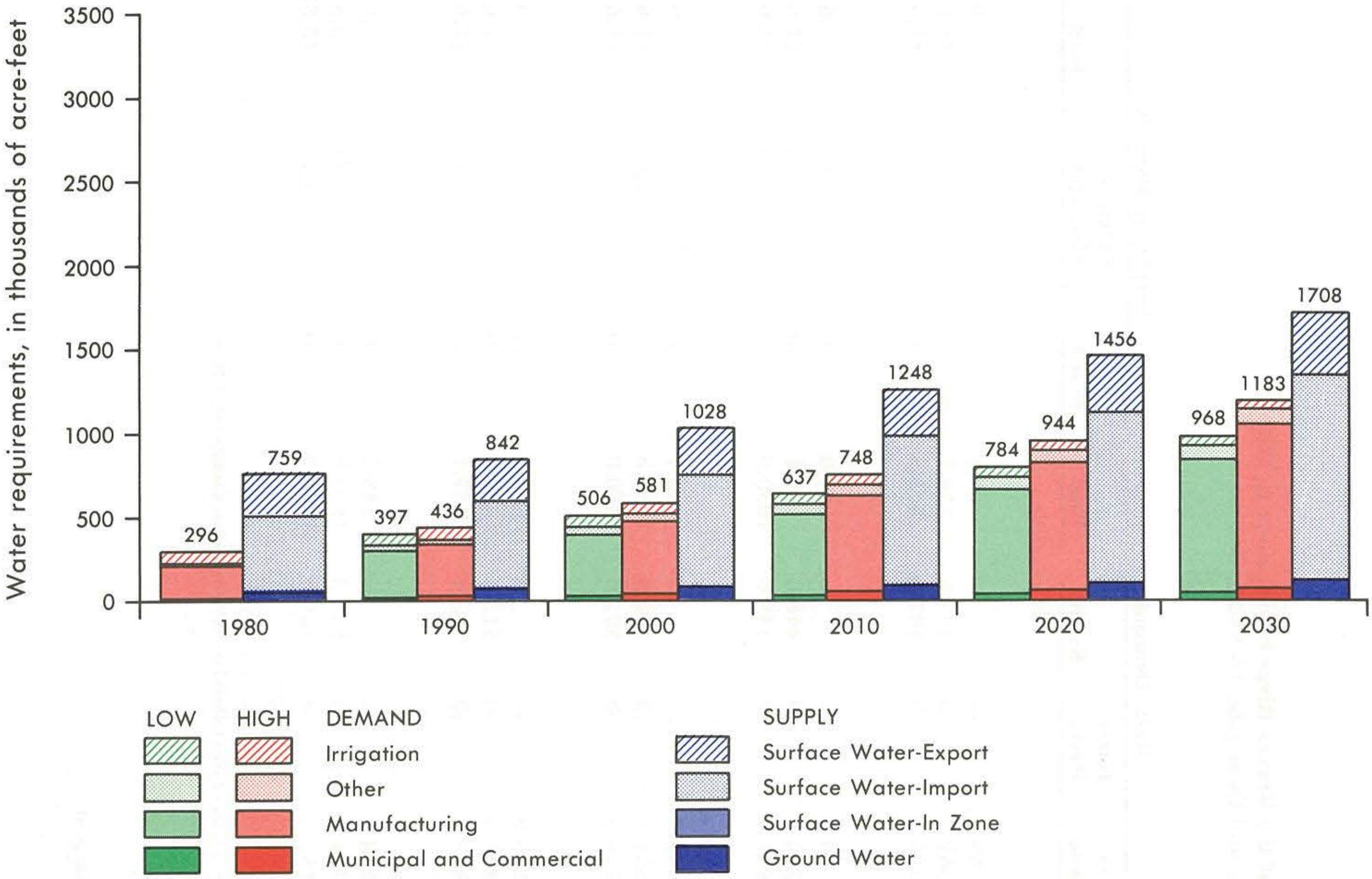

Figure III-12-8. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos River Basin, Zone 6, 1980-2030

Construction costs associated with municipal wastewater treatment facilities have been estimated to be approximately $482.0 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Brazos River Basin with approximately $131.4 million required for Zone 4, $117.0 million for Zone 3, $73.7 million for Zone 5, $69.8 million for Zone 1, $61.0 million for Zone 6, and $29.1 million for Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

The eight existing major reservoirs in the Brazos River Basin which have flood-control storage as a project purpose are Whitney, Belton, Proctor, Waco, Somerville, Stillhouse Hollow, Georgetown, and Granger. These reservoirs have a combined flood-control storage capacity of 3.86 million acre-feet.

Aquilla Lake, located on Aquilla Creek, has recently been completed and will provide an additional 89.5 thousand acre-feet of flood-control storage capacity.

The Munday Floodway System, completed in 1975, provides for flood protection to the City of Munday.

Millican Lake, one of the two authorized projects on the Navasota River, will initially provide 784.8 thousand acre-feet of flood-control storage capacity under current design criteria.

Under the Corps of Engineers' Small Flood Control Project Authority the following studies have been initiated: Burton Creek at Bryan, Texas; California Creek at Hamlin, Texas; Lake Creek at Round Rock, Texas; and Munday, Texas.

In addition to the work being done by the Corps of Engineers, the U.S. Soil Conservation Service has constructed 270 floodwater-retarding structures in the basin.

As of October 1980, an additional 97 structures were planned. About 90 percent of the existing and planned structures are located in Zones 3 and 4. The remaining 10 percent are distributed fairly equally among Zones 1, 2, and 5. There are no existing or planned structures in Zone 6.

13. BRAZOS-COLORADO COASTAL BASIN

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FIGURES

13. BRAZOS-COLORADO COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Brazos-Colorado Coastal Basin is bounded on the east by the Brazos River Basin, on the west by the Colorado River Basin, and on the south by the Gulf of Mexico. The San Bernard River and Caney Creek are the principal streams in the basin. Headwaters of the San Bernard River rise at an elevation of about 350 feet. Elevations in the area south of Bay City are generally below 50 feet. Total basin drainage area is 1,850 square miles. For planning purposes, the basin is treated as a single hydrologic unit (Figure III-13-1).

Surface Water

The average annual runoff during the period 1955 through 1970 was 446 acre-feet per square mile. The lowest annual flows during the period 1955-70 occurred in 1955 through 1956 and 1961 through 1963. Annual runoff averaged 101 acre-feet per square mile during 1955 through 1956, and 188 acre-feet per square mile during 1961 through 1963. Lowest runoff was 39 acre-feet per square mile in 1956.

Areas within the basin experience flooding occasionally from overflow of the Colorado River. The most severe flood occurred in the area in 1913. Other floods occurred within the basin in 1922, 1929, 1935, 1938, 1940, 1960, 1961, and 1979.

From June through November of each year, the Brazos-Colorado Coastal Basin, because of its proximity to the Gulf of Mexico, is subject to the threat of tropical cyclones.

Available water quality data indicate that runoff throughout the basin is generally low in concentrations of dissolved solids. Although low flows of the San Bernard River are sometimes saline in some reaches, as a result of oil and gas exploration and development, moderate to high flows commonly contain less than 100 milligrams per liter (mg/l) dissolved solids. The San Bernard River and the other coastal tributaries are tidally affected for several miles upstream.

Ground Water

The Gulf Coast Aquifer underlies the entire Brazos-Colorado Coastal Basin. The aquifer extends to a depth of more than 2,500 feet. Yields of large-capacity wells average 1,500 gallons per minute (gpm), but locally wells produce up to 3,100 gpm. The water generally contains less than 1,000 mg/l total dissolved solids.

In the past, intensive withdrawals of fresh to slightly saline ground water in the vicinity of the Gulf Sulfur mine located near the coast has lowered water levels to about 100 feet below sea level. Consequently, saline-water encroachment has occurred. In areas immediately adjacent to the coast in Matagorda and Brazoria Counties within the basin, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment as well as land-surface subsidence are very great, but can be controlled by proper well location, completion, and pumpage.

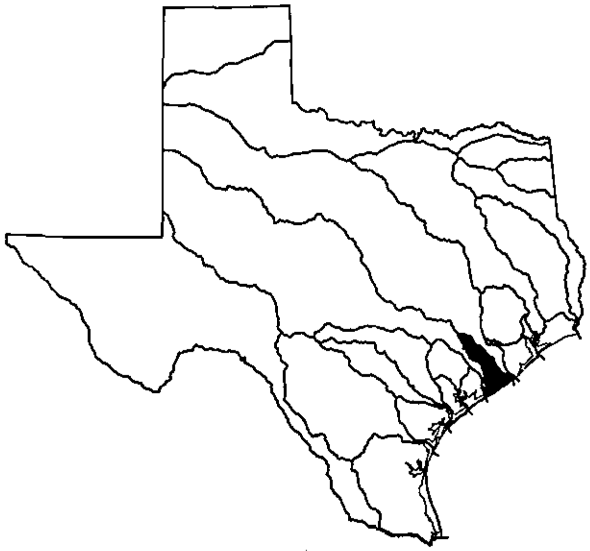
Population and Economic Development

The population of the Brazos-Colorado Coastal Basin was reported to be 81.7 thousand in 1980. Principal cities in the basin are Bay City, with a 1980 population of 17.8 thousand, and Wharton, with an in-basin population of 8.2 thousand.

The Brazos-Colorado Coastal Basin ranks lower than the statewide average in population density, percent urban, and median family income. The economy of the area is based on petroleum and petrochemical manufacturing, agriculture, agribusiness, and other manufacturing. Over two-thirds of the agricultural income is from crops. Mining activities in the basin include oil, gas, sulfur, clay, salt, and shell production. Recreational activities such as hunting, fishing, and coastal activities are also important to the basin economy.

Water Use

Municipal water use in the Brazos-Colorado Coastal Basin totaled 11.4 thousand acre-feet in 1980; over 98 percent of this amount was supplied by ground water. Municipal freshwater use in Brazoria County constituted



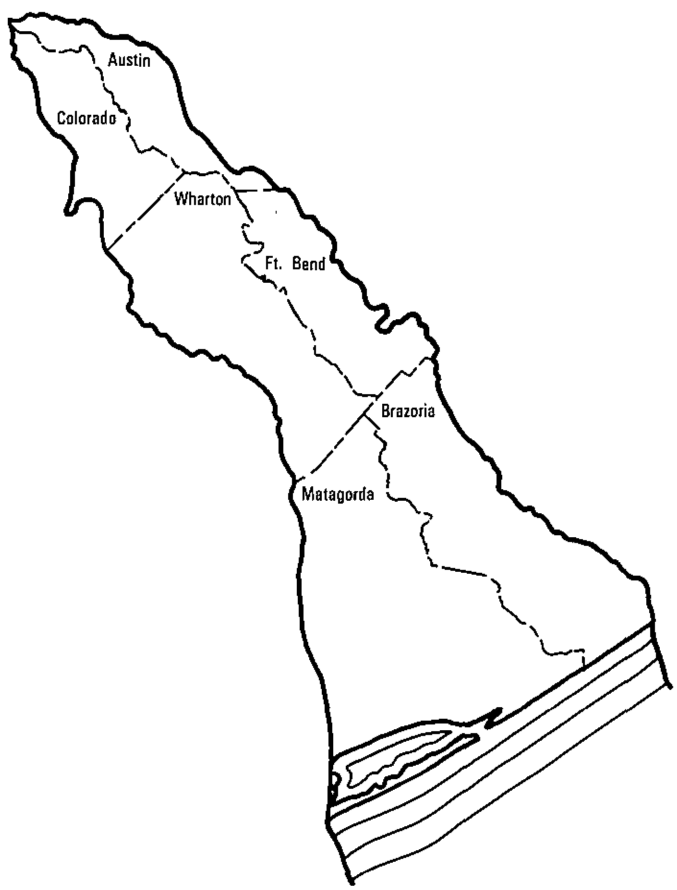


Figure III-13-1. Brazos-Colorado Coastal Basin

30 percent of the total basin use in 1980; Matagorda County, 35 percent; and Wharton County, 21 percent.

Manufacturing industries in the basin used 20.0 thousand acre-feet of freshwater in 1980. This amount accounts for approximately six percent of the total use in the basin during 1980. The water used by manufacturing included 16.4 thousand acre-feet from surface-water supplies and 3.6 thousand acre-feet from ground-water sources.

In 1980, about 74.5 thousand acres was irrigated in the basin with 304.8 thousand acre-feet of water, mostly for growing rice. Ground water pumped from the Gulf Coast Aquifer supplied about 26 percent of the total water used. Most of the surface water was supplied from the adjacent Colorado River Basin. Although additional lands in this area are suitable for irrigation, future municipal and industrial development can be expected to compete for both land and freshwater supplies.

Estimated freshwater use for mining in the Brazos-Colorado Coastal Basin totaled 11.5 thousand acre-feet in 1980. Of this total, virtually all water used was for nonmetal production, primarily in Wharton County. Freshwater withdrawals for oil and gas production were relatively small compared to other nonmetal production.

Livestock water use in 1980 totaled 1.7 thousand acre-feet in the Brazos-Colorado Coastal Basin, mostly for raising beef cattle.

Navigation facilities in the Brazos-Colorado Coastal Basin consist of the Gulf Intracoastal Waterway and its tributary waterway, the San Bernard River Channel. These navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the Brazos-Colorado Coastal Basin totaled about 15.6 thousand acre-feet. Irrigation return flows in the Brazos-Colorado Coastal Basin in 1980 were estimated to total 95.3 thousand acre-feet, mostly from rice irrigation. Most of the return flows are discharged into coastal waters.

Current Ground-Water Development

Approximately 100.3 thousand acre-feet of ground water was used in 1980 in the Brazos-Colorado Coastal Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 100.3 thousand acre-feet of ground water used in the basin, 79.5 thousand acre-feet or 79 percent was for irrigation purposes, and 11.2 thousand acre-feet or 11 percent was for municipal purposes.

A large overdraft of ground water occurred throughout the entire basin, due primarily to excessive withdrawals for irrigation purposes.

Current Surface-Water Development

There are no major reservoirs in the basin, although several off-channel storage facilities have been developed. Texas Gulf Sulphur operates a freshwater storage reservoir at Newgulf. Supply is obtained from the San Bernard River and from the Gulf Coast Aquifer.

Water Rights

A total of 91,116 acre-feet of surface water was authorized or claimed for diversion or use in the Brazos-Colorado Coastal Basin as of December 31, 1983 (Table III-13-1). This total was almost equally divided among industrial, irrigation, and mining uses (Table III-13-2).

Water Quality

Under low-flow conditions, Caney Creek has experienced dissolved-oxygen problems due primarily to industrial effluent. Caney Creek periodically contains high chloride concentrations due to runoff from oil and gas fields.

Flooding, Drainage, and Subsidence

Due to the limited amount of urbanization within the Brazos-Colorado Coastal Basin, flood damage estimates have not been sufficient to reveal the precise amount of damage experienced within the basin. However, the data indicate that flooding is a serious problem. In 1979, two federal flood disaster declarations occurred in the basin with $292 thousand spent in federal relief. During the period 1979-1981, 500 flood insurance claims were filed for $2.1 million in flood damages.

Austin, Matagorda, Colorado, and Brazoria Counties have adopted the necessary regulations for participation in the Flood Insurance Program. Matagorda and Brazoria Counties have entered the Regular Phase of the Program. Wharton and Fort Bend Counties have not yet entered the Program; however, rate studies are underway to provide more accurate 100-year flood data.

Table III-13-1. Authorized or Claimed Amount of Water, by Type of Right, Brazos-Colorado Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	36	73,601
Claims	24	4,255
Certified Filings	2	13,260
Certificates of Adjudication	0	0
Total Authorizations and Claims	62	91,116

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

A total of six cities have become eligible for the sale of flood insurance. Bay City, Wallis, and Sweeny have completed flood insurance rate studies and are participating in the Regular Phase of the Program. Efforts are underway to establish 100-year flood elevations in the remaining areas.

Table III-13-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Brazos-Colorado Coastal Basin

Type of Use	Number of Rights	Basin Total
Municipal	0	0
Industrial	2	32,000
Irrigation	57	33,766
Mining	2	25,350
Recreation	1	0
Total	62	91,116

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

Drainage problems in the Brazos-Colorado Coastal Basin are similar to drainage problems in other coastal basins. Rice-farming areas need on-farm drainage improvements and continued maintenance of ditches, outlets, and irrigation facilities. Minor urban drainage problems occur in and near Bay City and in isolated subdivisions within incorporated areas of Wharton County.

Since 1918, approximately 1.2 feet of subsidence has occurred at Bay City within the Brazos-Colorado Coastal Basin. This subsidence was probably caused by withdrawals of petroleum and associated saline waters as well as withdrawal of fresh ground water from the Gulf Coast Aquifer. The western edge of the subsidence "bowl", related primarily to ground-water withdrawals in the Houston-Galveston region, occurs in Fort Bend, Brazoria, and Matagorda Counties within the basin. However, the "bowl's" extension into eastern Matagorda County was caused by withdrawals of petroleum and associated saline ground waters from the Old Ocean Oil and Gas Field. A very large but unknown amount of subsidence has occurred locally at Gulf in southern Matagorda County. This subsidence was caused by large extractions of sulfur from the cap rock of a salt dome. Fault activation and movement, which can cause considerable damage to property, are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

There are no major reservoir facilities for providing flat-water recreation opportunities in the Brazos-Colorado Coastal Basin. Freshwater recreation resources available in the area include shoreline activities along the San Bernard River and other streams and ponds in the basin. Bay and coastal waters fronting the basin provide the major water-oriented recreation opportunities available to the public.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Brazos-Colorado Coastal Basin is projected to more than double by the year 2030, from the present 81.7 thousand to 222.5 thousand (Table III-13-3). A 71 percent increase to 139.3 thousand is anticipated from 1980 to 2000. This growth rate is expected to be 60 percent for the 2000-2030 period.

Brazoria and Fort Bend Counties are expected to contain 44 percent (61.0 thousand) of the 2000 population in the basin. In 2030, this portion of the basin population will

Table III-13-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Brazos-Colorado Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Brazos-Colorado Basin																		
Population			81.7			1,107.0			139.3			168.1			196.1			222.5
Municipal	11.2	0.2	11.4	14.9	8.3	23.2	19.3	10.7	30.0	23.5	12.7	36.2	27.5	14.8	42.3	30.7	17.3	48.0
Manufacturing	3.6	16.4	20.0	4.3	18.1	22.4	4.6	19.3	23.9	2.6	21.1	23.7	4.1	20.5	24.6	2.6	23.0	25.6
Steam Electric	0.0	0.0	0.0	.0	.0	.0	.0	.0	.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	5.1	6.4	11.5	4.9	7.2	12.1	4.9	7.8	12.7	5.4	8.8	14.2	5.9	9.8	15.7	8.2	9.0	17.2
Irrigation	79.5	225.3	304.8	39.5	192.7	232.2	36.4	179.2	215.6	33.7	180.9	214.6	33.3	180.2	213.5	31.1	181.3	212.4
Livestock	0.9	0.8	1.7	.3	1.8	2.1	.3	2.1	2.4	0.3	2.1	2.4	0.3	2.1	2.4	0.3	2.1	2.4
Basin Total Water	100.3	249.1	349.4	63.9	228.1	292.0	65.5	219.1	284.6	65.5	225.6	291.1	71.1	227.4	298.5	72.9	232.7	305.6

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

increase to 101.9 thousand. By 2030, Brazoria's percentage of basin population should be about 29 percent and Fort Bend's percentage should grow from 8 percent in 1980 to 16 percent in 2030. Although Matagorda County's population is projected to grow 157 percent by 2030, its share of the basin population is expected to be about 29 percent.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Brazos-Colorado Coastal Basin are projected to increase from the 1980 level of 11.4 thousand acre-feet by a projected maximum of 163 percent by the year 2000. In the year 2030, water requirements are projected to range from 29.1 to 48.0 thousand acre-feet.

Industrial

Manufacturing water requirements in 1980 were 20.0 thousand acre-feet in the Brazos-Colorado Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Brazos-Colorado Coastal Basin are projected to increase 28 percent by the year 2030, to a potential high of 25.6 thousand acre-feet by 2030. Most of the 1980 water use occurred in Brazoria County, and this trend is expected to continue throughout the planning period. In Brazoria County, industrial organic chemicals were the source of most of the manufacturing water requirements.

Steam-Electric Power Generation

No steam-electric power generation facilities are currently planned for construction in the basin.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Brazos-Colorado Coastal Basin are projected to decrease from the 1980 level of 304.8 thousand acre-feet by a projected maximum 29 percent by the year 2000 in the high and low cases. In the year 2030, water requirements in the basin are projected to be about 212.4 thousand acre-feet annually in the high case to irrigate about 71.8 thousand acres.

Livestock

Livestock production is expected to expand slightly in the coastal basin. The projected annual livestock water requirement by 2030 is 2.4 thousand acre-feet per year.

Mining

Projections of mining freshwater use in the Brazos-Colorado Coastal Basin for the 1980-2030 period indicate that the basin's 2030 mining water requirements are expected to total 17.2 thousand acre-feet.

Nonmetal mining freshwater requirements are expected to grow from 10.4 thousand acre-feet in 1980 to 16.8 thousand acre-feet in 2030.

Navigation

Currently, no navigation facilities which would require the use of regulated freshwater supplies are planned in the basin.

Hydroelectric Power

There are no planned hydroelectric power generating facilities in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Brazos-Colorado Coastal Basin through the year 2030 is 68.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the Brazos-Colorado Coastal Basin by decade from 1990 through 2030 is expected to be from 63.9 to 72.9 thousand acre-feet per year (Table III-13-3). The approximate average annual projected ground-water use within the basin is expected to be about 67.8 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

Surface-water requirements in the Brazos-Colorado Coastal Basin are projected to be satisfied through the year 2030 for all municipal and industrial purposes (Table III-13-4, Figure III-13-2). The water to meet the projected needs would be provided by importation from the Colorado and Brazos River Basins in the amount of 201.9 thousand acre-feet per year by the year 2030. Localized shortages for projected irrigation needs are forecast to be 12.8 thousand acre-feet by the year 2030. These shortages occur due to limitations in ground-water supplies in the basin.

Limited drainage area and relatively flat topography preclude the development of economically viable major reservoirs in this coastal basin. No reservoir projects are proposed for this basin.

Water Quality Protection

A water-quality management plan for the Brazos-Colorado Coastal Basin has been developed pursuant to the requirements of Federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water-quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $38.2 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Brazos-Colorado Coastal Basin in January 1980 dollars and are subject to revision as new data becomes available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water-quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Drainage improvements and levees are needed to protect agricultural lands and urban developments from potential flood damage in the basin.

There are no existing floodwater-retarding structures in the basin and none are currently planned, however, 14.5 miles of channel improvement have been completed by the Soil Conservation Service.

Table III-13-4. Water Resources of the Brazos-Colorado Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	63.9	—	—	—	63.9	63.9	—	—	63.9	.0	.0	.0
Surface Water	.0	—	.0	200.6	200.6	211.9	—	.0	211.9	.0	(11.3)	(11.3)
Total	63.9	—	.0	200.6	264.5	275.8	—	.0	275.8	.0	(11.3)	(11.3)
2000												
Ground Water	65.5	—	—	—	65.5	65.5	—	—	65.5	.0	.0	.0
Surface Water	.0	—	.0	189.9	189.9	202.0	—	.0	202.0	.0	(12.1)	(12.1)
Total	65.5	—	.0	189.9	255.4	267.5	—	.0	267.5	.0	(12.1)	(12.1)
2010												
Ground Water	65.5	—	—	—	65.5	65.5	—	—	65.5	.0	.0	.0
Surface Water	.0	—	.0	195.0	195.0	207.4	—	.0	207.4	.0	(12.4)	(12.4)
Total	65.5	—	.0	195.0	260.5	272.9	—	.0	272.9	.0	(12.4)	(12.4)
2020												
Ground Water	71.1	—	—	—	71.1	71.1	—	—	71.1	.0	.0	.0
Surface Water	.0	—	.0	196.5	196.5	208.2	—	.0	208.2	.0	(11.7)	(11.7)
Total	71.1	—	.0	196.5	267.6	279.3	—	.0	279.3	.0	(11.7)	(11.7)
2030												
Ground Water	72.9	—	—	—	72.9	72.9	—	—	72.9	.0	.0	.0
Surface Water	.0	—	.0	201.9	201.9	214.7	—	.0	214.7	.0	(12.8)	(12.8)
Total	72.9	—	.0	201.9	274.8	287.6	—	.0	287.6	.0	(12.8)	(12.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

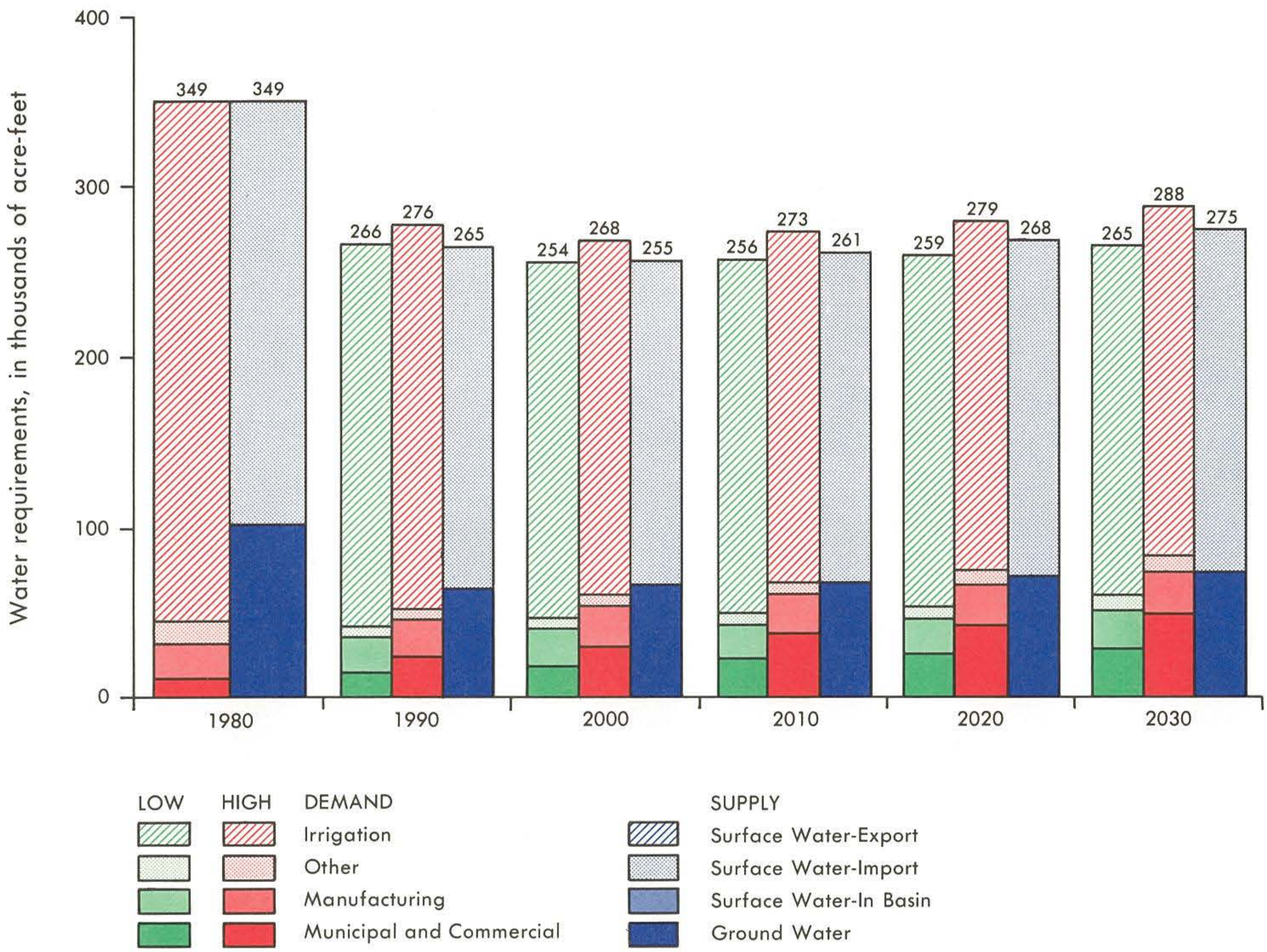


Figure III-13-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Brazos-Colorado Coastal Basin, 1980-2030

14. COLORADO RIVER BASIN

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14. COLORADO RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Colorado River Basin is bounded on the north and east by the Brazos River Basin and the Brazos-Colorado Coastal Basin, and on the south and west by the Lavaca, Guadalupe, Nueces, and Rio Grande Basins and the Colorado-Lavaca Coastal Basin. Maximum basin width is about 154 miles and the total basin drainage area is 41,763 square miles, of which 39,893 square miles is in Texas and the remainder in New Mexico. Drainage in the upper part of the basin in the High Plains is poorly defined. Headwaters of the Colorado River form in eastern Dawson County at an elevation of about 3,000 feet. The North and South Concho Rivers join in Tom Green County, emptying into the Colorado River at a streambed elevation of about 1,480 feet in Concho County. The San Saba River flows eastward from Schleicher County and joins the Colorado River near San Saba at a streambed elevation of about 1,102 feet. The North and South Llano Rivers join near Junction to form the Llano River, which flows eastward to join the Colorado River near Kingsland. The Pedernales River joins the Colorado River in western Travis County at a streambed elevation of about 681 feet, and Barton Creek joins the Colorado River at Austin at an elevation of about 428 feet. For planning purposes, the Colorado River Basin is divided into three zones as shown in Figure III-14-1.

Surface Water

The average annual runoff during the 1941-70 period was about 80 acre-feet per square mile in the contributing area. About 31 percent of the basin in Zone 1 does not contribute runoff. Average annual runoff ranges from approximately 350 acre-feet per square mile near the mouth of the Colorado River to less than 50 acre-feet per square mile in contributing areas in the western part of the basin.

Low flows during the 1941-70 period occurred in 1951-52, 1954, 1956, and 1962-64. Average annual runoff for the 1951-52 interval was about 23 acre-feet per square mile, and about 17 acre-feet per square mile during the 1962-64 period. During 1954 and 1956, average runoff was about 16 and 17 acre-feet per square mile, respectively.

In the upper Colorado River Basin, the flood plain is characterized by narrow, steep-sloped stream channels and low-density vegetation. Runoff is rapid from the rocky soils, and tributary streams produce sharp-crested floods with high peak discharges and velocities. As floods pass downstream, discharges and velocities are greatly reduced in the wider, shallow flood plains.

In the lower portion of the basin, the December 1913 flood produced a record gage height of 38.9 feet near Wharton; the June 1935 flood reached 38.2 feet, and the July 1938 flood reached 37.4 feet.

Areas where most of the serious flood damages can be expected to occur are in the vicinities of Lake Travis and Lake Austin, and in the Cities of Austin, Big Spring, Brownwood, Ballinger, La Grange, Columbus, Wharton, and Matagorda. The coastal portion of the basin is impacted by a hurricane in two out of every five years.

Water stored in Lake J.B. Thomas in the upper part of the basin is of good quality, with dissolved-solids concentrations generally not exceeding 60 milligrams per liter (mg/l) chloride, 60 mg/l sulfate, and 400 mg/l total dissolved solids. Below Lake J.B. Thomas, water quality deteriorates as the main stem of the Colorado River receives saline inflows from both natural and man-made sources. In the past, the total dissolved-solids concentrations of the low flow of the river between Lake J.B. Thomas and Lake E.V. Spence have exceeded 10,000 mg/l; however, salinity-control measures carried out by the Colorado River Municipal Water District in recent years have significantly improved the quality of the river.

Inflows from Morgan and Champion Creeks are low in total dissolved solids with discharge-weighted average concentrations less than 500 mg/l, thereby diluting the highly mineralized Colorado River waters. By contrast, other streams in the area are high in dissolved solids, particularly Beals Creek which drains a large part of the West Texas area of the basin. Beals Creek receives inflows from Natural Dam Salt Lake, where dissolved-solids concentrations occasionally exceed 250,000 mg/l. Beals Creek immediately downstream of Natural Dam Salt Lake often contains total dissolved-solids concentrations ranging from 5,000 to 40,000 mg/l, but where Beals Creek flows into the Colorado River, dissolved-solids concentrations are about 1,000 mg/l.

Water stored in Lake E.V. Spence contains about 450 to 500 mg/l chloride, 300 to 350 mg/l sulfate, and 1,400 to 1,500 mg/l total dissolved solids, although salinity has varied widely since the reservoir was completed in 1968. Below Lake Spence, many streams containing good quality water flow into the Colorado River, significantly improving

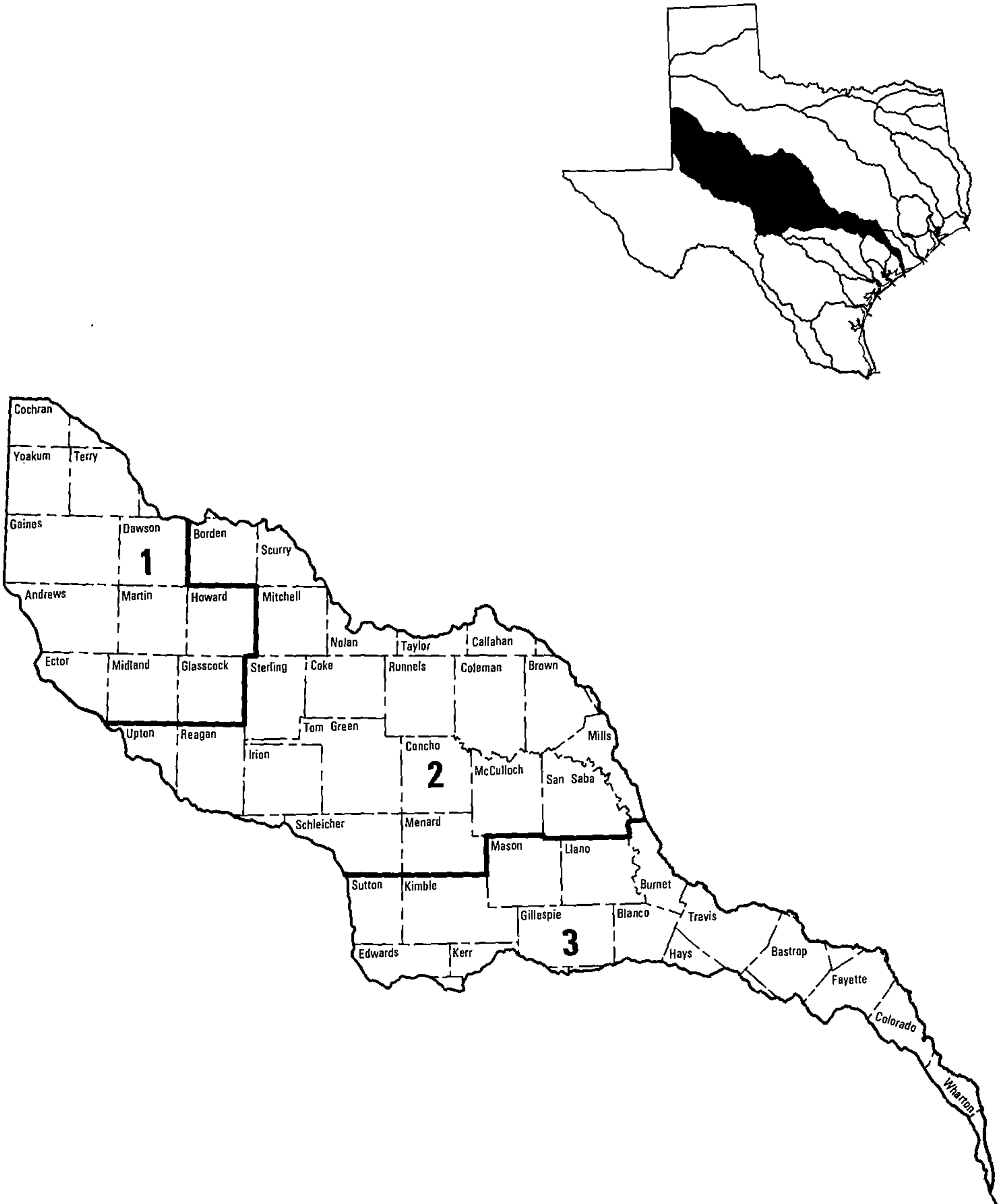

Figure III-14-1. Colorado River Basin and Zones the quality of the river. The Concho River, Pecan Bayou, and the San Saba River, between Lake Spence and the Highland Lakes system, have total dissolved-solids concentrations generally below 500 mg/l. Water in both the Concho and San Saba Rivers, which traverse limestone terrains, is very hard, while the water of Pecan Bayou is moderately hard.

Concentrations of dissolved solids in the Colorado River near San Saba are generally less than 500 mg/l, sulfate and chloride concentrations less than 100 mg/l, and hardness (as calcium carbonate) averages 250 to 300 mg/l.

The Highland Lakes system, which includes Lakes Buchanan, Inks, Lyndon B. Johnson, Marble Falls, Travis, Lake Austin, and Town Lake, receives inflow from the main stem and tributaries including the Llano and Pedernales Rivers. The quality of tributary inflows is excellent, and the water impounded by the lakes as well as runoff throughout the remainder of the Colorado River Basin is of good chemical quality. Total dissolved-solids concentrations seldom exceed 400 mg/l, and are below 300 mg/l over 50 percent of the time. Hardness levels are around 200 mg/l and sulfate and chloride concentrations average 30 to 40 mg/l.

Ground Water

The High Plains (Ogallala) Aquifer underlies most of the upper Colorado River Basin. The 1980 saturated thickness of the High Plains Aquifer within the basin ranges from about 20 to 300 feet. Yields of large-capacity wells average about 400 gallons per minute (gpm) and generally range from 200 to 900 gpm per minute. Locally, wells may yield as much as 2,000 gpm. The quality of water in the aquifer varies widely, ranging from about 300 to more than 3,000 mg/l total dissolved solids. In some areas of the basin, ground water of the High Plains (Ogallala) Aquifer has fluoride and nitrate concentrations which exceed Environmental Protection Agency-Texas Department of Health primary standards for fluoride and nitrate.

The Edwards-Trinity (Plateau) Aquifer underlies a large area in the west-central part of the Colorado River Basin. The lower part of the aquifer is generally less than 100 feet thick and consists of the Trinity Sands. Upper parts of the aquifer are commonly less than 500 feet thick. Yields of high-capacity wells average about 250 gpm, but locally wells produce up to 1,800 gpm. Water in the aquifer is generally fresh and contains from 200 to 700 mg/l total dissolved solids, although concentrations reach about 3,500 mg/l in the northwest part of the aquifer within the basin.

The Trinity Group Aquifer extends in a band across the south-central part of the basin. Well yields are generally less than 100 gpm. Water quality ranges from fresh to slightly saline.

The Edwards (Balcones Fault Zone) Aquifer extends in a narrow band across Hays and Travis Counties in the south-central part of the Colorado River Basin. Few large-capacity wells have been completed in the aquifer in the basin, but wells could yield several hundred gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids, with salinity increasing with depth.

The Carrizo-Wilcox Aquifer extends across the southeast part of the Colorado River Basin. Total thickness ranges up to about 2,000 feet. Yields of large-capacity wells average about 200 gpm, but locally yields exceed 600 gpm. The water generally contains less than 1,000 mg/l total dissolved solids, but salinity increases with depth.

The Gulf Coast Aquifer lies beneath the lower part of the Colorado River Basin. The aquifer extends to a maximum depth of about 2,500 feet. Yields of large-capacity wells average about 1,500 gpm, but locally reach 3,400 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids, but concentrations increase downdip, particularly near the Gulf.

The Edwards-Trinity (High Plains) Aquifer underlies the Ogallala in much of the western part of the Colorado River Basin. Total thickness ranges to about 300 feet. Yields of wells producing from the aquifer are generally low, but locally wells yield as much as 600 gpm where there is significant saturation of the limestones. The quality of water in the aquifer is relatively poor, with dissolved-solids concentrations ranging from 1,000 to 10,000 mg/l.

In east-central Tom Green County, along and south of the Concho River and east of San Angelo, are water-bearing deposits of alluvium which are part of the Alluvium and Bolson Deposits Aquifer. Saturated thickness of these water-bearing strata range up to a maximum of 117 feet. Yields to irrigation wells generally range from about 100 gpm to nearly 7,000 gpm.

The Santa Rosa Aquifer occurs in two areas of the western part of the Colorado River Basin. Thickness ranges to about 400 feet and averages about 200 feet. Yields of large-capacity wells average about 250 gpm, but locally reach 1,150 gpm. The western part of the aquifer underlies the High Plains (Ogallala) Aquifer and in most places contains poor quality water (1,000 to 10,000 mg/l total dissolved solids). The eastern part of the aquifer commonly contains water having less than 1,000 mg/l total dissolved solids, but concentrations increase rapidly downdip.

The Hickory Sandstone Aquifer occurs in the central part of the basin near the Llano Uplift. Total thickness averages approximately 400 feet. Yields of large-capacity wells generally range between about 200 and 500 gpm, but locally wells produce up to 1,500 gpm. Water in the aquifer commonly contains less than 500 mg/l total dissolved solids, but concentrations increase downdip.

The Ellenburger-San Saba Aquifer also occurs in the central part of the Colorado River Basin. Total thickness ranges to more than 1,000 feet. Wells yield as much as 1,000 gpm, but most wells yield less than 500 gpm. Water in the aquifer commonly contains less than 1,000 mg/l total dissolved solids, but concentrations increase downdip.

The Marble Falls Limestone Aquifer is also located in the central part of the Colorado River Basin. It reaches a maximum thickness of about 600 feet, and well yields range up to 2,000 gpm. The quality of the water is good at or near the outcrop area of the aquifer, although total dissolved-solids concentrations increase with depth.

The Queen City Aquifer occurs in a narrow band across the lower part of the basin. It reaches a maximum thickness of about 200 feet. Yields of most wells are less than 200 gpm, locally ranging up to about 400 gpm. Water quality varies considerably, ranging from less than 1,000 to more than 3,000 mg/l total dissolved solids.

The Sparta Aquifer also occurs in a narrow band across the lower part of the basin. Maximum thickness is about 90 feet, and yields of most wells are less than 100 gpm; however, properly constructed wells may yield up to 400 gpm. Water in the aquifer contains from less than 1,000 to over 3,000 mg/l total dissolved solids.

Except for the area of the Gulf Coast Aquifer, widespread land subsidence due to clay compaction caused by withdrawals of ground water is not a problem within the Colorado River Basin. However, the potential for locally significant subsidence exists within the upper-middle part of the basin. Due to compaction of clays caused by ground-water withdrawals from the Gulf Coast Aquifer, additional subsidence is a potential problem in Colorado, Wharton, and Matagorda Counties within the Colorado River Basin. Data to determine specifically the amounts and distribution of subsidence within the Colorado River Basin in Colorado and Wharton Counties are not available. Fault activation and movement which can cause considerable damage to property is sometimes associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain. Subsidence and fault movement also are caused locally by petroleum withdrawals and extractions of sulfur and other minerals in the Gulf Coastal Plain.

Population and Economic Development

The Colorado River Basin had a population of 1.06 million in 1980. Austin is the largest city in the Colorado River Basin and had a 1980 population of 345 thousand, 32.5 percent of the basin total. It is followed in population size by Odessa, San Angelo, Midland, Big Spring, and Brownwood.

The economy of the large and diverse geographic area of the Colorado River Basin is based on petroleum and other minerals, State and federal government, agriculture, agribusiness, research and industry, and manufacturing activities.

Water Use

Municipal water use in the Colorado River Basin totaled 224.4 thousand acre-feet in 1980. The distribution, by zone, and percent of total basin use was: Zone 1, 67.8 thousand acre-feet or 30 percent; Zone 2, 48.7 thousand acre-feet or 22 percent; and Zone 3, 107.9 thousand acre-feet or 48 percent. Travis County used 39 percent of the total basin water use; Tom Green, 10 percent; Midland, 9 percent; Howard, 4 percent; and Ector, 11 percent.

Water use by manufacturing industries in the basin totaled 24.8 thousand acre-feet in 1980. Almost 38 percent of the total basin manufacturing use occurred in Zone 1, while 14 percent and 48 percent of the 1980 water use occurred in Zones 2 and 3, respectively.

There was 4,105 megawatts of steam-electric power generating capacity in the Colorado River Basin in 1980. During 1980, these plants consumed nearly 30.1 thousand acre-feet of surface water (including 14.5 thousand acre-feet of estimated net adjusted evaporation) and used almost one thousand acre-feet of ground water.

About 1.1 million acres was irrigated in the Colorado River Basin in 1980 using almost 1.4 million acre-feet of water. Ground water supplied almost 1.2 million acre-feet and surface-water use totaled 211.0 thousand acre-feet for irrigation.

In the High Plains region of the basin (most of Zone 1), the Ogallala Formation supplies irrigation water from relatively shallow depths. In Zone 1, 889.1 thousand acres was irrigated in 1980 with 1.0 million acre-feet of water.

There was about 115.4 thousand irrigated acres in Zone 2, requiring 155.6 thousand acre-feet of water in 1980. Ground-water use totaled 75.9 thousand acre-feet and surface-water use totaled 79.7 thousand acre-feet. Ground water is supplied by the Alluvium Aquifer; surface water is diverted from the Colorado River and tributaries.

Irrigated acreage in Zone 3 was about 45.9 thousand acres using 172.5 thousand acre-feet of water in 1980. A total of 44.7 thousand acre-feet of ground water and 127.8 thousand acre-feet of surface water was used.

Estimated freshwater withdrawals for mining purposes in the Colorado River Basin totaled 70.7 thousand acre-feet in 1980, representing the largest mining water use in any river or coastal basin in Texas. Petroleum and natural gas production accounted for the major portion of the basin mining water requirements, with a total of 62.3 thousand acre-feet. The most intensive use of water for fuel production was concentrated in Yoakum County (21.0 thousand acre-feet), Gaines County (16.3 thousand acre-feet), Andrews County (7.6 thousand acre-feet), and Cochran County (5.4 thousand acre-feet).

Livestock water requirements in 1980 totaled about 27.9 thousand acre-feet in the Colorado River Basin, mostly for cattle production. Ground water supplied approximately 15.5 thousand acre-feet and surface water an additional 12.4 thousand acre-feet in 1980. It is estimated that livestock water use was 2.8 thousand acre-feet in Zone 1, 14.0 thousand acre-feet in Zone 2, and 11.1 thousand acre-feet in Zone 3.

The navigation facilities in the Colorado River Basin consist of the Gulf Intracoastal Waterway and its tributary waterway, the Channel to Bay City. The Channel to Bay City extends 15.5 miles up the Colorado River from its intersection with the Gulf Intracoastal Waterway. The river channel is navigable for small boats from the Gulf Intracoastal Waterway to the Gulf of Mexico. However, the river mouth is subject to severe shoaling and requires frequent dredging. These navigation facilities have no regulated freshwater requirements.

There is 230 megawatts of hydroelectric generating capacity in the Colorado River Basin.

Return Flows

In 1980, municipal and manufacturing return flows totaled 81.2 thousand acre-feet. Travis County accounted for 50.3 thousand acre-feet (62 percent) of the total freshwater municipal and manufacturing return flows in the Colorado River Basin.

Irrigation in Zone 1 is supplied almost entirely by ground water. Return flows from this irrigated acreage are negligible.

In the middle part of the basin, considerable irrigated acreage is supplied by ground water but very little return flow reaches streams. In 1980, 79.7 thousand acre-feet of surface water was used in the region. It is estimated that as much as 14.5 thousand acre-feet of return flows resulted from this irrigation.

In the lower basin (Zone 3), slightly more than 60 percent of the 50 thousand irrigated acres is supplied by surface water. Zone 3 return flows were estimated to total about 20.0 thousand acre-feet in 1980, largely from irrigated rice lands. These return flows are generally not recoverable for reuse.

Current Ground-Water Development

In 1980, approximately 1,314.2 thousand acre-feet of ground water was used in the Colorado River Basin. Of this amount, 1,143.0 thousand acre-feet was used in Zone 1, 96.5 thousand acre-feet in Zone 2, and 74.7 thousand acre-feet in Zone 3. Ground-water use in Zone 1 was about 95 percent from the High Plains (Ogallala) Aquifer, and about 4 percent from the Edwards-Trinity (Plateau) Aquifer. Use in Zone 2 was about 50 percent from the Edwards-Trinity (Plateau) Aquifer, 17 percent from minor Permian and other aquifers, 10 percent from the Santa Rosa Aquifer, 9 percent from the Hickory Sandstone Aquifer, and 4 percent from the Trinity Group Aquifer. In Zone 3, ground-water use in 1980 was about 45 percent from the Gulf Coast Aquifer, 24 percent from the Hickory Sandstone Aquifer, 6 percent from the Edwards-Trinity (Plateau) Aquifer, 6 percent from the Trinity Group Aquifer, 5 percent from the Carrizo-Wilcox Aquifer, and 4 percent from the Edwards (Balcones Fault Zone) Aquifer.

Of the 1,314.2 thousand acre-feet of ground water used in the basin, approximately 1,166.2 thousand acre-feet or 89 percent was for irrigation purposes, 63.1 thousand acre-feet or 5 percent for mining purposes, and 5 percent for municipal purposes.

Withdrawals of ground water in 1980 in Zone 1 from the High Plains (Ogallala) Aquifer are estimated at about 5 times the aquifer's annual natural recharge. Annual current and historical pumpages for irrigation purposes have removed large volumes of water from storage which has caused significant water level declines in some areas of Zone 1 within the Colorado River Basin. Also, large overdrafts of ground water primarily for irrigation purposes from the Edwards-Trinity (Plateau) Aquifer occurred in 1980 in Ector and Glasscock Counties within Zone 1 of the basin.

Within Zone 2 of the basin, large overdrafts of ground water for irrigation purposes occurred in 1980 in Reagan and Upton Counties. Excessive withdrawals of ground water for municipal, manufacturing, and irrigation purposes in McCulloch County caused an overdraft of ground water from the Hickory Sandstone Aquifer in 1980.

Overdrafts of ground water from the Gulf Coast Aquifer in Zone 3 occurred in Colorado and Wharton Counties, due to withdrawals for irrigation purposes. A small overdraft due to withdrawals for manufacturing purposes from the Edwards (Balcones Fault Zone) Aquifer occurred in 1980 in Hays County within Zone 3. Also a small overdraft due to withdrawals for municipal purposes from the Trinity Group Aquifer occurred in Travis County within Zone 3 of the basin.

Current Surface-Water Development

The Colorado River Basin has 25 major reservoirs. There are no major reservoirs in Zone 1; however, surface water is supplied to the area through the facilities of the Colorado River Municipal Water District and the Canadian River Municipal Water Authority Aqueduct. In 1980, the Canadian River Municipal Water Authority supplied 3.5 thousand acre-feet of surface water to the Cities of Brownfield, Lamesa, and O'Donnel. The Colorado River Municipal Water District supplied 36.4 thousand acre-feet of surface water to Zone 1 in 1980 for municipal and manufacturing purposes. Surface water was delivered to the Cities of Odessa, Big Spring, Coahoma, Stanton, and Midland, as well as to various manufacturing concerns within Zone 1.

Reservoirs located in Zone 2 include Lakes J.B. Thomas and E.V. Spence, both owned and operated by the Colorado River Municipal Water District. Diversions from these two projects totaled over 38.5 thousand acre-feet in 1980, with the principal demand areas in Zone 2 being the Cities of Snyder and San Angelo plus a small amount of water delivered to Fisher County in the Brazos River Basin. Most of the water diverted was delivered to Zone 1.

Lake Colorado City and Champion Creek Reservoir in Zone 2 are owned and operated by Texas Electric Service Company for steam-electric power generation cooling purposes. In addition, in 1980 Colorado City diverted 1.8 thousand acre-feet of water from Lake Colorado City for municipal water supply.

Oak Creek Reservoir is owned and operated by the City of Sweetwater, which is located in the Brazos River Basin. In 1980, 6.3 thousand acre-feet of water was diverted from Oak Creek Reservoir for municipal and manufacturing purposes, principally for the City of Sweetwater. The reservoir also provides cooling water for the steam-electric power generating plant at the reservoir, owned by West Texas Utilities Company.

O.C. Fisher Reservoir was constructed and is operated by the U.S. Army Corps of Engineers for flood-control and water supply purposes. The Upper Colorado River Authority has purchased the conservation storage. Twin Buttes Reservoir was constructed and is operated by the U. S. Bureau of Reclamation for water conservation and flood control. The San Angelo Water Supply Corporation owns the conservation storage in the reservoir for supplying municipal and manufacturing water to the City of San Angelo and project irrigation water in Tom Green County. Lake Nasworthy is owned by the City of San Angelo. These three reservoirs, plus surface water purchased from the Colorado River Municipal Water District, comprise the City of San Angelo's surface-water supply. Almost 21.0 thousand acre-feet of water was diverted from these projects in 1980 for municipal and manufacturing purposes in San Angelo. Twin Buttes Reservoir also supplied 23.8 thousand acre-feet of water for irrigation of 10.0 thousand acres.

Hords Creek Reservoir was constructed and is operated by the Corps of Engineers for flood control and water supply. The City of Coleman owns the conservation storage in the reservoir which, together with Lake Coleman which is owned and operated by the City of Coleman, provides surface-water supplies for the city. In 1980, 1.7 thousand acre-feet of water was diverted from the two projects.

Lake Clyde was constructed by the U.S. Department of Agriculture, Soil Conservation Service (SCS), for water supply and floodwater detention. The City of Clyde owns water supply storage in the project. In 1980, 400 acre-feet of water was diverted from Lake Clyde for municipal use.

Lake Brownwood is owned and operated by the Brown County Water Improvement District No. 1. The project provides municipal and manufacturing water for Brown and parts of Coleman Counties as well as water for irrigation. In 1980, slightly over 8.9 thousand acre-feet of water was supplied for municipal and manufacturing users as well as 5.5 thousand acre-feet for the irrigation of 5.0 thousand acres.

Brady Creek Reservoir is owned by the City of Brady to serve the city's long-term municipal water needs. No water was diverted from the project in 1980.

The City of Winters has completed construction of a new Lake Winters, about one mile downstream of the present city lake. The new lake has a capacity of 8,374 acre-feet and gives the city a firm annual supply of 1,160 acre-feet.

The City of Ballinger recently completed a dam downstream from its old surface-water reservoir. Both reservoirs combined will have a total capacity in excess of 5,000 acre-feet.

In Zone 3 of the Colorado River Basin, the Lower Colorado River Authority operates Lakes Buchanan, Inks, Lyndon B. Johnson, Marble Falls, Travis, and Austin for water supply and hydroelectric power generation. Lake Lyndon B. Johnson also provides water for the steam-electric power generation plant located adjacent to the reservoir. Lake Austin is operated by the Lower Colorado River Authority through a lease agreement with the City of Austin, owner of the project. Lakes Buchanan and Travis are the principal water supply projects, with the remaining reservoirs operated at or near constant level at all times. Four other projects in the basin—Lake Long, owned by the City of Austin; Lakes Bastrop and Cedar Creek, owned by the Lower Colorado River Authority; and Eagle Lake, owned by Lakeside Irrigation Company—are all off-channel reservoirs which are dependent upon diversions from the Colorado River for maintaining a firm supply. Long Lake, Cedar Creek Lake, and Lake Bastrop supply cooling water for steam-electric power generating plants, and Eagle Lake is used for storage and regulation of irrigation water pumped from the Colorado River. Through contracts with the Lower Colorado River Authority, the Lakeside Irrigation Company can purchase 60.0 thousand acre-feet annually from the Authority, and may also divert an additional 40.0 thousand acre-feet annually from the Colorado River as authorized by a 1901 certified filing.

The South Texas Reservoir Project, located in the Colorado-Lavaca Coastal Basin, was recently completed. The project, jointly owned by Houston Lighting and Power Company, Central Power and Light Co., and the Cities of Austin and San Antonio, will be operated by Houston Lighting and Power Company to provide cooling water for a nuclear-fueled electric power generation plant presently under construction. Water will be diverted from the Colorado River to a 187.0 thousand acre-feet capacity off-channel reservoir to maintain constant operating level for cooling and water quality control.

In 1980, approximately 97.6 thousand acre-feet of surface water was used for municipal and manufacturing purposes in Zone 3. The Colorado River provided slightly over 580.0 thousand acre-feet of surface water for project irrigation purposes, not only in Zone 3 of the Colorado River Basin but also for project irrigation in the Brazos-Colorado and Colorado-Lavaca Coastal Basins and Colorado and Wharton Counties in the Lavaca River Basin.

Water Rights

The total amount of surface water authorized or claimed for diversion and use in the Colorado River Basin was 9,037,023 acre-feet as of December 31, 1983 (Table III-14-1). Zone 3 accounted for over 94 percent of total basin rights including almost 6.8 million acre-feet to be used for hydroelectric use. Of the basin total, hydroelectric uses were 75 percent, irrigation uses 14 percent, industrial uses 6 percent, and municipal uses totaled 4 percent (Table III-14-2). Hydroelectric power is generated by run-of-the-river water or water released from reservoir storage for other downstream uses. Hydroelectric use is non-consumptive and the figure attributed to hydroelectric use is obtained by accumulating the use of water through each successive hydroelectric plant.

Table III-14-1. Authorized or Claimed Amount of Water, by Type of Right, Colorado River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	135	7,566,746
Claims	188	42,047
Certified Filings	23	1,011,171
Certificates of Adjudication	1,079	417,059
Total Authorizations and Claims	1,425	9,037,023

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

Water Quality

The upper Colorado River Basin is significantly affected by salinity problems; however, the remainder of

Table III-14-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Colorado River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Total
Municipal	49	1,700	315,041	56,465	373,206
Industrial	32	0	53,813	527,047	580,860
Irrigation	1,286	4,492	123,746	1,139,730	1,267,968
Mining	22	3,016	8,157	5,772	16,945
Recreation	45	322	3,974	3,011	7,307
Hydroelectric	14	0	0	6,790,736	6,790,736
Other	2	0	0	1	1
Total	1,425[1]	9,530	504,731	8,522,762	9,037,023

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

the basin has comparatively few water quality problems. Inflows of saline water in the upper Colorado Basin below Lake J.B. Thomas seriously degrade the quality of the main stem above Lake E.V. Spence. The principal salt-contributing area lies within a 30-mile segment of the river between Lake J.B. Thomas Dam and Colorado City in northern Mitchell County. The salt load contributed to the main stem within this 700-square mile drainage area is of both natural and man-made origin, and since chemical-quality data for the river do not precede the initial effects of man-made pollution, the relative contribution from each of these sources has proved difficult to define accurately.

Pecan Bayou in the vicinity of Brownwood experiences frequent low dissolved oxygen levels as a result of municipal wastewater discharges.

Flooding and Drainage

The main stem of the Colorado River has been spared in recent years from major floods such as those which severely impacted the basin in the 1930's and in 1957. Localized flooding and associated damages have occurred on numerous occasions on tributaries to the Colorado and at widely scattered points along the river.

May and June of 1981 will long be remembered by the City of Austin as the months when devastating floods turned the City's usually tranquil creeks into deadly torrents. The Memorial Day flood took 13 lives and caused an estimated $30.5 million in flood damages. Much of the damaged property was not covered by flood insurance as only 304 flood insurance claims were filed in 1981 for $3.3 million in damages. In other parts of the basin, floods in 1981 resulted in an additional 71 flood insurance claims for $652 thousand in flood damages. During the period 1978-1980, floods resulted in 69 flood insurance claims for $397 thousand in damages.

The Federal Emergency Management Agency has designated 78 incorporated cities as flood prone in the Colorado River Basin. Maps identifying areas subject to inundation from a 100-year frequency flood have been prepared for all but 3 of these cities and mapping of unincorporated areas is continuing at a slow pace.

Presently 49 of the designated cities have adopted flood plain management programs which satisfy the requirements of the National Flood Insurance Program. Detailed flood insurance rate studies which designate 100-year flood surface elevations are completed for 21 basin cities. Additional studies are underway for the City of Wharton and Travis County unincorporated areas.

Most drainage problems on agricultural lands in the basin occur in the alluvial plains along the Colorado River from below Bastrop to the Gulf of Mexico. Soils drain slowly when floods fill old river channels and low areas, resulting in blocked natural outlets which retard drainage from on-farm improvements. Frequent heavy rainfall and runoff from upland areas cause overflow of channels, and water spreads over large areas.

Urban drainage problems occur in cities located within the basin. In rapidly growing areas such as Travis County, new developments are approved and planned insuring that increased urban drainage will not aggrevate flood or drainage problems downstream. New subdivisions are required to provide adequate drainage.

Recreation Resources

The 23 major reservoirs in the Colorado River Basin provide a combined area of 116.3 thousand surface acres available for water-oriented recreation activities. Fifty-one percent of the total surface area is located in Zone 3, and the remaining 49 percent is in Zone 2. The largest reservoir in Zone 2 is Lake Spence (15.0 thousand surface acres). Lake Spence has 26 percent of the total surface area of the 13 lakes in Zone 2. Lakes Buchanan and Travis, with 23.1 and 18.9 thousand surface acres, respectively, account for over 75 percent of the surface area available for flat-water recreation of the nine lakes in Zone 3. In addition to the major reservoirs, the Colorado, Concho, San Saba, Llano, and Pedernales Rivers are also major water-oriented recreation resources available to recreationists. An estimated 1.29 million visits by recreationists were reported at reservoirs operated by the Corps of Engineers in the basin during 1980.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Colorado River Basin is projected to more than double by 2030, to about 2.6 million. From 1980 to 2000, a growth rate of 55 percent is expected, and from 2000 to 2030 the projected increase is 58 percent. The growth rates for the Colorado River Basin are comparable to those of the State, 49 percent and 62 percent, respectively (Table III-14-3).

Travis County, which includes the City of Austin, contained 39.5 percent of the basin population in 1980. Given an anticipated growth rate of over 200 percent, Travis County's share of the basin total will increase to 51 percent by 2030. This growth rate will produce a county population in excess of 1.3 million.

Ector County is the second most populous county in the basin, with 10.9 percent of the basin population in 1980. Although the county population, including Odessa, is expected to double by 2030, its share of the basin population is projected to decline to 8.9 percent.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Colorado River Basin are projected to increase from the 1980 level of 224.4 thousand acre-feet by a projected maximum of 82 percent by the year 2000. In the year 2030, water requirements are projected to range from 391.1 to 643.6 thousand acre-feet. Zone 1 is projected to account for 26 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 23 percent of the total.

A range of 48.4 to 66.7 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000. Total municipal water requirements in Zone 3 are projected to range from 162.0 to 234.6 thousand acre-feet in the year 2000, of which Travis County accounts for the greatest portion. By 2030, Zone 3 is projected to account for 60 to 62 percent of the total basin municipal water requirements.

Industrial

Manufacturing water requirements in 1980 were 24.8 thousand acre-feet in the Colorado River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Colorado River Basin are projected to increase more than eight times by the year 2030, to a potential high of 212.0 thousand acre-feet by 2030.

Zone 3, which includes Matagorda and Travis Counties, accounted for 48 percent of the basin 1980 manufacturing water use; by 2030, this share is expected to be 77 to 78 percent. Almost all of Matagorda County's requirements originate from the production of industrial organic chemicals.

Steam-Electric Power Generation

Installed steam-electric generating capacity will expand rapidly between 1980 and 2000, then grow more slowly through the year 2030. Projected increases include those uses associated with the large nuclear-fueled plant in Matagorda County which, although located partly in the Colorado-Lavaca Coastal Basin, will rely largely on Colorado River water for cooling purposes, and a large coal-fired plant in Fayette County.

These projections indicate water use will exceed 95.1 thousand acre-feet annually by the year 2000. By 2030, water consumption will approach 104.4 thousand acre-feet and 111.0 thousand acre-feet per year, low and high case, respectively.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in

Table III-14-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Colorado River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			306.2			385.9			426.3			464.9			520.7			588.5
Municipal	32.0	35.8	67.8	40.4	54.5	94.9	37.2	68.6	105.8	38.8	76.4	115.2	33.5	95.4	128.9	39.7	105.7	145.4
Manufacturing	2.6	6.7	9.3	1.5	11.9	13.4	1.6	16.1	17.7	2.0	20.3	22.3	2.4	25.5	27.9	2.9	32.0	34.9
Steam Electric	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0	1.0	2.6	0.0	2.6	4.3	0.0	4.3	6.0	0.0	6.0
Mining	59.4	0.9	60.3	39.1	0.9	40.0	19.1	0.4	19.5	14.3	0.3	14.6	9.5	0.1	9.6	4.6	0.1	4.7
Irrigation	1,045.6	3.5	1,049.1	1,511.9	3.5	1,515.4	1,703.9	3.5	1,707.4	1,512.8	3.5	1,516.3	1,466.4	3.4	1,469.8	1,541.4	3.5	1,544.9
Livestock	2.4	0.4	2.8	2.9	0.4	3.3	3.4	0.4	3.8	2.9	0.9	3.8	2.7	1.1	3.8	2.4	1.4	3.8
Zone Total Water	1,143.0	47.3	1,190.3	1,596.8	71.2	1,668.0	1,766.2	89.0	1,855.2	1,573.4	101.4	1,674.8	1,518.8	125.5	1,644.3	1,597.0	142.7	1,739.7
Zone 2																		
Population			214.2			239.1			264.4			297.0			337.9			385.7
Municipal	9.5	39.2	48.7	11.3	47.9	59.2	12.0	54.7	66.7	12.7	62.3	75.0	13.5	71.8	85.3	15.8	81.4	97.2
Manufacturing	2.1	1.5	3.6	1.7	3.4	5.1	2.2	4.4	6.6	2.8	5.3	8.1	3.9	6.1	10.0	4.2	8.0	12.2
Steam Electric	0.0	4.9	4.9	0.0	4.9	4.9	0.0	16.9	16.9	0.0	19.6	19.6	0.0	22.3	22.3	0.0	25.0	25.0
Mining	2.2	0.6	2.8	2.4	0.4	2.8	2.4	0.4	2.8	1.9	0.3	2.2	1.4	0.2	1.6	0.9	0.2	1.1
Irrigation	75.9	79.7	155.6	100.6	104.5	205.1	109.4	94.4	203.8	110.9	94.8	205.7	111.7	94.0	205.7	77.4	133.4	210.8
Livestock	6.8	7.2	14.0	12.0	4.4	16.4	12.7	6.1	18.8	12.3	6.5	18.8	12.3	6.5	18.8	12.2	6.6	18.8
Zone Total Water	96.5	133.1	229.6	128.0	165.5	293.5	138.7	176.9	315.6	140.6	188.8	329.4	142.8	200.9	343.7	110.5	254.6	365.1
Zone 3																		
Population			540.4			738.7			951.1			1,160.9			1,385.7			1,620.0
Municipal	20.0	87.9	107.9	27.5	152.1	179.6	32.6	202.0	234.6	37.0	249.6	286.6	40.2	302.4	342.6	43.5	357.5	401.0
Manufacturing	2.2	9.7	11.9	2.2	22.2	24.4	3.7	74.0	77.7	5.2	93.4	98.6	7.1	120.8	127.9	9.5	155.4	164.9
Steam Electric	0.0	25.2	25.2	0.0	61.2	61.2	0.0	77.2	77.2	0.0	78.2	78.2	0.0	79.1	79.1	0.0	80.0	80.0
Mining	1.5	6.1	7.6	0.2	9.4	9.6	0.3	11.3	11.6	0.2	13.1	13.3	0.1	14.9	15.0	0.0	16.8	16.8
Irrigation	44.7	127.8	172.5	17.6	79.9	97.5	17.8	74.7	92.5	17.9	74.9	92.8	17.9	74.9	92.8	17.8	75.0	92.8
Livestock	6.3	4.8	11.1	6.6	6.2	12.8	6.9	7.7	14.6	6.9	7.7	14.6	6.9	7.7	14.6	6.8	7.8	14.6
Zone Total Water	74.7	261.5	336.2	54.1	331.0	385.1	61.3	446.9	508.2	67.2	516.9	584.1	72.2	599.8	672.0	77.6	692.5	770.1
BASIN TOTALS																		
Population			1,060.7			1,363.7			1,641.8			1,922.8			2,244.3			2,594.2
Municipal	61.5	162.9	224.4	79.2	254.5	333.7	81.8	325.3	407.1	88.5	388.3	476.8	87.2	469.6	556.8	99.0	544.6	643.6
Manufacturing	6.9	17.9	24.8	5.4	37.5	42.9	7.5	94.5	102.0	10.0	119.0	129.0	13.4	152.4	165.8	16.6	195.4	212.0
Steam Electric	1.0	30.1	31.1	1.0	66.1	67.1	1.0	94.1	95.1	2.6	97.8	100.4	4.3	101.4	105.7	6.0	105.0	111.0
Mining	63.1	7.6	70.7	41.7	10.7	52.4	21.8	12.1	33.9	16.4	13.7	30.1	11.0	15.2	26.2	5.5	17.1	22.6
Irrigation	1,166.2	211.0	1,377.2	1,630.1	187.9	1,818.0	1,831.1	172.6	2,003.7	1,641.6	173.2	1,814.8	1,596.0	172.3	1,768.3	1,636.6	211.9	1,848.5
Livestock	15.5	12.4	27.9	21.5	11.0	32.5	23.0	14.2	37.2	22.1	15.1	37.2	21.9	15.3	37.2	21.4	15.8	37.2
Basin Total Water	1,314.2	441.9	1,756.1	1,778.9	567.7	2,346.6	1,966.2	712.8	2,679.0	1,781.2	807.1	2,588.3	1,733.8	926.2	2,660.0	1,785.1	1,089.8	2,874.9

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period. A high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Colorado River Basin are projected to increase from the 1980 level of 1.4 million acre-feet by a projected maximum 45 percent by the year 2000 in the high case, declining 39 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 0.9 to 1.8 million acre-feet annually, low and high case, respectively, to irrigate from 1.1 to 2.1 million acres.

Zone 1 is projected to account for about 85 and 84 percent of total basin irrigation requirements in 2000 and 2030, respectively. Zone 2 is projected to account for about 11 percent of the total and Zone 3 is projected to account for about 5 percent of the total in the high case in 2030.

A range of 0.6 to 1.7 million acre-feet of irrigation requirements is projected in Zone 1 by 2000. By 2030, the range for this Zone is from 0.7 to 1.5 million acre-feet annually. Irrigation water requirements in Zone 2 range from 111.0 to 203.8 thousand acre-feet in 2000 and from 111.1 to 210.8 thousand acre-feet in 2030. Zone 3 requirements are about 92.5 and 92.8 thousand acre-feet in 2000 and 2030, respectively, for the high case.

Livestock

Livestock water requirements within the basin are projected to increase from 27.9 thousand acre-feet in 1980 to 37.2 thousand acre-feet annually by 2030. It is anticipated that livestock water use in Zone 1 will total 3.8 thousand acre-feet; Zone 2—18.8 thousand acre-feet; and Zone 3—14.6 thousand acre-feet annually in 2030. By 2030, livestock needs in the basin are predicted to have increased 33 percent.

Mining

By 2030, mining water requirements in the Colorado River Basin are projected to decline from 1980 levels (70.7 thousand acre-feet) to 22.6 thousand acre-feet annually.

Mining water used in the secondary recovery of petroleum and natural gas in the basin was 62.3 thousand acre-feet in 1980.

Navigation

The Mouth of Colorado River project, authorized by Congress, will not require regulated freshwater releases in order to accommodate specified project purposes.

Hydroelectric Power

There are currently no plans to expand any of the existing hydroelectric power generating facilities in the Colorado River Basin. Therefore, total water releases for hydroelectric power production are not projected to exceed the currently permitted annual amount.

Estuarine Freshwater Inflows

The Colorado River discharges into the complex Colorado River delta. A portion of the water entering the delta flows directly into the Gulf of Mexico and a portion flows through a network of channels into the eastern arm of Matagorda Bay of the Lavaca-Tres Palacios estuary. Studies by the Department have developed a relationship between the Colorado River flows at the Bay City gaging station and the amount of Colorado River flows diverted into Matagorda Bay. An estimated 882.3 thousand acre-feet per year of gaged inflows to the eastern arm of Matagorda Bay is needed in order to sustain basic salinity gradients specified by the Subsistence Alternative. The actual gaged flow at the last downstream gage on the Colorado River at Bay City of 1.11 million acre-feet (Table III-14-4) is estimated to supply the needed inflow of 882 thousand acre-feet into the estuary, since the Colorado River delta has channels leading both to Matagorda Bay and to the Gulf and a portion of the gaged flow passes directly into the Gulf. For the Fisheries Maintenance Alternative, gaged river inflow needs of almost 1.27 million acre-feet per year from the Colorado River Basin (corresponding to 1.8 million acre-feet of flow at the Bay City gage) are estimated to meet salinity and inundation needs, and maintain the major commercial fisheries harvests categories at no less than their average historical levels for the 1962-1976 period (Table III-14-4). For the Harvest

Table III-14-4. Gaged River Inflow Needs of the Lavaca-Tres Palacios Estuary From the Colorado River Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Colorado River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Shellfish Harvest Enhancement	Biotic Species Viability
January	88.1	88.1	88.1	9.7
February	99.2	99.2	92.1	10.0
March	76.4	76.4	76.4	23.1
April	101.1	133.2	101.1	100.5
May	139.7	188.0	139.7	116.3
June	105.4	160.8	105.4	81.6
July	53.4	53.4	162.5	32.9
August	49.1	49.1	109.7	45.2
September	147.7	147.7	147.7	145.5
October	91.6	91.6	91.6	93.7
November	79.5	387.7	383.7	9.4
December	82.2	322.3	325.1	13.0
Annual	1,113.4	1,797.5	1,830.2	680.9

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Gaged streamflow of Colorado River at Bay City.

Enhancement Alternative, it is also established that maximizing the shellfish production in the estuary requires volumes of water from the Colorado River Basin equal to the annual inflow limit set at the average (1941-1976) annual gaged inflow. This inflow volume is 1.28 million acre-feet (1.8 million acre-feet at the Bay City gage) (Table III-14-4). Since the upper limit on annual freshwater inflow was met, it is believed, but not fully verified, that additional inflow from the basin (consistent with salinity and inundation bounds) could increase the annual shellfish harvest. For the Biotic Species Viability Alternative it is estimated that a total of 681 thousand acre-feet per year of gaged flow at Bay City is needed from the Colorado River Basin to maintain monthly salinities within the species limits of viability in the eastern arm of Matagorda Bay (Table III-14-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The ground-water availability through the year 2030 for the High Plains (Ogallala) Aquifer was estimated by imposing a set of total ground-water demands on a digital ground-water model of the aquifer developed by the Texas Department of Water Resources in 1982. The model analysis provided the following annual amounts of ground water available from the High Plains (Ogallala) Aquifer within the Colorado River Basin from 1990 through 2030 by decade: 1.16 million acre-feet in 1990, 1.07 million acre-feet in 2000, 0.80 million acre-feet in 2010, 0.69 million acre-feet in 2020, and 0.56 million acre-feet in 2030. The model analysis also estimated that from 1980 through 2030 approximately 24 million acre-feet of ground water would be removed from storage, and that of the 13.4 million acre-feet remaining in recoverable storage in the year 2031 about 10.9 million acre-feet would remain in the "caprock" (tillable) area and about 2.5 million acre-feet would remain in the "breaks" (non-tillable) area of the basin. Within the Colorado River Basin, the High Plains Aquifer receives on an average annual basis about 209.8 thousand acre-feet of recharge.

The approximate annual ground-water yield to the year 2030 within the remaining portion of the Colorado River Basin is 507.6 thousand acre-feet with the following amounts annually available by aquifer: 262.1 thousand acre-feet from the Edwards-Trinity (Plateau) Aquifer, 52.6 thousand acre-feet from the Hickory Sandstone Aquifer, 50.1 thousand acre-feet from the Carrizo-Wilcox Aquifer, 29.4 thousand acre-feet from the Ellenburger-

San Saba Aquifer, 26.0 thousand acre-feet from the Gulf Coast Aquifer, 20.1 thousand acre-feet from the Marble Falls Aquifer, 20.1 thousand acre-feet from the Santa Rosa Aquifer, 14.3 thousand acre-feet from the Trinity Group Aquifer, 10.5 thousand acre-feet from the Leona Alluvial Aquifer, 10.0 thousand acre-feet from the Sparta Aquifer, 8.7 thousand acre-feet from the Edwards (Balcones Fault Zone) Aquifer, and 3.7 thousand acre-feet from the Queen City Aquifer. In the year 2030, the yields of the Carrizo-Wilcox, Trinity Group, and Alluvium and Bolson Deposits Aquifers within the basin would be reduced to the average annual effective recharge of the aquifers which is 70.5 thousand acre-feet per year. These reductions decrease the total ground-water availability within the basin in 2030 to 503.2 thousand acre-feet (High Plains Aquifer not included).

The projected annual ground-water use within the Colorado River Basin by decade from 1990 through 2030 is expected to be from 0.76 to 1.34 million acre-feet per year (Table III-14-3). The approximate average annual projected ground-water use within the basin is expected to be about 1.05 million acre-feet per year. Of the 1.05 million acre-feet of average annual projected use, about 82 percent is expected to be from the High Plains (Ogallala) Aquifer, about 8 percent from the Edwards-Trinity (Plateau) Aquifer, about 2 percent from the Gulf Coast Aquifer, and about 1 percent from the Carrizo-Wilcox Aquifer.

Surface-Water Availability and Proposed Development

Existing and proposed surface-water development in the Colorado River Basin is estimated to be insufficient to supply all needs in the basin from 1990 through the year 2030 (Table III-14-5, Figure III-14-2).

Zone 1

The majority of the projected water shortage in the basin occurs in Zone 1 (Table III-14-6, Figure III-14-3). The projected annual water shortages, consisting essentially of water for irrigated agriculture, in this zone amount to about .66 million acre-feet in 2000 and 1.0 million acre-feet in 2030. The annual surface-water supply in year 2030 amounts to about 138 thousand acre-feet in this zone.

Existing surface-water resources in the Colorado River Basin are anticipated to be insufficient to meet all projected municipal and manufacturing water needs by the year 1990 in Zones 1 and 2 of the basin. The Colorado River Municipal Water District has been granted a permit by the Texas Water Commission to construct the Stacy Reservoir project on the Colorado River east of San Angelo by 1990. The permit is currently under litigation before the Texas Supreme Court. This reservoir in conjunction with existing supplies will supply anticipated water needs of the Cities of San Angelo, Midland, and Odessa through the year 2030.

Zone 2

All municipal and industrial water needs are projected to be satisfied in Zone 2 of the basin through the year 2030, with a surplus of 40.5 thousand acre-feet for municipal and industrial uses in 2030 (Table III-14-7, Figure III-14-4). An irrigation shortage of 94.4 thousand acre-feet is forecast in the year 2030. Total surface-water supply in this zone is estimated at 308.1 thousand acre-feet by the year 2030. Approximately 133.1 thousand acre-feet of this water supply is used in Zone 1 of the basin.

The authorized Upper Pecan Bayou Reservoir project, located on Pecan Bayou in Coleman and Callahan Counties, offers the potential for additional firm supplies in Zone 2 provided additional water needs develop in the area over and above current projections.

Zone 3

Existing and proposed surface-water supplies in Zone 3 of the basin are estimated to meet all surface-water needs through the year 2020, with a shortage in year 2030 of approximately 58.7 thousand acre-feet for irrigation purposes (Table III-14-8, Figure III-14-5). The surface-water supply in this zone by the year 2030 is projected at 967.1 thousand acre-feet. Surface water exported from this zone to adjacent basins along the Coast is estimated at 350.3 thousand acre-feet in year 2030.

Projected surface-water needs for the Lower Colorado River Authority (LCRA) service area are projected to exceed available supplies from the Highland Lakes system soon after the year 2000.

The Bureau of Reclamation is currently addressing the present and long-range water resource needs of the Colorado River Basin below Mansfield Dam, which impounds Lake Travis. The study, termed the "Colorado Coastal Plains Study, Texas", was authorized by P.L. 89-561, 89th Congress, and funds were appropriated to the Bureau of Reclamation by the 93rd Congress for initiation of the study in 1975. Previous studies of the lower Colorado River Basin have been conducted by the Bureau of Reclamation. Prior and current studies by the Bureau and studies by the Department have defined several alternative major reser-

Table III-14-5. Water Resources of the Colorado River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1338.2	—	—	—	1338.2	1778.9	—	—	1778.9	.0	(440.7)	(440.7)
Surface Water	935.6	—	107.5	4.3	1047.4	476.7	—	365.4	842.1	251.3	(46.1)	(205.2)
Total	2273.8	—	107.5	4.3	2385.6	2255.6	—	365.4	2621.0	251.3	(486.8)	(235.5)
2000												
Ground Water	1255.9	—	—	—	1255.9	1966.3	—	—	1966.3	.0	(710.4)	(710.4)
Surface Water	931.7	—	137.0	4.8	1073.5	617.4	—	337.7	955.1	154.7	(36.2)	118.5
Total	2187.6	—	137.0	4.8	2329.4	2583.7	—	337.7	2921.4	154.7	(746.6)	(591.9)
2010												
Ground Water	996.0	—	—	—	996.0	1781.2	—	—	1781.2	.0	(785.2)	(785.2)
Surface Water	1045.7	—	167.1	6.1	1218.9	705.1	—	349.0	1054.1	201.3	(36.5)	164.8
Total	2041.7	—	167.1	6.1	2214.9	2486.3	—	349.0	2835.3	201.3	(821.7)	(620.4)
2020												
Ground Water	885.4	—	—	—	885.4	1733.7	—	—	1733.7	.0	(848.3	(848.3)
Surface Water	1040.3	—	200.5	6.1	1246.9	827.7	—	355.2	1182.9	99.6	(35.7)	63.9
Total	1925.7	—	200.5	6.1	2132.3	2561.4	—	355.2	2916.6	99.6	(884.0)	(784.4)
2030												
Ground Water	756.3	—	—	—	756.3	1786.5	—	—	1786.5	.0	(1030.2)	(1030.2)
Surface Water	1037.2	—	236.5	6.2	1279.9	988.6	—	361.5	1350.1	64.5	(134.7)	(70.2)
Total	1793.5	—	236.5	6.2	2036.2	2775.1	—	361.5	3136.6	64.5	(1164.9)	(1100.4)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
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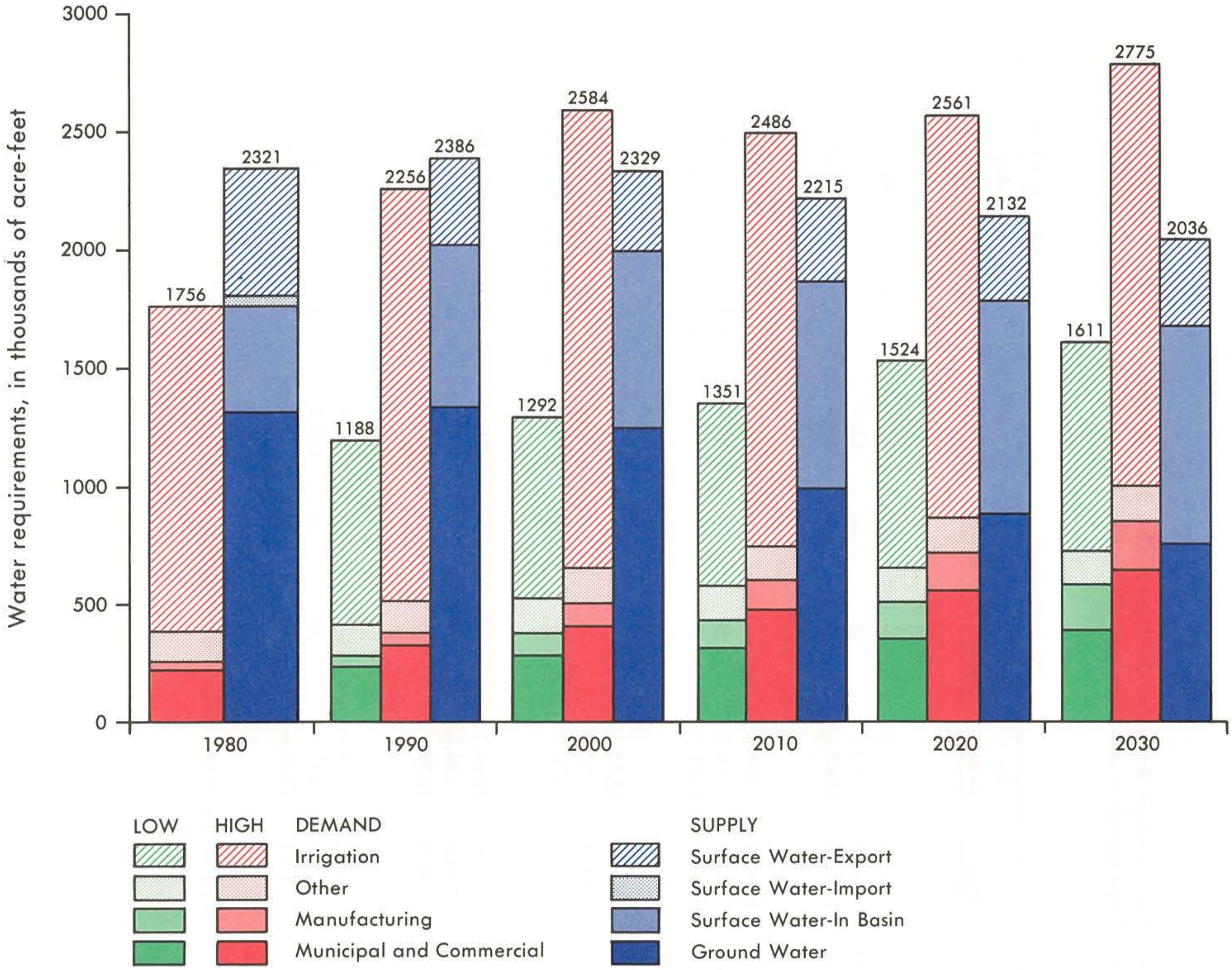

Figure III-14-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Colorado River Basin, 1980-2030

voir projects in the lower Colorado River Basin to meet the additional water supply demands in the lower basin. One of the alternatives presently under consideration is the potential Colorado Coastal Plains (CCP) Reservoir, which would be located on the main stem near Columbus, Colorado County. Although studies of the various alternative storage capacities of the CCP Project are continuing, for present planning purposes a reservoir at the proposed Columbus Bend site with an initial conservation storage capacity of 235.0 thousand acre-feet has been included in the present plan to meet projected water needs of the lower basin and adjacent coastal areas shortly after the year 2000. The project would provide a dependable supply of about 189.8 thousand acre-feet annually in year 2030 and has been included in the projected firm supply for Zone 3 of the basin. Future water needs in the LCRA service area through the year 2020 could be met through the construction of the Colorado Coastal Plains Reservoir on the Colorado River near Columbus during the 1990's.

Anticipated steam-electric power demands will necessitate construction of an additional cooling reservoir in Zone 3 before 2000. The Baylor Creek Reservoir in Fayette County is planned by the LCRA to meet this demand.

Table III-14-6. Water Resources of the Colorado River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	1193.5	—	—	—	1193.5	1596.9	—	—	1596.9	.0	(403.4)	(403.4)
Surface Water	.0	62.5	.0	4.0	66.5	66.5	.0	.0	66.5	.0	.0	.0
Total	1195.5	62.5	.0	4.0	1262.0	1663.4	.0	.0	1663.4	.0	(403.4)	(403.4)
2000												
Ground Water	1102.7	—	—	—	1102.7	1766.3	—	—	1766.3	.0	(663.6)	(663.6)
Surface Water	.0	80.1	.0	4.5	84.6	84.7	.0	.0	84.7	(.1)	.0	(.1)
Total	1102.7	80.1	.0	4.5	1187.3	1851.0	.0	.0	1851.0	(.1)	(663.6)	(663.7)
2010												
Ground Water	836.9	—	—	—	836.9	1573.5	—	—	1573.5	.0	(736.6)	(736.6)
Surface Water	.0	92.0	.0	4.7	96.7	96.7	.0	.0	96.7	.0	.0	.0
Total	836.9	92.0	.0	4.7	933.6	1670.2	.0	.0	1670.2	.0	(736.6)	(736.6)
2020												
Ground Water	719.9	—	—	—	719.9	1518.7	—	—	1518.7	.0	(798.8)	(798.8)
Surface Water	.0	116.1	.0	4.7	120.8	120.7	.0	.0	120.7	.1	.0	.1
Total	719.9	116.1	.0	4.7	840.7	1639.4	.0	.0	1639.4	.1	(798.8)	(798.7)
2030												
Ground Water	585.2	—	—	—	585.2	1597.0	—	—	1597.0	.0	(1011.8)	(1011.8)
Surface Water	.0	133.2	.0	4.7	137.9	137.8	.0	.0	137.8	.1	(.0)	.1
Total	585.2	133.2	.0	4.7	723.1	1734.8	.0	.0	1734.8	.1	(1011.8)	(1011.7)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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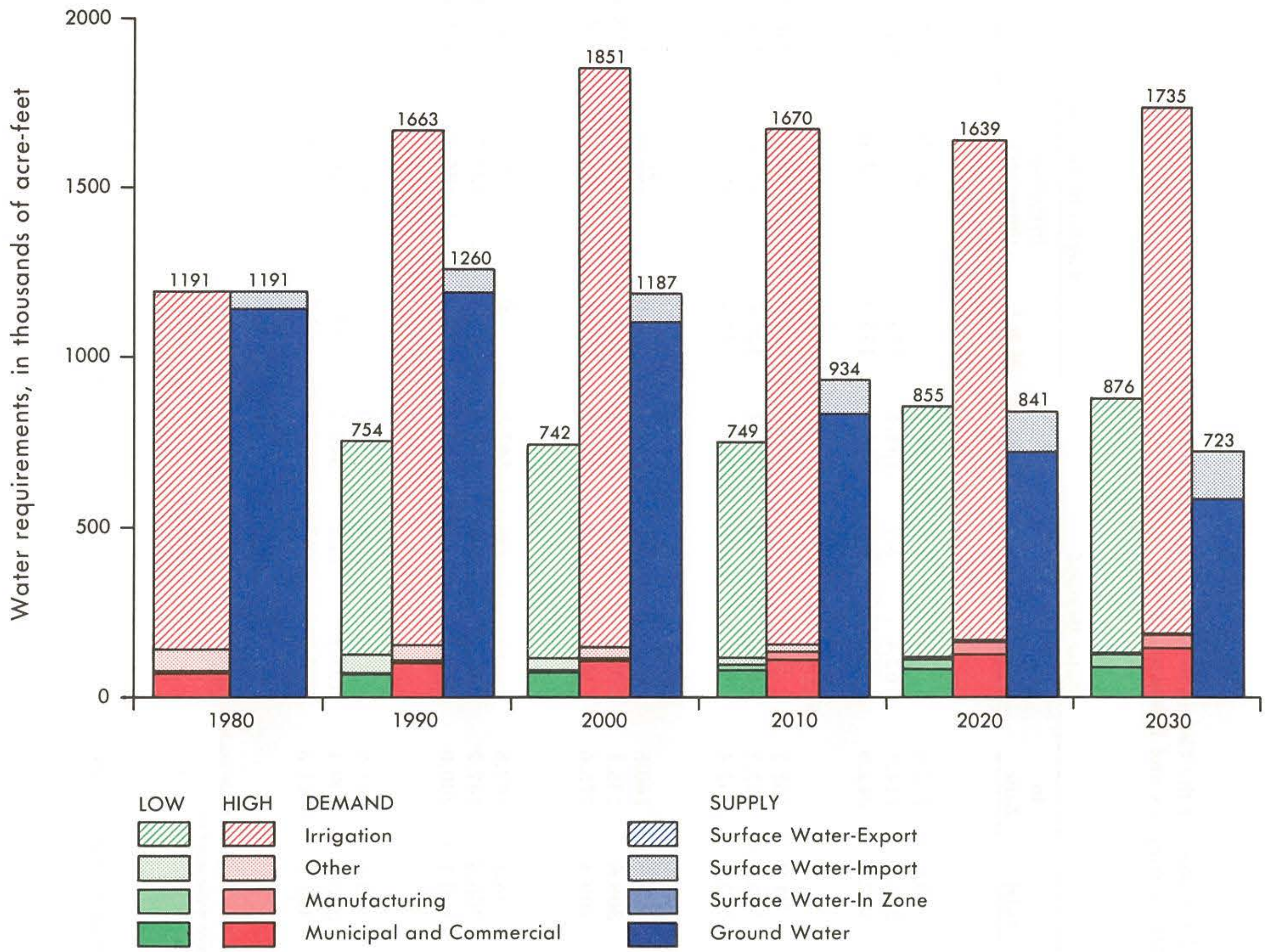

Figure III-14-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Colorado River Basin, Zone 1, 1980-2030

Additional surface-water supplies to meet anticipated shortages may be developed in Zones 2 and 3 of the Colorado River Basin at three reservoir sites in the Texas Hill Country: San Saba, in San Saba County; Mason, in Mason County; and Pedernales, in Blanco County. These sites have received only preliminary study and further extensive evaluations will be needed by State and local interests to determine the economic, environmental, and engineering feasibility of these projects.

Water Quality Protection

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $341.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Colorado River Basin with approximately $240.0 million required for Zone 3, $53.2 million for Zone 1, and $48.4 million for Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

A water quality management plan for the Colorado River Basin has been developed pursuant to the requirements of Federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facil-

Table III-14-7. Water Resources of the Colorado River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	90.6	—	—	—	90.6	127.9	—	—	127.9	.0	(37.3)	(37.3)
Surface Water	294.6	.0	17.1	.0	311.7	114.1	62.4	5.9	184.4	175.3	(46.1)	129.2
Total	385.2	.0	17.1	.0	402.3	242.0	62.4	5.9	310.4	175.3	(83.4)	91.9
2000												
Ground Water	91.9	—	—	—	91.9	138.7	—	—	138.7	.0	(46.8)	(46.8)
Surface Water	290.7	.0	19.5	.0	310.2	123.7	80.2	6.3	210.2	136.2	(36.2)	100.0
Total	382.6	.0	19.5	.0	402.1	262.4	80.2	6.3	348.9	136.2	(83.0)	53.2
2010												
Ground Water	91.9	—	—	—	91.9	140.5	—	—	140.5	.0	(48.6)	(48.6)
Surface Water	286.3	.0	22.3	.0	308.6	135.1	92.1	7.5	234.7	110.4	(36.5)	73.9
Total	378.2	.0	22.3	.0	400.5	275.6	92.1	7.5	375.2	110.4	(85.1)	25.3
2020												
Ground Water	93.3	—	—	—	93.3	142.8	—	—	142.8	.0	(49.5)	(49.5)
Surface Water	280.9	.0	25.9	.0	306.8	147.2	116.1	9.2	272.5	70.0	(35.7)	34.3
Total	374.2	.0	25.9	.0	400.1	290.0	116.1	9.2	415.3	70.0	(85.2)	(15.2)
2030												
Ground Water	93.5	—	—	—	93.5	111.9	—	—	111.9	.0	(18.4)	(18.4)
Surface Water	277.8	.0	30.3	.0	308.1	199.4	133.1	11.2	343.7	40.5	(76.0)	(35.5)
Total	371.3	.0	30.3	.0	401.6	311.3	133.1	11.2	455.6	40.5	(94.4)	(53.9)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
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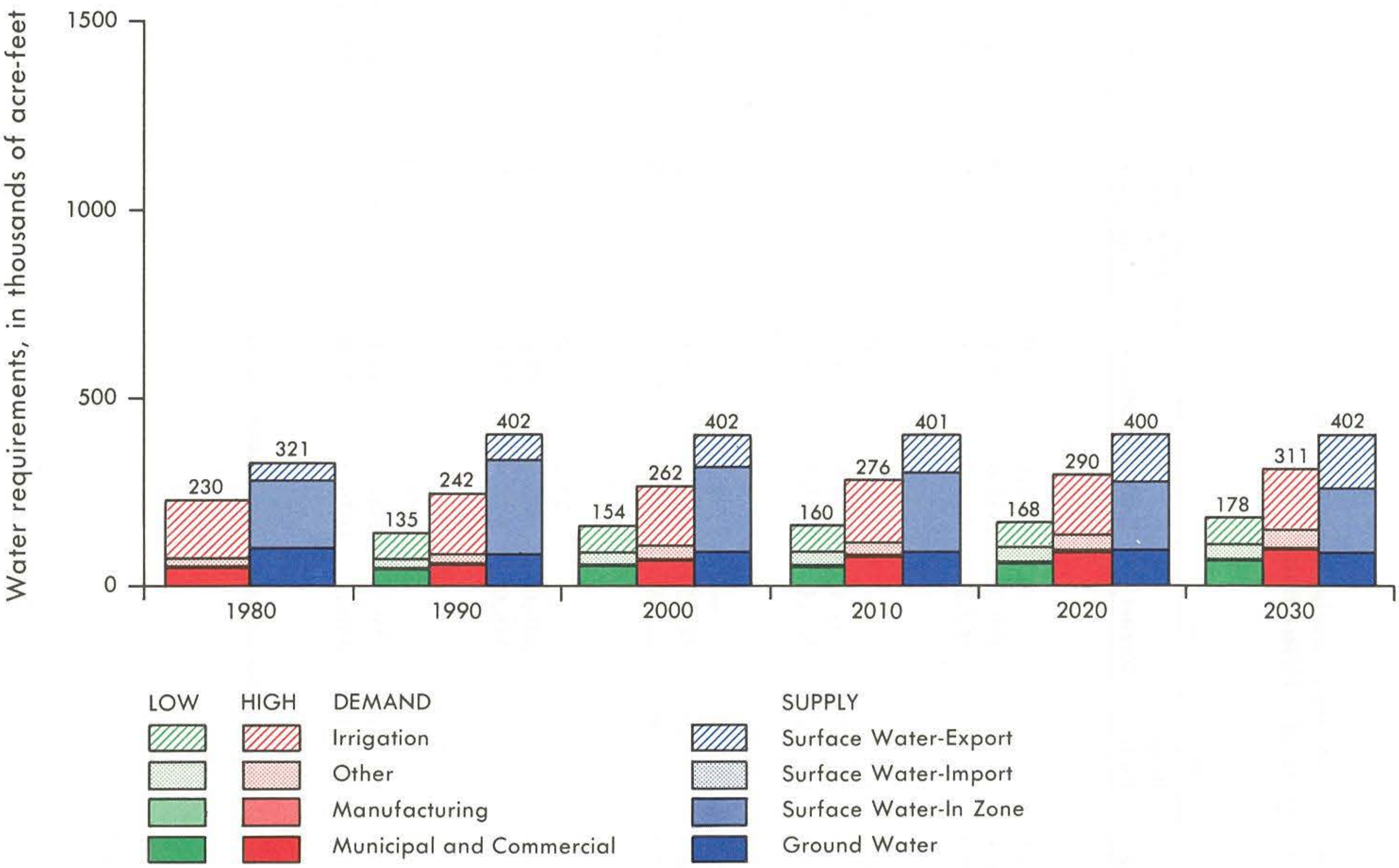

Figure III-14-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Colorado River Basin, Zone 2, 1980-2030

ities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

The four existing reservoirs which provide flood control in the basin are San Angelo, Twin Buttes, Hords Creek, and Lake Travis, with a combined flood-control storage capacity of 1,529,700 acre-feet.

Stacy Reservoir, or an alternative project in Zone 2, would be located on the Colorado River a few miles below Ballinger. A single-purpose water supply project would provide some flood-control benefits. Previous studies have included a multipurpose project at or near the Stacy site with flood-control storage capacity of 659,300 acre-feet. Additional studies of water supply needs in Zones 1 and 2 will include full evaluation of flood-control needs and benefits. The potential San Saba, Mason, and Pedernales Reservoir projects (Figure IV-14-4) require additional studies for long-range water supply needs and detailed analyses of flood-control capabilities and benefits. The Lake Brownwood Dam project, which will raise the dam height for additional flood protection, was completed October 1983.

The Corps of Engineers has also accomplished work in the lower part of the basin at Matagorda. The project consisted of enlarging an existing levee to protect the community from floods on the main stem of the Colorado River. Improvements consisted of 6.8 miles of earthen levees encircling the town, two roads and two railroad crossings, and alterations to 11 drainage structures. The project was completed in April 1962.

There is about 2,053 square miles of drainage area above 320 SCS floodwater-retarding structures within the

Table III-14-8. Water Resources of the Colorado River Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	54.1	—	—	—	54.1	54.1	—	—	54.1	.0	.0	.0
Surface Water	641.0	.0	90.4	.3	731.7	296.1	.0	359.5	655.6	76.1	.0	76.1
Total	695.1	.0	90.4	.3	785.8	350.2	.0	359.5	709.7	76.1	.0	76.1
2000												
Ground Water	61.3	—	—	—	61.3	61.3	—	—	61.3	.0	.0	.0
Surface Water	641.0	.0	117.5	.3	758.8	409.0	.0	331.4	740.4	18.4	.0	18.4
Total	702.3	.0	117.5	.3	820.1	470.3	.0	331.4	801.7	18.4	.0	18.4
2010												
Ground Water	67.2	—	—	—	67.2	67.2	—	—	67.2	.0	.0	.0
Surface Water	759.4	.0	144.8	1.4	905.6	473.3	.0	341.5	814.8	90.8	.0	90.8
Total	826.6	.0	144.8	1.4	972.8	540.5	.0	341.5	882.0	90.8	.0	90.8
2020												
Ground Water	72.2	—	—	—	72.2	72.2	—	—	72.2	.0	.0	.0
Surface Water	759.4	.0	174.6	1.4	935.4	559.8	.0	346.0	905.8	29.6	.0	29.6
Total	831.6	.0	174.6	1.4	1007.6	632.0	.0	346.0	978.0	29.6	.0	29.6
2030												
Ground Water	77.6	—	—	—	77.6	77.6	—	—	77.6	.0	.0	.0
Surface Water	759.4	.0	206.2	1.5	967.1	651.4	.0	350.3	1001.7	24.1	(58.7)	(34.6)
Total	837.0	.0	206.2	1.5	1044.7	729.0	.0	350.3	1079.3	24.1	(58.7)	(34.6)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

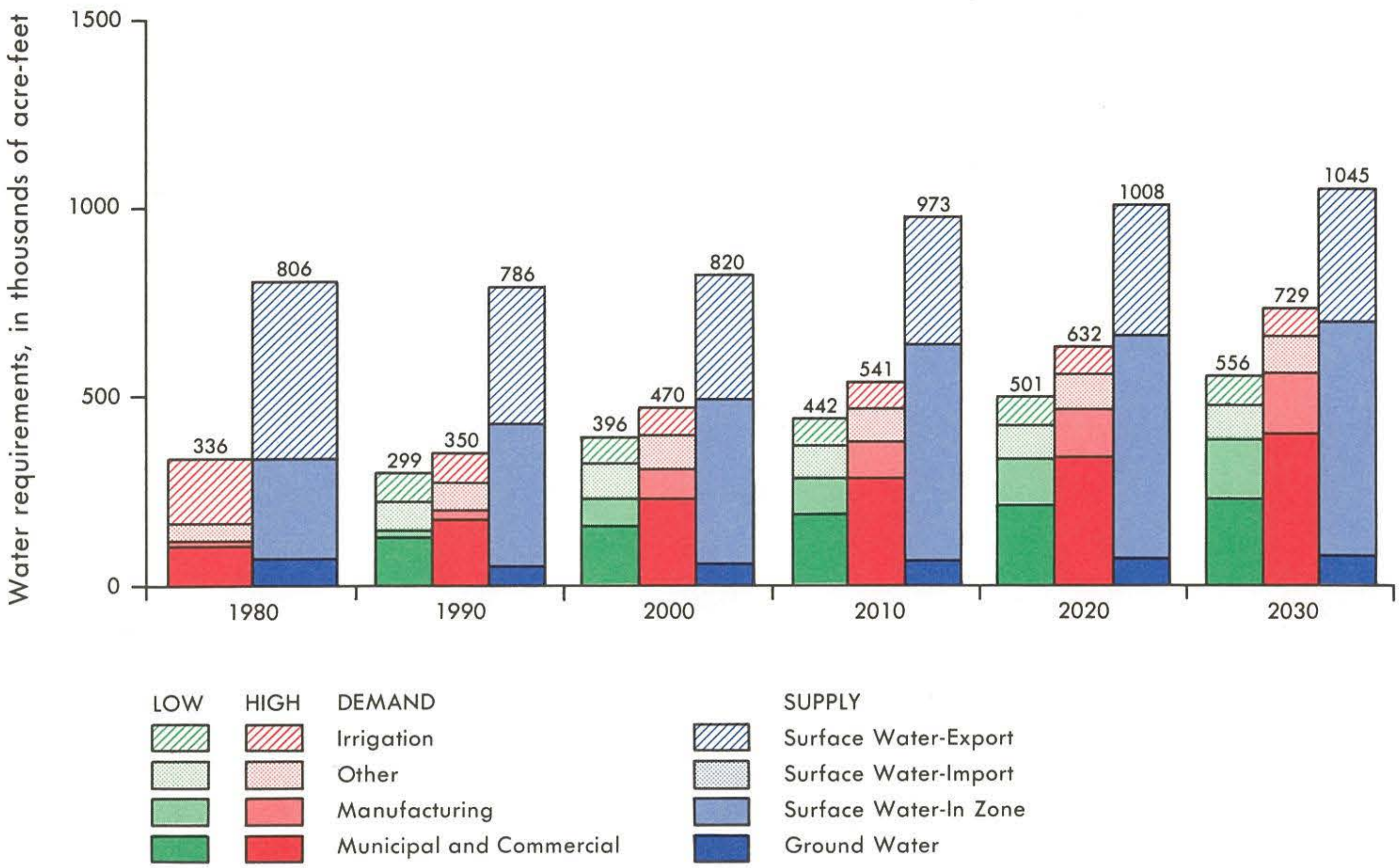

Figure III-14-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Colorado River Basin, Zone 3, 1980-2030

Colorado River Basin. As of October 1980, an additional 31 structures with a drainage area of 226 square miles were planned for construction. About 90 percent of the planned and existing structures are located within Zone 2 of the Colorado River Basin, and the remaining 10 percent are located in Zone 3.

The Corps has completed the Phase II General Design Memorandum for channel improvements on Boggy Creek at Austin, Texas. The project is awaiting authorization for construction from Congress.

The Corps has feasibility studies underway for flood-damage protection on Walnut, Shoal, Onion, and Williamson Creeks in the Austin area. These studies are due for completion in December 1986.

15. COLORADO-LAVACA COASTAL BASIN

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15. COLORADO-LAVACA COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Colorado-Lavaca Coastal Basin is bounded on the east by the Colorado River Basin and on the west by the Lavaca River Basin and the Lavaca-Guadalupe Coastal Basin. Average elevation in the basin is less than 50 feet, reaching a maximum of approximately 100 feet. Tres Palacios Creek, in the eastern part of the basin, and Carancahua Creek, in the western part, form the principal drainage system. Total area of the basin is 939 square miles. For planning purposes, the Colorado-Lavaca Coastal Basin is treated as a single hydrologic unit (Figure III-15-1).

Surface Water

The average annual runoff in the basin is estimated to be about 300 acre-feet per square mile. Very little data are available on low-flow characteristics of basin streams, since stream gages were installed in 1971 and no prior records exist. Tres Palacios Creek, above the tidally-affected reach, had a runoff rate of 485 acre-feet per square mile in 1971. However, streamflow includes irrigation return flows during the rice-growing seasons.

Because the Colorado-Lavaca Coastal Basin consists of the kind of flat terrain that is common to most of the coastal areas, heavy rainfall generally results in flooding for long durations. Severe flooding is most likely to occur in the late spring from very heavy thunderstorms triggered by rapidly-moving cold fronts or during the late summer and early autumn from weather systems moving westward out of the Gulf of Mexico.

Streams of the Colorado-Lavaca Coastal Basin have low dissolved-solids concentrations, generally less than 500 milligrams per liter (mg/l). However, both Tres Palacios Creek and Carancahua Creek are tidally-affected for considerable distances upstream from Tres Palacios and Carancahua Bays, respectively. During low-flow periods, Tres Palacios Creek is effluent-dominated as a result of discharges of treated municipal and industrial effluents from the El Campo area. Historically, data indicate pesticide residues have been relatively low, even with the substantial agricultural activity within the basin.

Ground Water

The Gulf Coast Aquifer underlies the entire Colorado-Lavaca Coastal Basin. The aquifer extends to a maximum depth of about 1,600 feet. Yields of high-capacity wells average 1,500 gallons per minute (gpm), but locally wells produce up to about 3,500 gpm. The water generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip. Near the Gulf, fresh water in the aquifer is overlain by saline water.

In areas immediately adjacent to the Coast in Jackson, Matagorda, and Calhoun Counties within the basin, fresh-water deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline water. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage. In the past, industrial pumpage of ground water has lowered water levels below sea level in Calhoun and southern Jackson Counties. Consequently, saline-water encroachment has occurred in these areas.

Population and Economic Development

The estimated population in the Colorado-Lavaca Coastal Basin in 1980 was reported at 25.6 thousand. El Campo, in Wharton County, is the largest city in the basin with an estimated in-basin population of 9,400 in 1980.

The principal economic activities in the Colorado-Lavaca Coastal Basin are agriculture and petroleum production. The average annual income from agriculture in the basin, principally rice production, exceeds $100 million. El Campo has a significant manufacturing sector, centering around aluminum and other metal products.

Water Use

Municipal water use in the Colorado-Lavaca Coastal Basin amounted to 4.3 thousand acre-feet in 1980. Most of the water was used in Wharton County (52.7 percent) and Matagorda County (36.8 percent). Cities using significant amounts of the total municipal use were Palacios (22 percent) and El Campo (31 percent). Water use by manufacturing industries in the basin during 1980 totaled over 2.0 thousand acre-feet. Almost all of this water was used in the Calhoun County portion of the basin for manufacturing of primary metals.

Figure III-15-1. Colorado-Lavaca Coastal Basin

There are no steam-electric power plants in the Colorado-Lavaca Coastal Basin which use freshwater for cooling; however, a 240 megawatt unit located near Cox Bay consumed about 1,200 acre-feet of saline water in 1980. This plant used almost 100 acre-feet of ground water for boiler feedwater makeup, sanitation, and other uses.

In 1980, about 66.1 thousand acres in the Colorado-Lavaca Coastal Basin was irrigated with 245.0 thousand acre-feet of water. About 40.8 thousand acres was irrigated with 118.0 thousand acre-feet of ground water and the remaining 25 thousand acres was irrigated with 127.0 thousand acre-feet of surface water. Use of the clay and clay loam soils of the Coastal Prairie is rotated between rice and pasture. Industrial and urban development are encroaching on the irrigable soils in the coastal areas. Most of the surface water used for irrigation is diverted from the Colorado River.

Mining industries in the Colorado-Lavaca Coastal Basin required an estimated 400 acre-feet of freshwater in 1980. Mining of nonmetals and production of petroleum and natural gas throughout the basin accounted for most of the water use.

Livestock water use in 1980 totaled 900 acre-feet in the Colorado-Lavaca Coastal Basin. Of this total, surface water supplied 400 acre-feet while ground water supplied the remaining 500 acre-feet.

The navigation facilities in the Colorado-Lavaca Coastal Basin include the Gulf Intracoastal Waterway and its tributary channel to Palacios and a portion of the Matagorda Ship Channel. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the Colorado-Lavaca Coastal Basin totaled 2.9 thousand acre-feet.

Irrigation water requirements in the Colorado-Lavaca Coastal Basin are primarily for rice production. Irrigation return flows in the basin in 1980 amounted to approximately 86 thousand acre-feet. Most of the return flows cannot be reused as they are discharged into tidal waters.

Current Ground-Water Development

Approximately 125.3 thousand acre-feet of ground water was used in 1980 in the Colorado-Lavaca Coastal Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 125.3 thousand acre-feet of ground water used in the basin, 118.0 thousand acre-feet or 94 percent was for irrigation purposes, and 4.3 thousand acre-feet or 3 percent was for municipal purposes.

In 1980, excessive withdrawals of ground water for irrigation purposes caused large to very large overdrafts from the Gulf Coast Aquifer throughout the Colorado-Lavaca Coastal Basin.

Current Surface-Water Development

There is one major reservoir in the basin. This reservoir is a 187 thousand acre-feet capacity cooling lake which is part of the South Texas Project, a major nuclear-fueled electric power generating complex now under construction, owned by Houston Lighting and Power Company, City Public Service Board of San Antonio, Central Power and Light Company, and the City of Austin. The cooling lake covers 7 thousand acres, which includes about seven miles (13.7 square miles of the drainage area) of Little Robbins Slough, a coastal tributary which drains into marshlands adjacent to the Gulf Intracoastal Waterway. The lake will be maintained at desired operating levels for salinity and temperature control by recirculation of Colorado River flows through the reservoir. Water will be diverted from the main stem of the Colorado River for initial filling of the cooling lake and, when operational, discharges will be made periodically through a spillway discharge channel to the main stem of the river downstream from the river intake structure. With two 1,250 megawatt nuclear-fueled steam turbine generators in operation, the project will use water diverted from the Colorado River Basin, with a maximum annual diversion not to exceed 102 thousand acre-feet. Water requirements for the project are included in the Colorado River Basin data.

Natural lakes, old river channels, and natural depressions provide some storage in the basin; however, these are subject to salt-water contamination, both by tidal intrusion during periods of low stream flow and by wind-borne salt water during hurricanes. Most of the surface water used for irrigation in the basin is delivered from the adjoining Colorado River Basin through the Lower Colorado River Authority Canal System. Total water use for irrigation in the basin in 1980 amounted to about 245.0 thousand acre-feet, of which approximately 127.0 thousand acre-feet, or 52 percent, was surface water.

Total surface-water use within the Colorado-Lavaca Coastal Basin in 1980 was 127.4 thousand acre-feet.

Municipal and manufacturing water use within the Colorado-Lavaca Coastal Basin was supplied from ground-water sources.

Water Rights

A total of 41,348 acre-feet of surface water was authorized or claimed for diversion and use in the Colorado-Lavaca Coastal Basin as of December 31, 1983 (Table III-15-1). Irrigation uses accounted for 34,748 acre-feet or 84 percent of the total quantity of water authorized or claimed in the basin (Table III-15-2).

Table III-15-1. Authorized or Claimed Amount of Water, by Type of Right, Colorado-Lavaca Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	8	31,850
Claims	15	5,333
Certified Filings	2	4,165
Certificates of Adjudication	0	0
Total Authorizations and Claims	25	41,348

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

Water Quality

There are no major water quality problems in the Colorado-Lavaca Coastal Basin. Lavaca Bay receives treated effluent from a relatively large number of point sources. The Texas Department of Water Resources is closely monitoring the basin to assure continued compliance with stream quality standards.

Table III-15-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Colorado-Lavaca Coastal Basin

Type of Use	Number of Rights	Basin
Municipal	0	0
Industrial[1]	1	6,600
Irrigation	24	34,748
Recreation[2]	0	0
Total	25	41,348

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include an authorized diversion of 315 acre-feet/year from a saline source

Flooding, Drainage, and Subsidence

Due to limited urbanization within the Colorado-Lavaca Coastal Basin, flood induced damages have not been substantial. Urban areas throughout the basin experienced considerable flooding from Hurricane Carla in 1961. During the period of 1979-1981, minor flooding produced 24 flood insurance claims for $47 thousand in flood damages.

The Federal Emergency Management Agency has designated four communities within the Colorado-Lavaca Coastal Basin as having one or more potential flood hazards. Three of these communities are participating in the National Flood Insurance Program.

The Cities of Palacios and El Campo completed flood insurance rate studies and are participating in the Regular Phase of the Program. A study is nearing completion for Point Comfort. The City of LaWard has completed a study, but is currently suspended from the Regular Program for noncompliance with Program requirements.

Due to the flat terrain of the basin, drainage occurs very slowly. Streams in the basin flood frequently and fill depressions and old channels; irrigation drainage systems are not adequate in many areas for proper drainage. Since much of the land area of the basin is under cultivation, poor drainage frequently causes crop damages. Problems have been mitigated in some areas through the use of on-site and group drainage facilities.

Since 1918, subsidence of one foot or more has occurred in a relatively large area in eastern Jackson and western Matagorda Counties within the Colorado-Lavaca Coastal Basin. Maximum amounts of measured subsidence within the area range from 1.3 to 2.0 feet. Correlation of this area with the locations of oil and gas fields and areas of concentrated ground-water withdrawals for irrigation indicate that the primary cause of the measured subsidence probably is due to petroleum and associated saline ground-water withdrawals in the Francitas North, Midfield, and Blessing Oil Fields. However, measured subsidence data are not available for the areas of concentrated ground-water withdrawals. Therefore, subsidence in the areas of ground-water withdrawals may be as great or greater than the measured subsidence related to petroleum withdrawals. Fault activation and movement, which can cause considerable damage to property, are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

As there are no existing major reservoir facilities located in the Colorado-Lavaca Coastal Basin, freshwater recreation consists principally of activities along streams, ponds, and shoreline in the basin. Matagorda Bay and the coastal shoreline in Calhoun and Jackson Counties provide a combined bay shoreline frontage of 298 miles, 90 miles of which is considered accessible to the general public.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Colorado-Lavaca Coastal Basin is projected to increase 123 percent between 1980 and 2030, resulting in a total gain of over 31 thousand people from the 1980 population of 25.6 thousand (Table III-15-3). Population increases are expected in all counties in the basin.

Wharton County is the most populous county with a 1980 population of 11,805. Although Wharton County is expected to double in population by 2030, its percentage of the basin total should decline from 46 in 1980 to 44 percent in 2030. Matagorda County percentage of the basin population should increase from 40 percent in 1980 to 45 percent in 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Colorado-Lavaca Coastal Basin are projected to increase from the 1980 level of 4.3 thousand acre-feet by a projected maximum of 86 percent by the year 2000 (high case). In the year 2030, water requirements are projected to range from 7.6 to 12.1 thousand acre-feet. Wharton County is expected to account for most of the projected municipal water required in the basin.

Industrial

Manufacturing water requirements in 1980 were 2.0 thousand acre-feet in the Colorado-Lavaca Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Colorado-Lavaca Coastal Basin are projected to increase more than ten times by the year 2000, to a potential high of 20.8 thousand acre-feet. By 2030, manufacturing water requirements are predicted to have increased an additional 62 percent.

In 1980, almost all of the manufacturing water requirement was in Calhoun County. This trend is expected to continue to 2030. In Calhoun County, manufacturing of industrial organic chemicals requires almost all of the projected industrial water requirements.

Steam-Electric Power Generation

Currently, there are no plans to install additional steam-electric power generating capacity using freshwater for cooling in the Colorado-Lavaca Coastal Basin. However, installed capacity of plants using saline cooling water is projected to increase. Small volumes of freshwater will be needed at these plants to provide water for boiler feedwater

Table III-15-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Colorado-Lavaca Coastal Basin

	1980			1990			2000			2010			2020			2030		
River Basin Zone & Category of Use	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total
Colorado-Lavaca Basin																		
Population			25.6			31.4			37.1			43.9			50.1			57.1
Municipal	4.3	0.0	4.3	2.6	4.2	6.8	2.6	5.4	8.0	2.5	6.9	9.4	2.7	8.0	10.7	2.8	9.3	12.1
Manufacturing	2.0	0.0	2.0	0.1	12.8	12.9	0.2	20.8	21.0	0.2	24.4	24.6	0.3	28.6	28.9	0.3	33.8	34.1
Steam Electric	0.1	0.0	0.1	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.4	0.4	0.0	0.7	0.7	0.0	1.0	1.0
Mining	0.4	0.0	0.4	0.3	0.0	0.3	0.3	0.0	0.3	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2
Irrigation	118.0	127.0	245.0	5.3	186.6	191.9	5.3	177.9	183.2	4.8	178.9	183.7	4.8	178.9	183.7	4.4	179.4	183.8
Livestock	0.5	0.4	0.9	0.1	0.9	1.0	0.1	1.1	1.2	0.1	1.1	1.2	0.1	1.1	1.2	0.1	1.1	1.2
Basin Total Water	125.3	127.4	252.7	8.5	204.5	213.0	8.5	205.3	213.8	7.8	211.7	219.5	8.1	217.3	225.4	7.8	224.6	232.4

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

makeup and sanitary and plant maintenance uses. If, however, plants are coal-or lignite-fired power plants, freshwater consumption requirements for dust control and stackgas scrubbing (based on current technology) for sulfur dioxide control could increase total water consumption.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Colorado-Lavaca Coastal Basin are projected to decrease from the 1980 level of 245.0 thousand acre-feet by a projected maximum 27 percent by the year 2000 in the high case and in the low case. In the year 2030, water requirements in the basin are projected to remain at 183.8 thousand acre-feet annually, in the low and high cases to irrigate about 66.1 thousand acres.

Livestock

Livestock water requirements in the basin are projected to increase from 900 acre-feet in 1980 to 1.2 thousand acre-feet annually in 2030.

Mining

Mining water requirements in the Colorado-Lavaca Coastal Basin are projected to nearly half between 1980 and 2030, to about 200 acre-feet annually. The quantity available for the secondary recovery of crude petroleum and natural gas is projected to decline in the basin, with a corresponding decrease in the need for freshwater.

Navigation

Currently, no navigation facilities which would require the use of regulated freshwater supplies are planned in the basin.

Hydroelectric Power

There are no planned hydroelectric power generating facilities in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Colorado-Lavaca Coastal Basin through the year 2030 is 8.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the Colorado-Lavaca Coastal Basin by decade from 1990 through 2030 is expected to be from 7.8 to 8.5 thousand acre-feet per year (Table III-15-3). The approximate average annual projected ground-water use within the basin is expected to be about 8.1 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

The Colorado-Lavaca Coastal Basin has projected surface-water needs for irrigation in excess of available water resources in decades from 1990 through 2030 (Table III-15-4, Figure III-15-2). However, municipal and industrial needs, as well as a portion of the irrigation requirement, are projected to be satisfied from the present through 2030 with surface water imported from the Lavaca and Colorado River Basins. The annual irrigation shortages of about 80 thousand acre-feet for 1990 through 2030 are forecasted to occur as a result of limited ground-

Table III-15-4. Water Resources of the Colorado-Lavaca Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	8.5	—	—	—	8.5	8.5	—	—	8.5	.0	.0	.0
Surface Water	.0	—	.0	114.9	114.9	196.2	—	.0	196.2	.0	(81.3)	(81.3)
Total	8.5	—	.0	114.9	123.4	204.7	—	.0	204.7	.0	(81.3)	(81.3)
2000												
Ground Water	8.5	—	—	—	8.5	8.5	—	—	8.5	.0	.0	.0
Surface Water	.0	—	.0	115.5	115.5	196.8	—	.0	196.8	.0	(81.3)	(81.3)
Total	8.5	—	.0	115.5	124.0	205.3	—	.0	205.3	.0	(81.3)	(81.3)
2010												
Ground Water	7.8	—	—	—	7.8	7.8	—	—	7.8	.0	.0	.0
Surface Water	.0	—	.0	123.2	123.2	203.2	—	.0	203.2	.0	(80.0)	(80.0)
Total	7.8	—	.0	123.2	131.0	211.0	—	.0	211.0	.0	(80.0)	(80.0)
2020												
Ground Water	8.1	—	—	—	8.1	8.1	—	—	8.1	.0	.0	.0
Surface Water	.0	—	.0	128.8	128.8	208.8	—	.0	208.8	.0	(80.0)	(80.0)
Total	8.1	—	.0	128.8	136.9	216.9	—	.0	216.9	.0	(80.0)	(80.0)
2030												
Ground Water	7.8	—	—	—	7.8	7.8	—	—	7.8	.0	.0	.0
Surface Water	.0	—	.0	136.1	136.1	216.1	—	.0	216.1	.0	(80.0)	(80.0)
Total	7.8	—	.0	136.1	143.9	223.9	—	.0	223.9	.0	(80.0)	(80.0)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

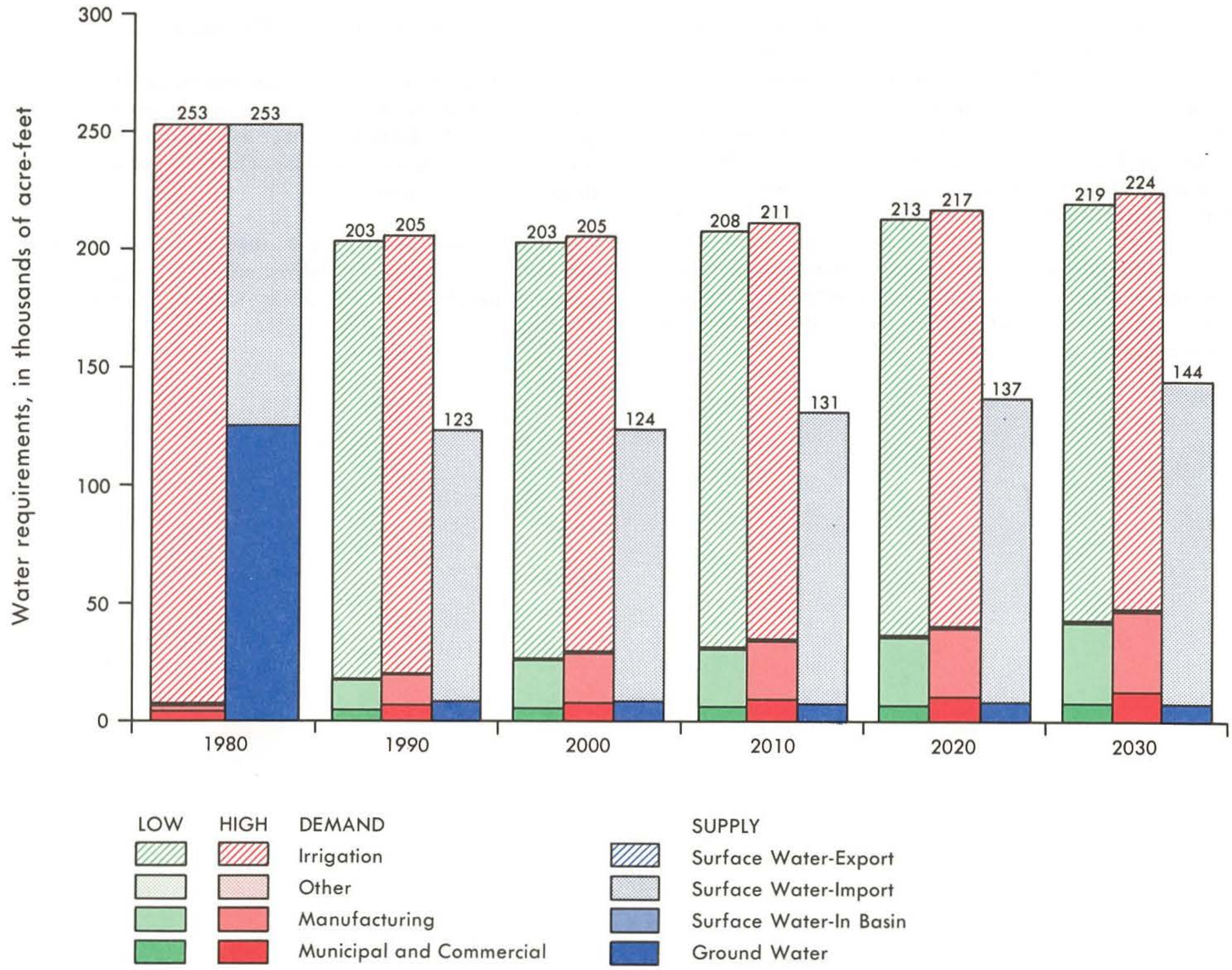

Figure III-15-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Colorado-Lavaca Coastal Basin, 1980-2030

water resources in the basin. Surface-water import into the basin is projected to be 136.1 thousand acre-feet annually by 2030.

There are no major reservoirs proposed for this basin. Surface-water needs projected for municipal and industrial uses in the basin are anticipated to be met from 1990 through the year 2030 from Lake Texana in the Lavaca River Basin and the Highland Lakes of the Colorado River Basin.

Water Quality Protection

A water quality management plan for the Colorado-Lavaca Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $4.5 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Colorado-Lavaca Coastal Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Structural flood control measures in the Colorado-Lavaca Coastal Basin have been limited largely to local projects. Local efforts to protect agricultural lands from flooding will continue to consist of levee construction and drainage improvements.

Flood-plain management regulations need to be established by political subdivisions within the basin to manage development in areas subject to hazardous flooding.

16. LAVACA RIVER BASIN

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16. LAVACA RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Lavaca River Basin is bounded on the north and east by the Colorado River Basin, on the west by the Guadalupe River Basin, on the southeast by the Colorado-Lavaca Coastal Basin, and the southwest by the Lavaca-Guadalupe Coastal Basin. Drainage area of the basin is 2,309 square miles. Headwaters of the Lavaca River originate at an elevation of 470 feet and flow southeast from southern Fayette County into Lavaca Bay. About 60 percent of the basin is drained by the Navidad River and its principal tributary Mustang Creek. Headwaters of the Navidad River rise in the East and West Navidad Rivers which form at an elevation of 440 feet in southern Fayette County, joining near Oakland at an elevation of 201 feet. The Navidad drains into the Lavaca River about two miles east of Vanderbilt in Jackson County. The basin empties into Lavaca Bay, an arm of Matagorda Bay. For planning purposes the Lavaca River Basin is treated as a single hydrologic unit (Figure III-16-1).

Surface Water

Average annual runoff during the 1941-70 period in the western and eastern parts of the Lavaca River Basin was 236 and 335 acre-feet per square mile, respectively. Low flows in the western part of the Lavaca River Basin during 1941-70 occurred in two periods, 1950-56 and 1962-64. Average annual runoff was 75 acre-feet per square mile during the 1950-56 drought and 77 acre-feet per square mile during the period 1962-64. Lowest runoff during two consecutive years (47 acre-feet per square mile) occurred in 1950 and 1951.

Floodwaters in the upper part of the Lavaca River Basin generally rise and fall quickly. The lower part of the basin is characterized by flat slopes, narrow main channels, and wide, timbered flood plains which are inundated frequently. The eastern extremity of the basin, the sector closest to the Gulf of Mexico, is susceptible to the effects of damaging storm surges, as well as the combination of flooding rains, high winds, and occasional tornadoes during the hurricane season, which traditionally extends from June through November.

Total suspended solids concentrations of the Lavaca and Navidad River vary between about 50 and 100 milligrams per liter (mg/l). Although concentrations of total dissolved solids vary widely, runoff throughout the basin is of excellent quality. Total dissolved solids concentrations of the Navidad River in the vicinity of Lake Texana has historically ranged from less than 45 to about 650 mg/l. The discharge-weighted average concentration is about 150 mg/l. Chloride and sulfate concentrations are similarly very low. The Lavaca River is of similar quality, with total dissolved solids concentrations of the river above the tidal reach seldom exceeding 500 mg/l.

Ground Water

The Carrizo-Wilcox Aquifer occurs in a very narrow strip along the northwest edge of the Lavaca River Basin. Only the most downdip part of the aquifer occurs in this basin. In adjacent basins, total thickness ranges upward to about 2,000 feet. Large-capacity wells yield an average of about 200 gallons per minute (gpm) with a maximum of about 600 gpm. The quality of the ground water ranges from about 2,000 to 10,000 mg/l total dissolved solids.

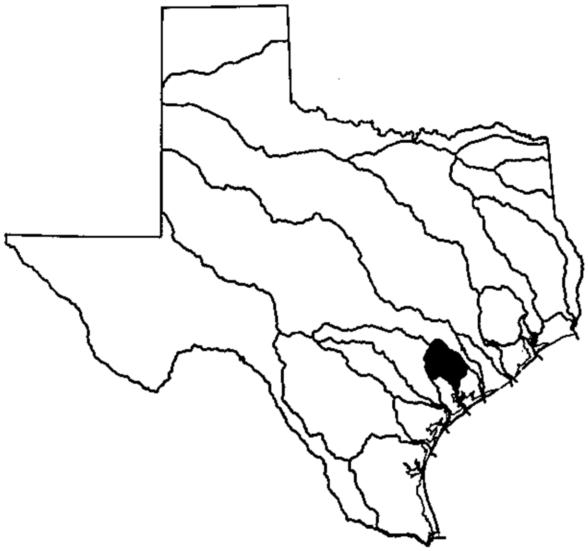
The Gulf Coast Aquifer underlies the entire Lavaca River Basin. The aquifer extends to a maximum depth of about 1,800 feet. Yields of large-capacity wells average about 1,000 gpm, but locally wells yield up to a maximum of about 3,000 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids, but salinity increases downdip and near Lavaca Bay. Saline water overlies fresh water in the lowermost part of the basin.

Population and Economic Development

There were approximately 43.9 thousand residents in the Lavaca River Basin in 1980. Yoakum is the largest population center. The economy of the Lavaca River Basin is based largely on agriculture and mineral production. Although livestock and poultry dominate agricultural production, rice and grains are also important. Oil-field supplies and services are important support activities to the area. Lavaca County is a center for leather goods.

Water Use

Municipal water use in the Lavaca River Basin totaled 7.7 thousand acre-feet in 1980. Large portions of total use originated in Lavaca County (38.0 percent) and Jackson County (36.4 percent). Rural areas and cities of less than 1,000 population accounted for almost 42 percent of total basin municipal use. Freshwater use by manufacturing industries totaled 0.6 thousand acre-feet in 1980. There



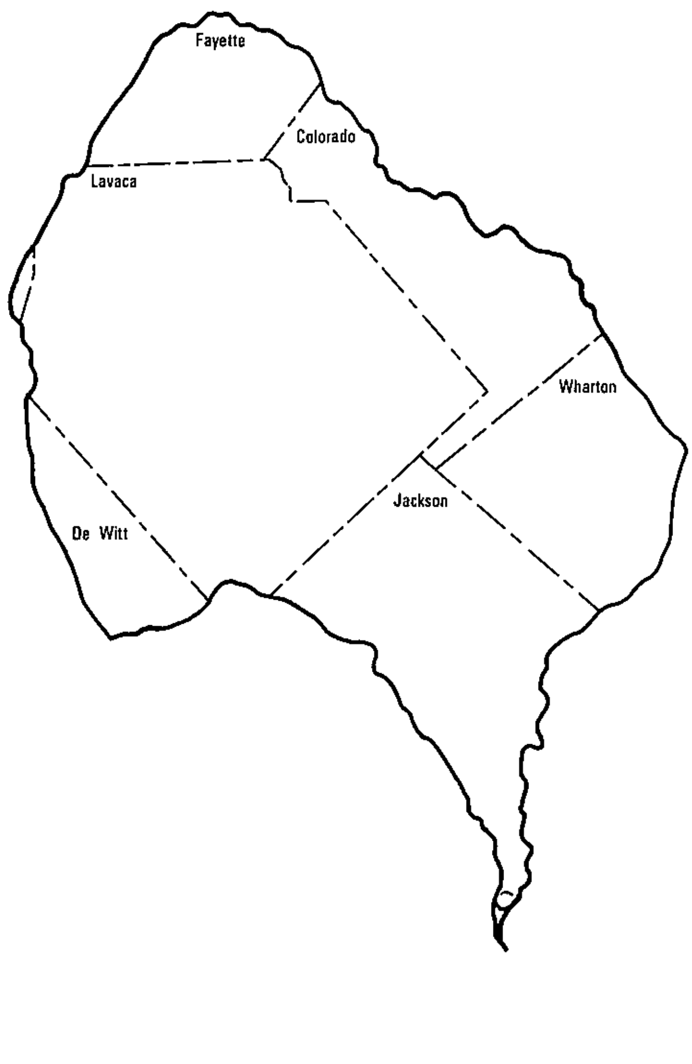


Figure III-16-1. Lavaca River Basin

are a small number of manufacturing establishments operating in the basin.

In 1980, 315.7 thousand acre-feet of water was used on about 92.8 thousand irrigated acres in the Lavaca River Basin. Most irrigation was for rice production on coastal prairie soils which are well suited for rice production in this basin. Ground water supplied about two-thirds of the 1980 water use. Surface water was supplied largely from the Colorado River and conveyed to irrigators through distribution systems which serve the area. Surface water is diverted locally from the Lavaca River in Jackson County. Competition for land by municipal and industrial expansion may limit future irrigated acreage to about the present level.

Mining water requirements in the Lavaca River Basin were estimated at three thousand acre-feet of freshwater in 1980. The largest freshwater withdrawals were associated with mining of nonmetals (sand and gravel washing operations), and petroleum and natural gas production. Water use was concentrated in Colorado County.

Livestock water use in the Lavaca River Basin was 3.3 thousand acre-feet in 1980. Of this total, ground water provided approximately one thousand acre-feet and surface water supplied 2.3 thousand acre-feet.

The navigation facility in the Lavaca River Basin consists of the channel to Red Bluff. This channel extends from its intersection with the channel to Port Lavaca, across Lavaca Bay, up the Lavaca River to the Navidad River, and then up the Navidad River for approximately three miles to Red Bluff. This channel has no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the Lavaca River Basin totaled 2.9 thousand acre-feet, most of which originated in Lavaca County. Based on detailed studies by the Department, irrigation return flows in the basin are considered to be 40 percent of on-farm use of irrigation water applied from surface-water supplies and 35 percent of ground-water supplies, or about 107 thousand acre-feet in 1980.

Current Ground-Water Development

Approximately 220.5 thousand acre-feet of ground water was used in 1980 in the Lavaca River Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 220.5 thousand acre-feet of ground water used in the basin, 208.8 thousand acre-feet or 95 percent was for irrigation purposes, and 7.7 thousand acre-feet or 3 percent was for municipal purposes.

In 1980, withdrawals of ground water primarily for irrigation purposes caused very large overdrafts from the Gulf Coast Aquifer in Colorado, Jackson, and Wharton Counties within the Lavaca River Basin.

Current Surface-Water Development

Lake Texana, constructed by the U.S. Bureau of Reclamation, is the only major reservoir project in the Lavaca River Basin. This project, which is operated by the Lavaca-Navidad River Authority, will supply municipal and industrial water to meet expanding water demands within the region. Lake Texana provides a dependable annual firm supply of 75.0 thousand acre-feet of water.

In 1980, total water use within the Lavaca River Basin exceeded 330.3 thousand acre-feet, approximately 96 percent of which was for irrigation purposes. The major source of water in the Lavaca River Basin is ground water. However, surface water for irrigation is delivered from the Colorado River Basin via the Garwood Irrigation District. The water-rights permit for this project allows an annual diversion of 120 thousand acre-feet. In 1980, 104.8 thousand acre-feet was delivered to the Lavaca River Basin. The major agricultural areas which receive water from the District are located in Colorado and Wharton Counties.

Water Rights

The total amount of surface water authorized or claimed for diversion and use in the Lavaca River Basin was 100,608 acre-feet as of December 31, 1983 (Table III-16-1). Most of the rights were for industrial uses, 56.8 percent; municipal use accounted for 17.7 percent and irrigation for 25.0 percent of total authorized or claimed rights (Table III-16-2).

Water Quality

The Lavaca River Basin contains oil and gas fields, which present a potential threat of localized pollution. Fish kills which have occurred in the past have been linked to the use of pesticides in adjacent irrigation fields. Throughout parts of the basin, there are frequent incidents of high coliform levels.

Table III-16-1. Authorized or Claimed Amount of Water, by Type of Right, Lavaca River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	17	10,781
Claims	0	0
Certified Filings	0	0
Certificates of Adjudication	27	89,827
Total Authorizations and Claims	44	100,608

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

Table III-16-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Lavaca River Basin

Type of Use	Number of Rights	Basin Basin
Municipal	1	17,826
Industrial	1	57,174
Irrigation	42	25,153
Recreation	1	455
Total	44[1]	100,608

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

Flooding, Drainage, and Subsidence

Average annual damages for the period 1939 through 1959, based on analysis of flood peaks and the area flooded, are $101.9 thousand for the Lavaca River and $99.8 thousand for the Navidad River. In August 1981, major flooding occurred in Hallettsville, Shiner, Yoakum, and areas in Lavaca County. A resulting Presidential disaster declaration brought more than $963 thousand in federal relief. A total of 44 flood insurance claims were filed for $745 thousand in flood damages.

The Federal Emergency Management Agency has designated seven communities within the Lavaca River Basin as having one or more potential flood hazards. At present, six cities are participating in the National Flood Insurance Program. Flood insurance rate studies, which determine the 100-year flood elevations, have been completed for the Cities of Hallettsville, Ganado, and Edna and for Jackson County. All of these cities have adopted the necessary regulations to make them eligible for participation in the Regular Phase. A flood insurance study is currently in progress for Wharton County.

Inadequate drainage systems in many areas have resulted in slow removal of excess water in rice fields. Lack of land levelling has created depressions in otherwise well drained fields and has caused locally severe drainage problems. Drainage problems are further complicated by frequent flooding of the Lavaca and Navidad Rivers and their tributaries, blocking tributary channels with sediment and debris.

Maximum amounts of measured subsidence since 1918, within the Lavaca River Basin occur in Jackson County and range from 0.9 to 1.2 feet. The largest amount measured was 1.2 feet in the Lolita Oil and Gas Field on the eastern edge of the basin. Approximately 1.1 feet of subsidence was measured near the confluence of the Lavaca and Navidad Rivers. These amounts of measured subsidence correlate with oil, gas, and related saline ground-water withdrawal areas in the southern part of the basin. Subsidence slightly greater than 1.0 foot has occurred due to fresh and saline ground-water and petroleum withdrawals in the Cordele area of northern Jackson County. Measured subsidence data is not available for Wharton, Colorado, Lavaca, DeWitt, and Fayette Counties within the basin. Fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

The recently completed Lake Texana will provide 9.9 thousand surface acres of water available for flat-water recreation. Freshwater recreation resources currently available in the basin include the Lavaca and Navidad Rivers and smaller streams and ponds.

PROJECTED WATER REQUIREMENTS

Population Growth

The Lavaca River Basin population is projected to increase 56 percent by the year 2030, from the present 43.9 thousand to 68.4 thousand (Table III-16-3). A 22 percent increase to 53.5 thousand is expected from 1980 to the year 2000, and a growth rate of 28 percent is projected for the 2000 to 2030 period. Lavaca County population is expected to increase by 80.4 percent by 2030. Its share of the basin population is anticipated to increase from 43.0 percent in 1980 to 46.2 percent in 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Lavaca River Basin are projected to increase from the 1980 level of 7.7 thousand acre-feet by a projected maximum of 52 percent by the year 2000 (high case). In the year 2030, water requirements are projected to range from 10.4 to 15.0 thousand acre-feet.

Industrial

Manufacturing water requirements in 1980 were 0.6 thousand acre-feet in the Lavaca River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Lavaca River Basin are projected to increase more than four times by the year 2030, to a potential high of 2.5 thousand acre-feet by 2030.

Steam-Electric Power Generation

There are currently no plans to install steam-electric power generating capacity in the Lavaca River Basin. If steam-electric power generating capacity is installed in the future, saline water could be used for cooling. However, freshwater would be needed at these plants to provide water for boiler feedwater makeup and sanitary and maintenance uses. These freshwater uses are small when compared to cooling water requirements, but if the plant were a coal- or lignite-fired power plant, freshwater consumption for dust control and stackgas scrubbing for sulfur dioxide control could increase total water consumption.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects the demand for water based on the effects of changes in the above variables, but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Lavaca River Basin are projected to decrease from the 1980 level of 315.7 thousand acre-feet by a projected maximum 21 percent by the year 2000 in the high and low cases. In the year 2030, water requirements in the basin are projected to remain at 236.6 thousand acre-feet annually in the low and high cases to irrigate 92.8 thousand acres.

Table III-16-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Lavaca River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Lavaca Basin																		
Population			43.9			48.9			53.5			59.3			64.0			68.4
Municipal	7.7	0.0	7.7	9.6	0.8	10.4	10.6	1.1	11.7	11.6	1.4	13.0	12.4	1.6	14.0	13.1	1.9	15.0
Manufacturing	0.6	0.0	0.6	0.8	0.1	0.9	1.2	0.0	1.2	1.5	0.1	1.6	1.9	0.1	2.0	2.5	0.0	2.5
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	2.4	0.6	3.0	2.4	0.7	3.1	2.3	0.8	3.1	2.4	0.9	3.3	2.6	1.0	3.6	2.7	1.1	3.8
Irrigation	208.8	106.9	315.7	52.6	203.7	256.3	52.6	195.6	248.2	52.6	196.2	248.8	51.7	197.3	249.0	47.4	189.2	236.6
Livestock	1.0	2.3	3.3	1.3	2.6	3.9	1.3	3.2	4.5	1.3	3.2	4.5	1.3	3.2	4.5	1.3	3.2	4.5
Basin Total Water	220.5	109.8	330.3	66.7	207.9	274.6	68.0	200.7	268.7	69.4	201.8	271.2	69.9	203.2	273.1	67.0	195.4	262.4

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

Livestock

The livestock requirement in the basin is projected to increase from 3.3 thousand acre-feet in 1980 to 4.5 thousand acre-feet in 2030.

Mining

Estimates of mining water requirements in the Lavaca River Basin are projected to increase to over 3.8 thousand acre-feet by 2030. Almost all of the increase will be used in nonmetal mining operations, requiring 83 percent of the basin total mining water use at the end of the planning period. The remaining requirements will be for the secondary recovery of petroleum and natural gas.

Navigation

Currently, no navigation facilities which would require the use of regulated freshwater supplies are planned in the basin.

Hydroelectric Power

There are no planned hydroelectric power generating facilities in the basin.

Estuarine Freshwater Inflows

The Lavaca River discharges into the Lavaca-Tres Palacios estuary. Combining inundation and salinity requirements for the Subsistence Alternative yields a 343 thousand acre-feet per year estimate of gaged Lavaca Basin inflows needed for the Lavaca Bay portion of this estuarine system (Table III-16-4). Ungaged inflow needs from the basin for this alternative are estimated at 70 thousand acre-feet annually. For the Fisheries Maintenance Alternative, a gaged river inflow from the Lavaca River Basin of 611 thousand acre-feet per year, in addition to 127 thousand acre-feet per year of ungaged inflow, is estimated to satisfy the salinity and marsh inundation needs, and to maintain annual commercial fisheries harvests at levels greater than the mean harvests for the 1962-1976 period (Table III-16-4). For the Harvest Enhancement Alterna-

Table III-16-4. Gaged River Inflow Needs of the Lavaca-Tres Palacios Estuary From the Lavaca River Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Lavaca River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability
January	21.8	21.8	21.8	8.8
February	26.8	26.8	26.8	8.8
March	17.0	17.0	17.0	5.5
April	25.6	67.5	114.8	17.8
May	116.2	116.2	167.0	15.7
June	32.0	98.4	116.4	8.7
July	15.6	18.4	15.6	5.7
August	10.4	35.1	10.4	7.3
September	24.2	97.1	24.2	17.0
October	18.2	77.8	18.2	13.3
November	17.6	17.6	17.6	7.2
December	17.5	17.6	17.5	9.8
Annual	342.9	611.3	617.3	125.6

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Combined gaged streamflow of Lavaca River near Edna and Navidad River near Ganado.

tive, the annual commercial shellfish harvest of the estuary is maximized while using no more than the average (1941-1976) annual inflow. The estimated inflows needed from the ungaged portion of the Lavaca River Basin amount to 123 thousand acre-feet yearly. The inflow needs from the gaged portion of the basin total 617 thousand acre-feet (Table III-16-4). An estimated 126 thousand acre-feet annually of gaged inflow from the Lavaca River Basin is needed to maintain salinities within the species limits of viability in upper Lavaca Bay.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Lavaca River Basin through the year 2030 is 86.0 thousand acre-feet. This amount of safe annual ground-water supply is from the Gulf Coast Aquifer which is the only readily accessable fresh to slightly saline water-bearing unit within the basin.

The projected annual ground-water use within the Lavaca River Basin by decade from 1990 through 2030 is expected to be from 66.7 to 69.9 thousand acre-feet per year (Table III-16-3). The approximate average annual projected ground-water use within the basin is expected to be about 68.2 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

Projected annual surface-water needs in the Lavaca River Basin exceed supplies available by 54.8 thousand acre-feet in 2000 and 63.2 thousand acre-feet in 2030 (Table III-16-5, Figure III-16-2). These net shortages result from irrigation shortages of about 100.0 thousand acre-feet per year balanced with annual surpluses for municipal and industrial purposes of 48.2 thousand acre-feet in 2000 and 29.8 thousand acre-feet in 2030. Approximately 87.4 thousand acre-feet of the 163.4 thousand acre-feet of surface water supplied to the basin in year 2030 is projected to be provided from sources outside of the basin, principally the Colorado River Basin.

Projected surface-water needs for municipal and manufacturing purposes in the Lavaca River Basin can be met from Lake Texana (Stage I, Palmetto Bend Reservoir) through the year 2030. No additional reservoirs are proposed for this basin.

Should future surface-water needs for municipal and manufacturing purposes in the Lavaca River Basin and adjacent areas exceed projections, regional water deficits can be supplied, in part, by construction of the authorized Stage II Palmetto Bend Reservoir. This project would add about 35 thousand acre-feet of firm annual yield to the basin supply.

Water Quality Protection

A water quality management plan for the Lavaca River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $5.3 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Lavaca River Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

There are presently no flood control structures in the Lavaca River Basin, nor are any currently planned. The only structural flood-control measure in the basin has been channel rectification at Hallettsville, which has included clearing, straightening, and enlarging the upstream reaches of the Lavaca and Navidad Rivers. The works, which are located 88 miles above the mouth of the Lavaca River, were completed in September 1960.

Table III-16-5. Water Resources of the Lavaca River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	66.7	—	—	—	66.7	66.7	—	—	66.7	.0	.0	.0
Surface Water	75.0	—	.8	92.0	167.8	195.7	—	17.2	212.9	57.9	(103.0)	(45.1)
Total	141.7	—	.8	92.0	234.5	262.4	—	17.2	279.6	57.9	(103.0)	(45.1)
2000												
Ground Water	68.0	—	—	—	68.0	68.0	—	—	68.0	.0	.0	.0
Surface Water	75.0	—	.9	83.8	159.7	187.8	—	26.7	214.5	48.2	(103.0)	(54.8)
Total	143.0	—	.9	83.8	227.7	255.8	—	26.7	282.5	48.2	(103.0)	(54.8)
2010												
Ground Water	69.4	—	—	—	69.4	69.4	—	—	69.4	.0	.0	.0
Surface Water	75.0	—	1.0	86.4	162.4	188.7	—	32.0	220.7	42.5	(100.8)	(58.3)
Total	144.4	—	1.0	86.4	231.8	258.1	—	32.0	290.1	42.5	(100.8)	(58.3)
2020												
Ground Water	69.9	—	—	—	69.9	69.9	—	—	69.9	.0	.0	.0
Surface Water	75.0	—	1.0	87.4	163.4	190.0	—	37.7	227.7	36.7	(101.0)	(64.3)
Total	144.9	—	1.0	87.4	233.3	259.9	—	37.7	297.6	36.7	(101.0)	(64.3)
2030												
Ground Water	67.0	—	—	—	67.0	67.0	—	—	67.0	.0	.0	.0
Surface Water	75.0	—	1.0	87.4	163.4	182.1	—	44.5	226.6	29.8	(93.0)	(63.2)
Total	142.0	—	1.0	87.4	230.4	249.1	—	44.5	293.6	29.8	(93.0)	(63.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

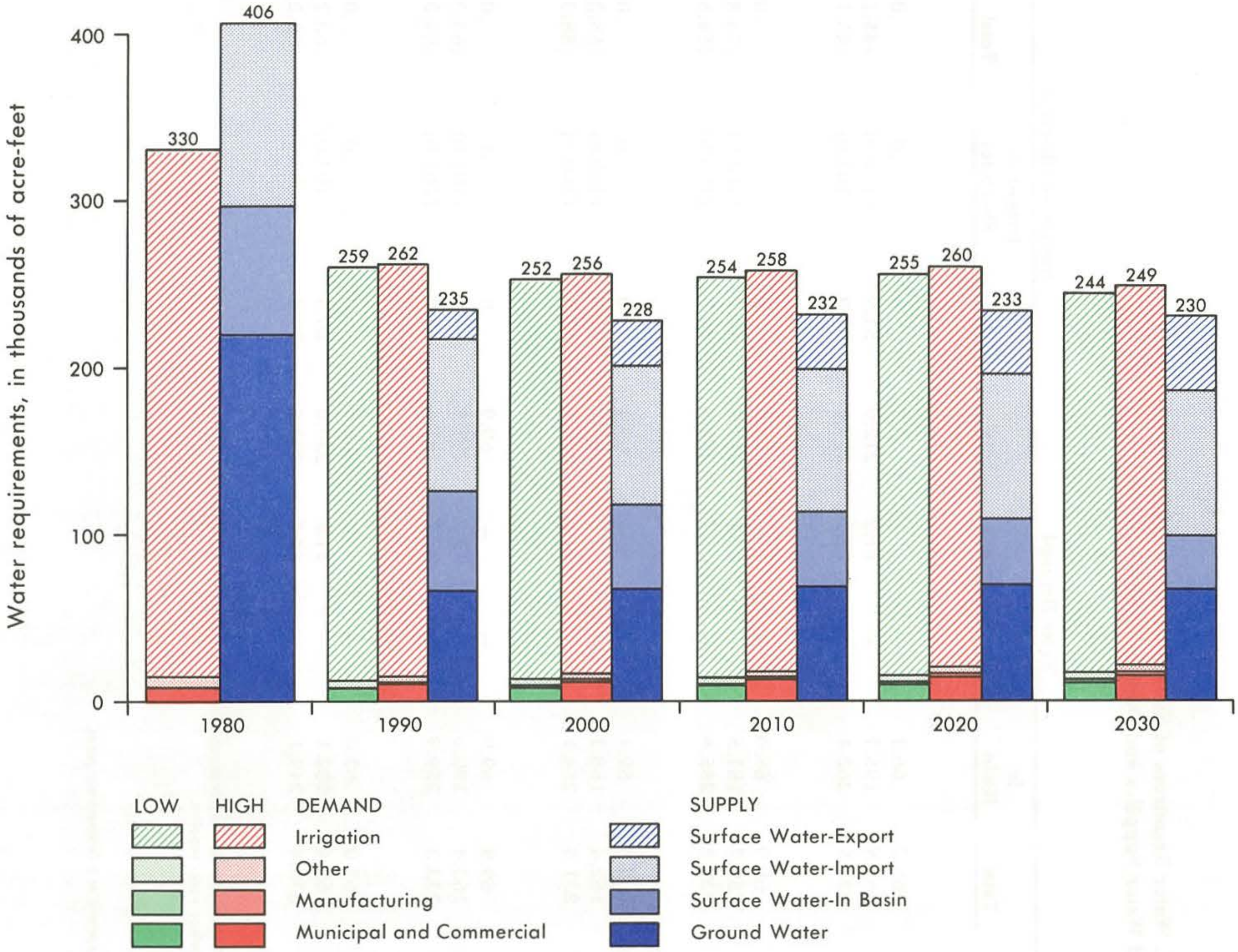


Figure III-16-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Lavaca River Basin, 1980-2030

17. LAVACA-GUADALUPE COASTAL BASIN

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17. LAVACA-GUADALUPE COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Lavaca-Guadalupe Coastal Basin is bounded on the east by the Lavaca River Basin and the Colorado-Lavaca Coastal Basin and on the west by the Guadalupe River Basin and the San Antonio-Nueces Coastal Basin. The basin originates in southeastern DeWitt County at an elevation of about 200 feet and is approximately 20 miles wide and 60 miles long. Arenosa, Garcitas, and Placedo Creeks and Chocolate Bayou are the principal streams draining the basin. Runoff from the basin flows into Lavaca, Matagorda, Espiritu Santo, and San Antonio Bays. Total area of the basin is 998 square miles. For planning purposes, the Lavaca-Guadalupe Coastal Basin is treated as a single hydrologic unit (Figure III-17-1).

Surface Water

The average annual runoff in the basin is approximately 200 acre-feet per square mile. Available data are insufficient to accurately define low-flow characteristics of streams draining the basin. Stream gages were installed in 1970 on Garcitas and Placedo Creeks, above their tidal-affected reaches. There are substantial diversions, principally for irrigation, and return flows above the gages during rice-growing seasons.

Flat terrain typical of much of the Texas coastal plain characterizes the Lavaca-Guadalupe Coastal Basin. Consequently, appreciable rains frequently cause widespread flooding. Rainfall from heavy thunderstorms in the spring often is substantial enough to cause flooding, but the most severe flooding is usually reserved for the late summer and early autumn, when hurricanes and other tropical weather systems bring torrential rains that may persist for one or several days.

Runoff within the Garcitas Creek drainage system is of good quality. Dissolved-solids concentrations in water from Garcitas Creek near Inez have ranged from 40 to 400 milligrams per liter (mg/l), and concentrations of dissolved solids in Arenosa Creek near Inez have ranged from 30 to 600 mg/l. However, data collected periodically in the lower part of the basin indicate total dissolved-solids concentrations locally exceed 3,000 mg/l. High concentrations of dissolved solids, particularly chloride, indicate local degradation of stream quality by oil-field wastes.

Ground Water

The Gulf Coast Aquifer covers the entire Lavaca-Guadalupe Coastal Basin. The aquifer extends to a maximum depth of approximately 1,800 feet. Large-capacity well yields average about 1,200 gallons per minute (gpm); however, locally wells produce up to 3,000 gpm. The quality of water in the aquifer is suitable for most purposes, generally containing less than 1,000 mg/l total dissolved solids. In some areas of Calhoun County, saline water overlies fresh water.

Population and Economic Development

The Lavaca-Guadalupe Coastal Basin population was 37,900 in 1980. Nearly 30 percent of the basin population resided in Port Lavaca, the major population center in the basin. The economy of the basin is dominated by mineral production, which yields products valued at about $120 million annually. Oil-field services and equipment dominate the manufacturing sector. Agriculture is a major contributor to the area economy, with produce valued at over $37 million annually. Another important influence on the economy is tourism and water-oriented recreation.

Water Use

Municipal water use in the Lavaca-Guadalupe Coastal Basin totaled 5.4 thousand acre-feet in 1980. Portions of Calhoun and Victoria Counties accounted for 47 and 52 percent, respectively, of the total municipal water use in the basin. Cities using significant portions of the total basin municipal use were Port Lavaca (32 percent) and the in-basin portion of the City of Victoria (30 percent). Thirty percent of the basin total municipal use was in rural areas or in cities with less than 1,000 population.

The 1980 freshwater use by manufacturing industries in the basin totaled 14.2 thousand acre-feet, primarily for manufacturing of chemicals and allied products.

In 1980, a total of 98.1 thousand acre-feet of water was used to irrigate 27.4 thousand acres in the Lavaca-Guadalupe Coastal Basin. Nearly all of this water was used to irrigate rice, with some water used for irrigation of

Figure III-17-1. Lavaca-Guadalupe Coastal Basin

improved pasture. Irrigation in the upper part of the basin is supplied principally from ground-water sources. Surface water diverted primarily from the Guadalupe River supplies the Calhoun County area in the lower basin. Relatively small quantities of water were diverted for irrigation from the Lavaca River in Jackson County and from Garcitas Creek. Water supplied from ground and surface sources for irrigation in the basin in 1980 was about 53.8 thousand acre-feet from ground water and 44.3 thousand acre-feet from surface water.

Estimated freshwater withdrawals associated with mining operations in the Lavaca-Guadalupe Coastal Basin, primarily in Victoria County, totaled almost 700 acre-feet in 1980.

Livestock water use in 1980 totaled 1.2 thousand acre-feet in the Lavaca-Guadalupe Coastal Basin. Surface- and ground-water sources supplied approximately 500 and 700 acre-feet, respectively.

The navigation facilities in the Lavaca-Guadalupe Coastal Basin include a portion of the Matagorda Ship Channel to Point Comfort, the side channel to Port Lavaca, the Gulf Intracoastal Waterway and its tributary channel to Seadrift, and a portion of the Victoria Barge Canal. These navigation facilities have no regulated freshwater requirements from the Lavaca-Guadalupe Coastal Basin.

Return Flows

In 1980, municipal and manufacturing return flows in the Lavaca-Guadalupe Coastal Basin totaled 11.9 thousand acre-feet. Over 95 percent of the total was produced by industry and municipalities in Calhoun County.

Irrigation return flows, principally from irrigated rice, total about 40 percent of surface water applied and 35 percent of ground water applied. Irrigation return flows in the basin totaled 33 thousand acre-feet in 1980. Return flows are generally not recoverable as they are discharged into tidal waters.

Current Ground-Water Development

Approximately 58.2 thousand acre-feet of ground water was used in 1980 in the Lavaca-Guadalupe Coastal Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 58.2 thousand acre-feet of ground water used in the basin, 53.8 thousand acre-feet or 92 percent was for irrigation purposes, and 3.3 thousand acre-feet or 6 percent was for municipal purposes.

In 1980, withdrawals of ground water for irrigation purposes caused very large overdrafts from the Gulf Coast Aquifer in Calhoun and Jackson Counties within the Lavaca-Guadalupe Coastal Basin.

Current Surface-Water Development

There are no major reservoirs in the Lavaca-Guadalupe Coastal Basin. Green Lake, a natural lake in Calhoun County and the largest natural lake in the State, has been used as a source of irrigation water. Garcitas Creek and other creeks also furnish small amounts of irrigation water. The Guadalupe-Blanco River Authority currently supplies surface water from the Guadalupe River to the coastal basin for municipal, manufacturing, and agricultural purposes through the Calhoun County Diversion System. Water is supplied through this system to the City of Port Lavaca and neighboring rural areas.

In 1980, water use in the Lavaca-Guadalupe Coastal Basin totaled about 119.6 thousand acre-feet. Of this quantity, 61.4 thousand acre-feet was supplied from surface sources, with the remainder coming from ground water. Almost all of the surface water was supplied by the Guadalupe-Blanco River Authority which delivered 43.4 thousand acre-feet of water to Calhoun County irrigation users and 16.2 thousand acre-feet of water to cities and industries.

Water Rights

A total of 2,010 acre-feet of surface water was authorized or claimed for diversion and use in the Lavaca-Guadalupe Coastal Basin (Table III-17-1). This entire quantity was authorized and claimed for agricultural uses in the basin.

Water Quality

The basin has no significant surface-water quality problems at present. The basin is being closely monitored by the Texas Department of Water Resources to assure continued compliance with stream quality standards.

Flooding, Drainage, and Subsidence

Due to limited development within the Lavaca-Guadalupe Coastal Basin, flooding of streams has caused only minor damage. Damages are principally incurred in the agricultural sector. This damage commonly results from poor drainage. Minor flooding during 1979, 1980,

Table III-17-1. Authorized or Claimed Amount of Water, by Type of Right, Lavaca-Guadalupe Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	1	2,000
Claims	0	0
Certified Filings	0	0
Certificates of Adjudication	1	10
Total Authorizations and Claims	2	2,010[2]

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

[2]Irrigation

and 1981 produced 99 flood insurance claims for $580 thousand in flood damages.

The Federal Emergency Management Agency has designated two communities within the Lavaca-Guadalupe Coastal Basin as having one or more special flood-hazard areas. The Cities of Seadrift and Port Lavaca have completed Flood Insurance Rate Studies and are participating in the Regular Phase of the National Flood Insurance Program. Unincorporated areas of Calhoun County are also covered by insurance under the Regular Phase.

As is common in most of the coastal basins, drainage waters in the Lavaca-Guadalupe Coastal Basin result largely from irrigation of rice fields. The flat terrain and poorly defined drainage systems produce slow drainage. Excessive rainfall in the basin results in stream overflow and causes considerable inundation of the area. Wetlands prevail in many areas.

Since 1918, the maximum amount of subsidence measured within the Lavaca-Guadalupe Coastal Basin was about 1.2 feet near Placedo in southern Victoria County. Approximately 0.6 foot of subsidence occurred near the LaSalle Oil Field at the eastern edge of the basin. Since 1943, subsidence of 0.5 to 1.0 foot has been measured near Highway 59, halfway between Victoria and Edna, and just south of the intersection of Highway 87 and the Calhoun-Victoria County line. All of this recorded subsidence is believed to be due to withdrawals of petroleum and related saline ground waters. Fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

Water-oriented recreation resources available in the Lavaca-Guadalupe Coastal Basin are largely marine related. Since there are no major reservoirs in the basin, freshwater recreation is limited to the streams and ponds. Green Lake, a large natural lake located near the Guadalupe River in western Calhoun County, is privately owned but is available for fishing on a fee basis. Information from surveys by the Texas Department of Water Resources and the Texas Parks and Wildlife Department indicates an estimated 50 thousand sport fishing parties visited the Guadalupe estuary during 1976-1977. This recreation use produced an estimated total economic impact of over $6 million to local and State economies.

PROJECTED WATER REQUIREMENTS

Population Growth

Population of the Lavaca-Guadalupe Coastal Basin is expected to more than double between 1980 and 2030, (Table III-17-2), with a projected growth rate of 109 percent during the period. The projected growth rate from 1980 to 2000 is 42 percent and 47 percent from 2000 to 2030. These rates compare to the projected statewide rates of 49 and 62 percent for the 1980-2000 and 2000-2030 periods, respectively.

Victoria County, currently the most populous county in the basin, is expected to have the highest growth rate (134.2 percent) from 1980 to 2030. Its share of the total basin population is projected to increase from 52 percent in 1980 to 53.4 percent in 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per

Table III-17-2. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Lavaca-Guadalupe Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Lavaca-Guadalupe Basin																		
Population			37.9			46.5			53.7			61.0			70.4			79.1
Municipal	3.3	2.1	5.4	5.5	3.9	9.4	6.3	4.9	11.2	6.9	5.8	12.7	7.8	6.8	14.6	8.8	7.6	16.4
Manufacturing	0.1	14.1	14.2	0.0	32.4	32.4	0.0	44.4	44.4	0.0	59.0	59.0	0.0	76.5	76.5	0.0	98.2	98.2
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.3	0.4	0.7	0.8	0.0	0.8	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.1	0.0	1.1
Irrigation	53.8	44.3	98.1	29.9	43.2	73.1	30.0	43.0	73.0	30.0	43.0	73.0	30.0	43.0	73.0	30.0	43.0	73.0
Livestock	0.7	0.5	1.2	0.2	1.2	1.4	0.2	1.4	1.6	0.2	1.4	1.6	0.2	1.4	1.6	0.2	1.4	1.6
Basin Total Water	58.2	61.4	119.6	36.4	80.7	117.1	37.5	93.7	131.2	38.1	109.2	147.3	39.0	127.7	166.7	40.1	150.2	190.3

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

capita water use. Water requirements in the Lavaca-Guadalupe Coastal Basin are projected to increase from the 1980 level of 5.4 thousand acre-feet by a projected maximum of 107 percent by the year 2000. In the year 2030, water requirements are projected to range from 10.1 to 16.4 thousand acre-feet. Calhoun County is expected to account for over half of the water requirements.

Industrial

Manufacturing water requirements in 1980 were 14.2 thousand acre-feet in the Lavaca-Guadalupe Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Lavaca-Guadalupe Coastal Basin are projected to increase more than six times by the year 2030, to a potential high of 98.2 thousand acre-feet by 2030 (high case).

Manufacturing water requirements in the Lavaca-Guadalupe Coastal Basin are projected to grow 592 percent by the year 2030 (compared to the State average of 230 percent over the same period).

Almost all of the in-basin industrial water use in 1980 occurred in Calhoun County. This concentration of water requirement in Calhoun County is not expected to change over the projection period. In 2030, manufacturing of industrial organic chemicals is expected to account for almost all of Calhoun County's projected requirements.

Steam-Electric Power Generation

Currently, there are no plans for installation of steam-electric power generation plants in the basin.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Lavaca-Guadalupe Coastal Basin are projected to decrease from the 1980 level of 98.1 thousand acre-feet by a projected maximum 26 percent by the year 2000 in the high case and in the low case. In the year 2030, water requirements in the basin are projected to be about 73.0 thousand acre-feet annually in the low and high cases to irrigate about 27.4 thousand acres.

Livestock

Livestock water requirements within the basin are projected to increase from 1.2 thousand acre-feet in 1980 to 1.6 thousand acre-feet annually in 2030.

Mining

Mining water requirements in the Lavaca-Guadalupe Coastal Basin are projected to total 1.1 thousand acre-feet in the year 2030. Nonmetal mining water use, as a share of total basin requirements, is projected to increase, while water use in the recovery of crude petroleum and natural gas is expected to decline as the potential quantities available for production decrease throughout the planning period.

Navigation

There are presently no authorized improvements or modifications of existing coastal navigation facilities in the basin other than authorized maintenance dredging of the Gulf Intracoastal Waterway. There are presently no requirements for regulated freshwater releases for navigation in the basin, and none are projected.

Hydroelectric Power

Currently, there are no plans to install hydroelectric power generating facilities in the Lavaca-Guadalupe Coastal Basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Lavaca-Guadalupe Coastal Basin through the year 2030 is 48.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the Lavaca-Guadalupe Coastal Basin by decade from 1990 through 2030 is expected to be from 36.4 to 40.1 thousand acre-feet per year (Table III-17-2). The approximate average annual projected ground-water use within the basin is expected to be about 38.2 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

The Lavaca-Guadalupe Coastal Basin has projected water needs slightly in excess of projected water supplies in each decade from 1990 through 2030 (Table III-17-3, Figure III-17-2). Shortages of 4.7 thousand acre-feet are projected to occur in the irrigation water demands through the year 2030. This irrigation shortage results from limited ground-water supplies. Sufficient water is projected to be available for all other purposes in the basin through the year 2030, if surface water continues to be imported to the basin from the Guadalupe and San Antonio River Basins. In 2000 and 2030, this import is projected to be 86.7 thousand and 143.2 thousand acre-feet per year, respectively.

No major reservoirs are proposed for construction in this coastal basin. Future surface-water needs can be fully met through the development of water resources in the San Antonio and Guadalupe River Basins and the diversion of a portion of these waters through existing and potential conveyance facilities.

Water Quality Protection

A water quality management plan for the Lavaca-Guadalupe Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $15.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Lavaca-Guadalupe Coastal Basin in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Existing structural flood-control measures consist of local projects to protect agricultural lands and improve drainage. Urban developments in the basin subject to hurricane tidal flooding will continue to be studied by the U.S. Army Corps of Engineers to determine the feasibility of providing flood protection. Construction of any economically feasible project will depend upon Congressional appropriations and the ability of local sponsors to contribute their share of project costs.

There are no U.S. Soil Conservation Service floodwater-retarding structures in the basin, however 48 miles of channel work has been completed.

Nonstructural measures such as zoning and minimum building standards will continue to assist in minimizing future flood damages.

Table III-17-3. Water Resources of the Lavaca-Guadalupe Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	36.4	—	—	—	36.4	36.4	—	—	36.4	.0	.0	.0
Surface Water	.0	—	.0	73.9	73.9	78.6	—	.0	78.6	.0	(4.7)	(4.7)
Total	36.4	—	.0	73.9	110.3	115.0	—	.0	115.0	.0	(4.7)	(4.7)
2000												
Ground Water	37.5	—	—	—	37.5	37.5	—	—	37.5	.0	.0	.0
Surface Water	.0	—	.0	86.7	86.7	91.4	—	.0	91.4	.0	(4.7)	(4.7)
Total	37.5	—	.0	86.7	124.2	128.9	—	.0	128.9	.0	(4.7)	(4.7)
2010												
Ground Water	38.1	—	—	—	38.1	38.1	—	—	38.1	.0	.0	.0
Surface Water	.0	—	.0	102.2	102.2	106.9	—	.0	106.9	.0	(4.7)	(4.7)
Total	38.1	—	.0	102.2	140.3	145.0	—	.0	145.0	.0	(4.7)	(4.7)
2020												
Ground Water	39.0	—	—	—	39.0	39.0	—	—	39.0	.0	.0	.0
Surface Water	.0	—	.0	120.7	120.7	125.4	—	.0	125.4	.0	(4.7)	(4.7)
Total	39.0	—	.0	120.7	159.7	164.4	—	.0	164.4	.0	(4.7)	(4.7)
2030												
Ground Water	40.1	—	—	—	40.1	40.1	—	—	40.1	.0	.0	.0
Surface Water	.0	—	.0	143.2	143.2	147.9	—	.0	147.9	.0	(4.7)	(4.7)
Total	40.1	—	.0	143.2	183.3	188.0	—	.0	188.0	.0	(4.7)	(4.7)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

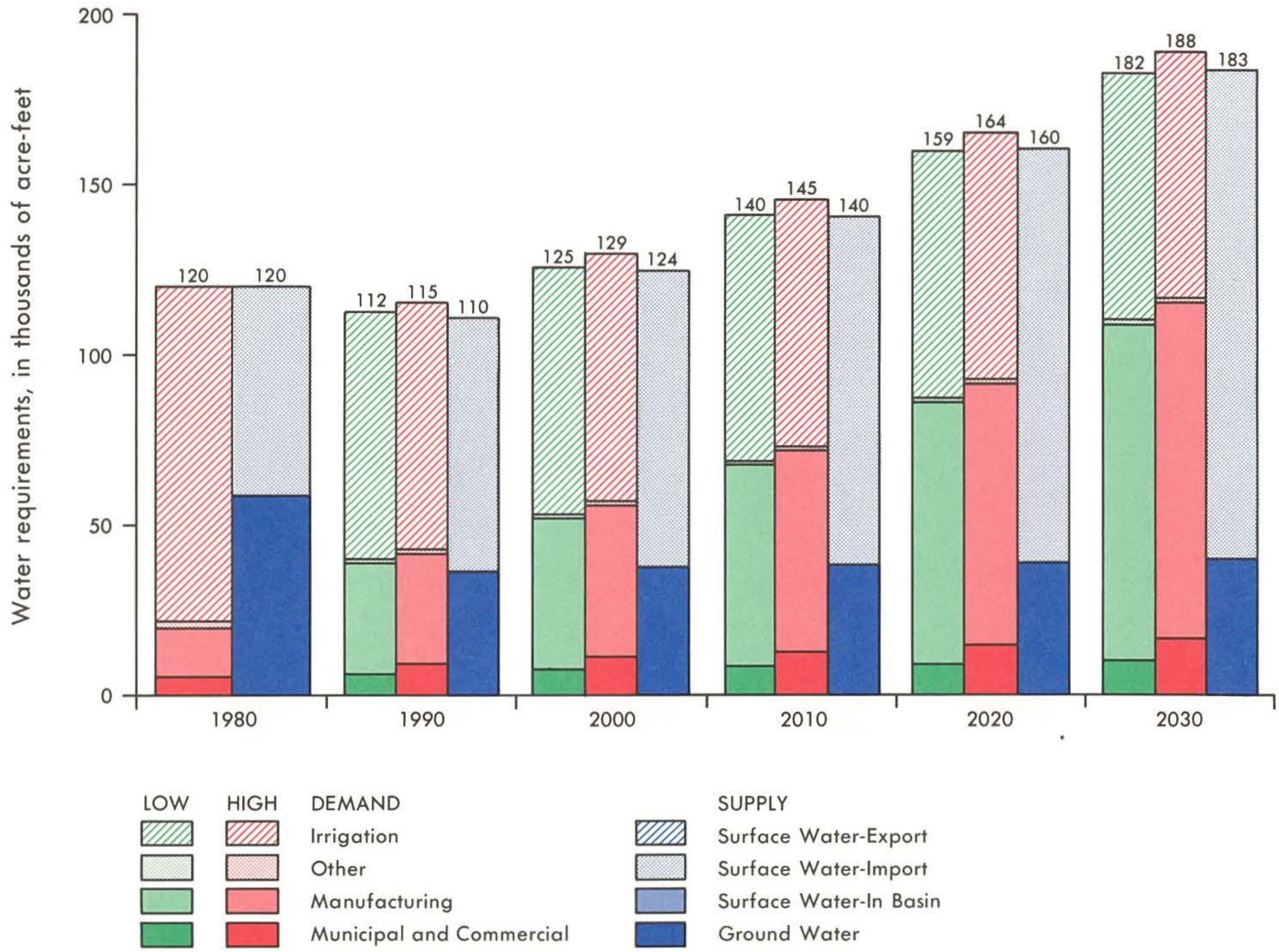

Figure III-17-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Lavaca-Guadalupe Coastal Basin, 1980-2030

18. GUADALUPE RIVER BASIN

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18. GUADALUPE RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Guadalupe River Basin is bounded on the north by the Colorado River Basin, on the east by the Lavaca River Basin and Lavaca-Guadalupe Coastal Basin, and on the west and south by the Nueces and San Antonio River Basins. Total basin drainage area is 6,070 square miles. Headwaters of the Guadalupe River form in southwestern Kerr County at an elevation of approximately 2,360 feet. The river flows easterly to Gonzales and then southeasterly into Guadalupe Bay, part of the San Antonio Bay system. The Blanco and San Marcos Rivers are the principal tributaries of the Guadalupe River. For planning purposes, the Guadalupe River Basin has been divided into two zones (Figure III-18-1).

Surface Water

The average annual runoff in the southern part of the basin during the period 1941-70 was 178 acre-feet per square mile. In the northeastern part of the basin, average annual runoff during the period 1960-71 was 236 acre-feet per square mile. West of Comfort, the average annual runoff was 123 acre-feet per square mile for the period 1940-71. The lowest runoff rate during the 1941-70 period was 22 acre-feet per square mile in 1956. Low runoff rates occurred during the droughts of 1950-56 and 1960-64, when average runoff was 84 and 88 acre-feet per square mile, respectively.

The Balcones Fault Zone, which crosses the basin in Hays and Comal Counties, is the dividing line between distinctly different flood-plain characteristics. Above the fault zone in the Edwards Plateau Region, stream slopes are steep, channels are narrow, and runoff is rapid from the sparsely vegetated, shallow, rocky soils. In the Coastal Plain below New Braunfels, the topography is gently rolling with wide, shallow flood plains. Deep soils, wooded terrain, and highly cultivated areas retard runoff of floodwaters. As the sharp-crested, high-velocity floods cross the fault zone and enter the coastal plain, peaks and velocities diminish rapidly.

Devastating floods are a perennial threat to this basin during the hurricane season, which extends from early June through the end of November. All of the basin is subject to widespread flooding from torrential rains that often accompany the invasion of a hurricane or tropical storm from the Gulf of Mexico.

Concentrations of dissolved solids in the upper part of the Guadalupe River Basin are generally less than 500 milligrams per liter (mg/l). Canyon Reservoir, on the main stem of the Guadalupe River, has dissolved-solids concentrations ranging from less than 200 mg/l to about 325 mg/l. Low flows of several streams in the lower part of the basin, particularly Peach Creek and Sandies Creek, contain relatively high concentrations of dissolved solids; however, floodflows are of good quality and the long-term discharge-weighted average dissolved-solids concentration of the Guadalupe River at Victoria is less than 300 mg/l.

Ground Water

The Edwards-Trinity (Plateau) Aquifer occurs in a small area in the northern part of the Guadalupe River Basin. Total thickness ranges up to about 500 feet. Most existing wells have low yields, but well yields of 250 to 500 gallons per minute (gpm) are possible where there is sufficient saturation in the limestones. The quality of water in the aquifer is good, generally containing less than 500 mg/l total dissolved solids.

The Trinity Group Aquifer also occurs in a small area in the northern part of the Guadalupe River Basin. Well yields range up to about 100 gpm. Water in the aquifer is generally fresh.

The Edwards (Balcones Fault Zone) Aquifer extends across Comal and Hays Counties in the north-central part of the Guadalupe River Basin. Thickness ranges from 400 to 500 feet. Yields of large-capacity wells average 1,500 gpm, but locally wells produce up to 3,000 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids.

The Carrizo-Wilcox Aquifer occurs in the central part of the Guadalupe River Basin. Total thickness ranges up to more than 2,000 feet. Yields of high-capacity wells average 500 gpm, but locally reach 1,500 gpm. Water in the aquifer generally contains less than 1,000 mg/l total dissolved solids.

The Gulf Coast Aquifer occurs over the entire southern part of the basin. The aquifer extends to a maximum depth of about 1,600 feet. Yields of large-capacity wells average 500 gpm, but locally reach 1,500 gpm. The water generally contains less than 1,000 mg/l total dissolved solids.

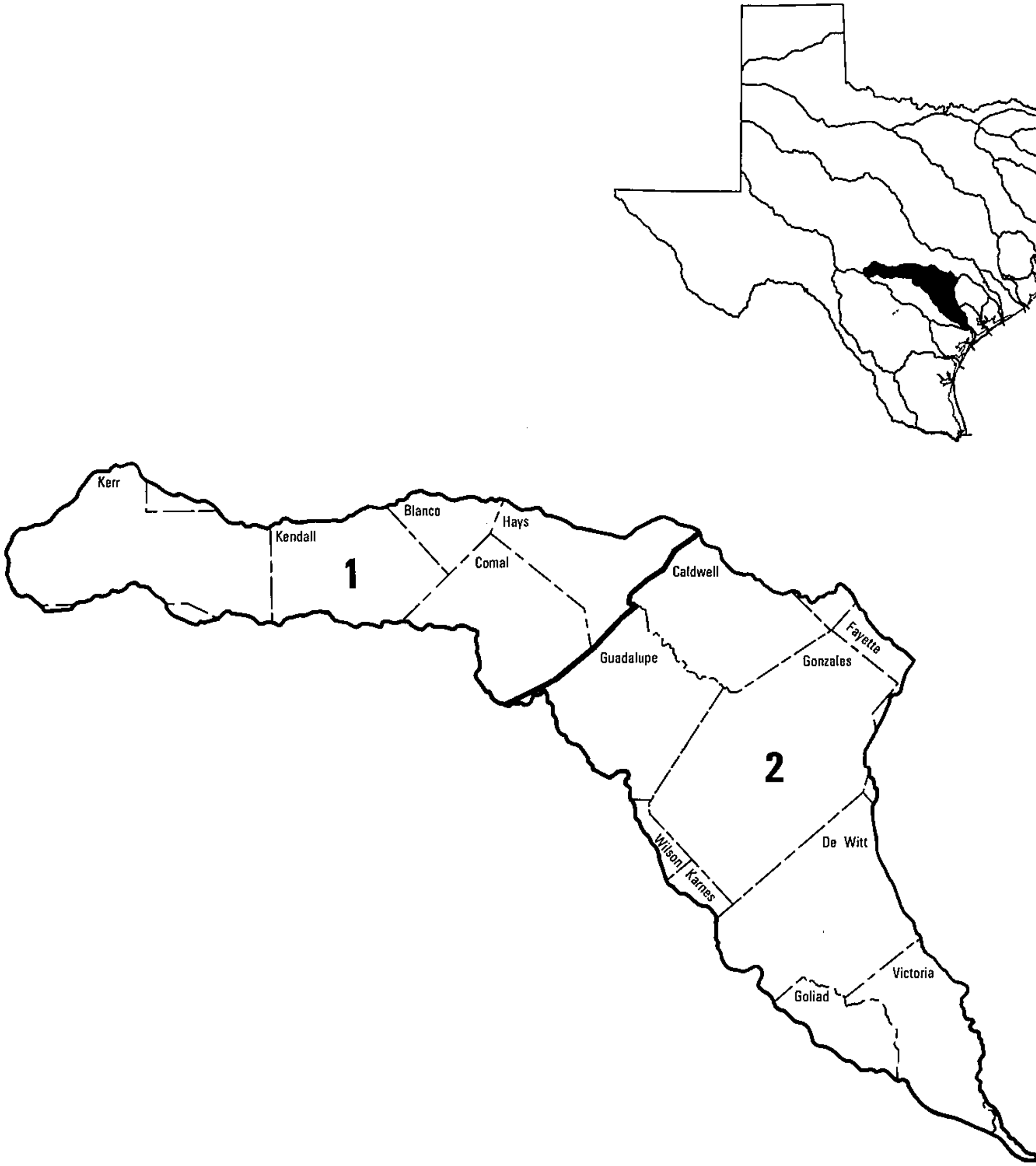

Figure III-18-1. Guadalupe River Basin and Zones

The Hickory Sandstone Aquifer occurs in a small area along the northern edge of the upper part of the Guadalupe River Basin. Total thickness averages about 400 feet. Only the downdip part of the aquifer extends into the Guadalupe River Basin. Few wells penetrate the Hickory Sandstone Aquifer in the basin, but in adjacent basins well yields range from 200 to 1,500 gpm. Water in the aquifer varies widely, containing from less than 3,000 to 10,000 mg/l total dissolved solids.

The Ellenburger-San Saba Aquifer also occurs along the northern edge of the Guadalupe River Basin. Only the most downdip portion of the aquifer extends into the Guadalupe River Basin. No wells are known to penetrate the aquifer in the basin; however, in adjacent basins the total thickness ranges up to about 1,000 feet and yields of large-capacity wells range up to 1,000 gpm.

The Queen City Aquifer occurs in a narrow band across the middle part of the Guadalupe River Basin. The aquifer has a maximum thickness of about 400 feet. Yields of large-capacity wells are generally less than 200 gpm, but locally reach a maximum of about 400 gpm. Water in the aquifer varies widely, containing from less than 1,000 to as much as 3,000 mg/l total dissolved solids.

The Sparta Aquifer occurs in a narrow band across the middle part of the Guadalupe River Basin. Maximum thickness is approximately 100 feet. Yields of most wells are less than 100 gpm, but properly constructed wells could produce higher yields. Water in the aquifer contains from less than 1,000 to about 3,000 mg/l total dissolved solids.

Over pumpage of the Trinity Group Aquifer in Comal and Hays Counties can cause gradual deterioration of ground-water quality because of saline-water encroachment. The same condition is true for the Carrizo-Wilcox Aquifer in eastern Wilson, northern Karnes, southern and eastern Gonzales, and western Fayette Counties within the basin. Saline-water encroachment adjacent to the downdip extents of these aquifers, as well as the Queen City and Sparta Aquifers, can be controlled by proper well location, completion, and pumpage.

The potential for saline-water encroachment may be very great in the Edwards (Balcones Fault Zone) Aquifer within the basin. Since the aquifer is composed of fractured and faulted limestones with locally unpredictable secondary porosity and permeability, it is impossible to define or predict with any accuracy the aquifer's flow system on a local basis. Of great importance is the aquifer's regional flow system which generally consists of major natural recharge (inflow) in the Nueces River Basin, movement of water in the subsurface artesian zone northeastward beneath the Nueces and San Antonio River Basins, and major natural discharge (outflow) of water at Comal and San Marcos Springs in the Guadalupe River Basin. At the aquifer's downdip extent under natural conditions, ground-water quality deteriorates rapidly across the fresh-saline water interface. Therefore, a very large amount of saline waters occurs immediately adjacent to and southeast of the fresh water-bearing deposits of the aquifer. During the drought of the 1950's when water level elevations were at historical lows and when amounts of ground-water withdrawals from the aquifer were large, no significant saline-water encroachment was detected. However, what will happen to the aquifer's water quality if water level elevations are lowered below the levels of the 1950's? Considering the aquifer's regional flow system, an extreme lowering of water levels below the 1950's level in the Nueces, San Antonio, and Guadalupe River Basins may cause a significantly large invasion of saline water which may contaminate not only the municipal, industrial, and irrigation freshwater supplies but also any reduced flows at Comal, San Marcos, and other springs which are located near the fresh-saline water interface of the aquifer.

In areas immediately adjacent to the Coast in Victoria County, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage.

Population and Economic Development

The 1980 population of the Guadalupe River Basin was reported to be 243.4 thousand. Victoria is the largest population center in the basin, with an in-basin population of 40 thousand, followed by San Marcos, New Braunfels, and Seguin.

The basin economy is fairly diversified. Oil and gas are produced in most counties, as well as sand, gravel, and clay. The area is heavily agricultural, primarily livestock and dairy products.

Water Use

Municipal water use in the Guadalupe River Basin totaled 44.3 thousand acre-feet in 1980. Forty-eight percent was used in Zone 1 and 52 percent was used in Zone 2. Twenty-five percent of the total municipal freshwater use was in rural areas or in cities of less than 1,000 population. Cities using significant portions of the total use were New Braunfels, San Marcos, Kerrville, Seguin, and Victoria. Victoria used 14 percent of the total basin use.

In 1980, manufacturing industries used 41.5 thousand acre-feet of freshwater. Most of the freshwater use (88 percent) originated in the lower part of the basin (Zone 2). Manufacturers of chemicals are the predominant users of water in Zone 2, and textile product manufacturers use relatively large quantities of water in Zone 1.

In 1980, there was 1,036 megawatts of installed steam-electric generating capacity in the Guadalupe River Basin. These power plants withdrew 2.2 thousand acre-feet of ground-water and consumed 18.4 thousand acre-feet of surface water (including 9.9 thousand acre-feet of estimated net evaporation). All plants are located in Zone 2.

A total of about 10.5 thousand acres was irrigated in the Guadalupe River Basin with about 10.7 thousand acre-feet of water in 1980. About 4.6 thousand acres was irrigated with ground water, and 5.9 thousand acres was irrigated with surface water. Zone 1 required 3.1 thousand acre-feet of water in 1980, while Zone 2 used 7.6 thousand acre-feet. About 4.5 thousand acre-feet of surface water was applied in Zone 2 of the basin. Most of the Zone 1 acreage is in scattered farms and fields along spring-fed streams of the Edwards Plateau area.

Mining industries in the Guadalupe River Basin used an estimated 1.1 thousand acre-feet of freshwater in 1980. Nonmetal mining operations (e.g., sand and gravel) accounted for almost all of the mining use in the basin, with Comal and Victoria Counties using approximately 99 percent of the total basin mining freshwater.

Livestock water use in the basin in 1980 totaled 9.0 thousand acre-feet, with 4.8 thousand acre-feet being surface water and 4.2 thousand acre-feet ground water. Zone 1 supplied 1.3 thousand acre-feet in 1980 from ground-water sources. Livestock water use in Zone 2 was 7.4 thousand acre-feet, with surface water supplying 4.5 thousand acre-feet and ground water 2.9 thousand acre-feet.

The upper portion of the Victoria Barge Canal and the turning basin are located in the Guadalupe River Basin. The canal which extends from the Gulf Intracoastal Waterway through the Lavaca-Guadalupe Coastal Basin requires approximately 7 thousand acre-feet per year of freshwater for periodic flushing and maintenance. Rainfall and localized runoff provides a substantial amount of freshwater to the barge canal. This inflow is generally sufficient to meet the flushing need.

There is 16.1 megawatts of hydroelectric generating capacity in the Guadalupe River Basin. These turbines are installed in a series of small impoundments located on the main stem in the reach between Canyon Dam and Victoria; specifically, Lake Dunlap (3.6 megawatts), Lake McQueeny (2.8 megawatts), Lake Placid (2.4 megawatts), Nolte (2.5 megawatts), H-4 Dam (2.4 megawatts), and H-5 Dam (2.4 megawatts). Other small units at Cuero and Gonzales are now being reactivated.

Return Flows

In 1980, municipal and manufacturing return flows in the Guadalupe River Basin totaled 44.1 thousand acre-feet. Return flows from Victoria County alone totaled 26 thousand acre-feet, of which nearly 18.2 thousand acre-feet was from industrial sources.

Irrigation return flows in 1980 totaled approximately 200 acre-feet in Zone 1. In Zone 2, irrigation return flows in 1980 totaled about 1.0 thousand acre-feet. Return flows from irrigation are reused in the lower part of the basin.

Current Ground-Water Development

In 1980, approximately 51.6 thousand acre-feet of ground water was used in the Guadalupe River Basin. Of this amount, 26.1 thousand acre-feet was used in Zone 1, and 25.5 thousand acre-feet in Zone 2. In Zone 1 in 1980, about 67 percent was used from the Edwards (Balcones Fault Zone) Aquifer, about 20 percent from the Edwards-Trinity (Plateau) Aquifer, and about 12 percent from the Trinity Group Aquifer. In Zone 2, about 68 percent of the ground water used was from the Gulf Coast Aquifer, and about 27 percent was from the Carrizo-Wilcox Aquifer.

Of the 51.6 thousand acre-feet of ground water used in the basin, approximately 35.8 thousand acre-feet or 69 percent was used for municipal purposes.

In 1980, no overdraft of ground water was evident in Zone 1. However, in Zone 2, overdrafts occurred in Fayette and Victoria Counties due to withdrawals of ground water from the Gulf Coast Aquifer, primarily for municipal purposes.

Current Surface-Water Development

Canyon Lake, located in Comal County on the Guadalupe River, is a multipurpose project, providing flood control, water conservation and supply, and recreation. The project was constructed and is operated by the U.S. Army Corps of Engineers. The Guadalupe-Blanco River Authority (GBRA) has acquired the conservation storage (386.2 thousand acre-feet) in the project and currently holds a permit from the Texas Water Rights Commission to divert up to 50 thousand acre-feet of water annually from the reservoir.

The six small hydroelectric power dams in Zone 2 on the Guadalupe River between New Braunfels and the confluence with the San Marcos River are owned and operated by the GBRA. Three of these projects, McQueeney, Dunlap and H-4, have storage capacities greater than 5,000 acre-feet. Releases of water from flood-control storage in Canyon Lake, runoff below Canyon Lake, and flows from Comal Springs provide water for hydroelectric power generation at these facilities. No releases are made from conservation storage in Canyon Lake for hydroelectric purposes. Supplies from the lower basin (Zone 2) are presently diverted to the adjacent Lavaca-Guadalupe Coastal Basin through the GBRA Calhoun County Canal System under existing permits.

The GBRA operates Coleto Creek Reservoir, located in Victoria and Goliad Counties, as a cooling pond for the steam-electric plant being constructed by Central Power and Light Company. The reservoir contains approximately 35,000 acre-feet of storage at normal elevation. It is anticipated as the power plant expands, a channel dam will be constructed across the Guadalupe River to divert releases from Canyon Reservoir.

Also, the GBRA operates a salt-water barrier located below the confluence of the San Antonio and Guadalupe Rivers. This dam prevents salt-water intrusion upstream and allows diversion of river flows into the Calhoun Canal System. Consequently, the dam is important to basin development and operation.

Water Rights

The total amount of surface water authorized or claimed for diversion and use in the Guadalupe River Basin was 11,874,970 acre-feet as of December 31, 1983 (Table III-18-1). Zone 2 accounted for over 94 percent of total basin rights including almost 10.3 million acre-feet to be used for hydroelectric use. Of the basin total, hydroelectric uses were 90 percent (Table III-18-2). Hydroelectric power is generated by run-of-the-river water or water released from reservoir storage for other downstream uses. Hydroelectric use is nonconsumptive and the figure attributed to hydroelectric use is obtained by accumulating the use of water through each successive hydroelectric plant.

Water Quality

The Guadalupe River Basin is characterized by generally high quality water throughout; however, localized problems occur. Between New Braunfels and Gonzales, the Guadalupe River experiences prolific growths of rooted aquatic vegetation. Because of the intensity of recreational development in the area and use of Guadalupe River flows for domestic water supply, this problem is being closely monitored by the Texas Department of Water Resources.

Table III-18-1. Authorized or Claimed Amount of Water, by Type of Right, Guadalupe River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	110	10,065,626
Claims	141	202,966
Certified Filings	26	1,597,182
Certificates of Adjudication	148	9,197
Total Authorizations and Claims	425	11,874,970

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

Table III-18-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Guadalupe River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	31	41,325	12,163	53,488
Industrial	23	160,936	811,931	972,867
Irrigation[2]	335	13,106	101,435	114,541
Mining	5	1,353	60	1,413
Hydroelectric	8	470,580	10,251,431	10,722,011
Recreation	48	8,399	2,251	10,650
Total	425[1]	695,699	11,179,271	11,874,970

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include an authorized diversion of 9,676 acre-feet/year from a saline source.

Flooding, Drainage, and Subsidence

Floods in the Guadalupe River Basin over the past 10 years have been extremely damaging. Although numerous floods occurred prior to 1965, the only reliable estimates of flood damages are for the 1957 flood. Basin-wide flood damages to agriculture were estimated to be in excess of $3 million, and nonagricultural damages exceeded $160 thousand.

In May 1965, a flood on the Guadalupe River caused $932 thousand in agricultural damages from New Braunfels downstream to the mouth of the river. Nonagricultural damages were heavy in Gonzales and Victoria. Total estimated nonagricultural damages were $82 thousand.

The floods of 1967 and 1968 caused extensive damage in the lower Guadalupe River Basin from Gonzales to the Coast, with an estimated $4.9 million in total damages.

The May 1972 flood was the most devastating flood of record in the Guadalupe River Basin. The flood caused an estimated $4.1 million in damages to nonagricultural properties outside of urban areas. New Braunfels suffered severe urban damages estimated to have exceeded $9.1 million. Total combined damages from the 1972 flood were estimated as approximately $14.7 million.

Floods in 1973 and 1975 caused total estimated damages near $5.8 million.

Hurricane flood damages in the lower basin have resulted in two Presidential disaster declarations. Victoria County was one of 14 counties included in the disaster declaration as a consequence of Hurricane Carla in 1961. Heavy damage from Hurricane Beulah in 1967 necessitated that DeWitt, Victoria, and Gonzales Counties be included in a 26-county disaster declaration. Other areas within the Guadalupe River Basin which were declared disaster areas by the President due to flooding included Hays County in May 1970 and Caldwell, Comal, Gonzales, Guadalupe, and Hays Counties in May 1972.

Tropical Storm Amelia, in August 1978, produced record flood levels on many streams in the upper basin. A Presidential disaster declaration brought more than $3.1 million in federal relief. Fifty-six flood insurance claims were filed for $378 thousand in flood damages. During 1981, major flooding in San Marcos pushed basin flood insurance claims to 197 for a total of $2.1 million in flood damages.

The Federal Emergency Management Agency has designated 17 cities as having one or more flood-prone areas within their respective boundaries. Urgent need for flood insurance coverage has led to 15 cities adopting flood-plain management standards for participation in the National Flood Insurance Program. Eight counties have also chosen to participate in the program. Detailed flood insurance rate studies have been completed for 12 basin cities and 4 counties. All are participants in the Regular Phase. A study for Caldwell County is nearing completion. Flood-plain maps showing areas subject to inundation by the 100-year flood are available for the incorporated cities. Work is underway to identify and map the flood plain in the unincorporated areas of the county. Detailed flood maps with expected 100-year flood surface elevations are available in areas where flood insurance studies have been completed.

Drainage problems in the Guadalupe River Basin are confined largely to the Rio Grande Plain and the Coastal Prairie land-resource areas. The Rio Grande Plain is characterized by poorly defined channels which do not have sufficient capacities to carry large volumes of storm runoff. The flat topography of the Coastal Prairie and relatively impermeable soils make artificial surface channels necessary to remove excess rainfall.

The amount and distribution of subsidence in the coastal areas of the Guadalupe River Basin are unknown. The potential for subsidence and active faulting in the Kay Creek and McFaddin North Oil Fields exists in southern Victoria County. However, the subsidence associated with petroleum and related saline-water withdrawals in these fields is probably less than 0.5 foot.

Recreation Resources

Canyon Lake, with 8.2 thousand surface acres, is the only major reservoir in Zone 1, but it provides 64 percent of the total surface area in the Guadalupe River Basin available for flat-water recreation purposes. Lake Dunlap (400 surface acres), Lake McQueeney (400 surface acres), and H-4 Lake (700 surface acres), all in Zone 2, provide additional flat-water recreation opportunities. The Corps of Engineers reported over 1.3 million visitors at Canyon Lake in 1980. The Corps manages seven parks totaling 1,401 land acres adjacent to the lake. The recently completed Coleto Creek Lake will provide 3.1 thousand acres for flat-water recreation in Zone 2. In addition to the flat-water recreation opportunities available in the basin, canoeing on the Guadalupe River is a very popular recreation activity in the basin. The extensive recreation opportunities available by developments at Comal Springs and San Marcos Springs are virtually unique in Texas.

PROJECTED WATER REQUIREMENTS

Population Growth

Population of the Guadalupe River Basin is expected to more than double between 1980 and 2030 (Table III-18-3). A 56 percent rise is projected between 1980 and 2000, and 58 percent between 2000 and 2030.

Although Victoria County has the largest percentage of the total basin population and is expected to double in size, its share of the basin population should drop slightly. The largest increase, an estimated 357 percent, should occur in Hays County, the second most populous county in the basin in 1980. By 2030, it should be the most populous, with 25.1 percent of the basin population.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Guadalupe River Basin are projected to increase from the 1980 level of 44.3 thousand acre-feet by a projected maximum of 97 percent by the year 2000. In the year 2030, water requirements are projected to range from 83.9 to 139.3 thousand acre-feet. Zone 1 is projected to account for 52 to 54 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 57 to 59 percent of the total.

A range of 27.5 to 40.1 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000.

Industrial

Manufacturing water requirements in 1980 were 41.5 thousand acre-feet in the Guadalupe River Basin. Projections of future water requirements for manufacturing purposes were made by decade. Low and high case projections were made for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Guadalupe River Basin are projected to increase more than four times by the year 2030, to a potential high of 205.7 thousand acre-feet. The rate of change projected for manufacturing freshwater requirements in the Guadalupe River Basin is 396 percent, compared to 230 percent for the State by the year 2030.

In 1980, 88 percent of total basin manufacturing water use occurred in Zone 2. Because of the increase in water requirements projected for Victoria County, this figure should reach 93 percent by 2030. In 2030, the production of industrial organic chemicals will dominate Victoria County's industrial freshwater requirements.

Steam-Electric Power Generation

Steam-electric power generating capacity in the Guadalupe River Basin is projected to expand rapidly by 53 percent to the year 2000, and then expand more slowly between 2000 and 2030. One of the major projects in the basin is the Coleto Creek coal-fired plant near Victoria, which will have an ultimate capacity of 1,100 megawatts. Unit Number 2 of the Coleto Creek Power Station with a capacity of 720 megawatts is scheduled for commercial operation in 1990.

The projections show that water consumption will approach 31.6 thousand acre-feet annually by the year 2000. By 2030, water consumption is projected to be 37 thousand acre-feet annually (Table III-18-3).

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables, but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects the demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water

Table III-18-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Guadalupe River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			102.5			145.2			194.4			246.9			290.7			333.7
Municipal	20.3	0.9	21.2	26.2	8.1	34.3	34.9	12.1	47.0	31.5	28.5	60.0	33.6	37.5	71.1	36.1	45.7	81.8
Manufacturing	2.4	2.7	5.1	2.1	3.9	6.0	2.9	4.7	7.6	3.0	6.3	9.3	3.2	8.7	11.9	3.4	11.5	14.9
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.9	0.0	0.9	1.1	0.0	1.1	1.4	0.0	1.4	1.6	0.0	1.6	1.8	0.0	1.8	2.1	0.0	2.1
Irrigation	1.2	1.9	3.1	0.2	2.3	2.5	0.3	2.2	2.5	0.2	2.4	2.6	0.2	2.4	2.6	0.2	2.4	2.6
Livestock	1.3	0.3	1.6	1.6	0.3	1.9	1.7	0.4	2.1	1.7	0.4	2.1	1.7	0.4	2.1	1.7	0.4	2.1
Zone Total Water	26.1	5.8	31.9	31.2	14.6	45.8	41.2	19.4	60.6	38.0	37.6	75.6	40.5	49.0	89.5	43.5	60.0	103.5
Zone 2																		
Population			140.9			168.0			185.0			203.3			232.4			266.0
Municipal	15.5	7.6	23.1	14.7	20.9	35.6	14.3	25.8	40.1	16.4	27.6	44.0	17.5	32.8	50.3	18.4	39.1	57.5
Manufacturing	1.8	34.6	36.4	1.2	58.4	59.6	1.4	83.3	84.7	1.5	112.0	113.5	1.7	146.3	148.0	1.9	188.9	190.8
Steam Electric	2.2	18.4	20.6	2.0	24.6	26.6	2.0	29.6	31.6	2.0	31.4	33.4	2.0	33.2	35.2	2.0	35.0	37.0
Mining	0.0	0.2	0.2	0.1	0.3	0.4	0.2	0.3	0.5	0.1	0.4	0.5	0.1	0.4	0.5	0.0	0.5	0.5
Irrigation	3.1	4.5	7.6	1.3	6.2	7.5	1.3	6.3	7.6	1.3	6.3	7.6	1.3	6.3	7.6	1.3	6.3	7.6
Livestock	2.9	4.5	7.4	2.7	6.0	8.7	2.8	7.2	10.0	2.8	7.2	10.0	2.5	7.5	10.0	2.6	7.4	10.0
Zone Total Water	25.5	69.8	95.3	22.0	116.4	138.4	22.0	152.5	174.5	24.1	184.9	209.0	25.1	226.5	251.6	26.2	277.2	303.4
BASIN TOTALS																		
Population			243.4			313.2			379.4			450.2			523.1			599.7
Municipal	35.8	8.5	44.3	40.9	29.0	69.9	49.2	37.9	87.1	47.9	56.1	104.0	51.1	70.3	121.4	54.5	84.8	139.3
Manufacturing	4.2	37.3	41.5	3.3	62.3	65.6	4.3	88.0	92.3	4.5	118.3	122.8	4.9	155.0	159.9	5.3	200.4	205.7
Steam Electric	2.2	18.4	20.6	2.0	24.6	26.6	2.0	29.6	31.6	2.0	31.4	33.4	2.0	33.2	35.2	2.0	35.0	37.0
Mining	0.9	0.2	1.1	1.2	0.3	1.5	1.6	0.3	1.9	1.7	0.4	2.1	1.9	0.4	2.3	2.1	0.5	2.6
Irrigation	4.3	6.4	10.7	1.5	8.5	10.0	1.6	8.5	10.1	1.5	8.7	10.2	1.5	8.7	10.2	1.5	8.7	10.2
Livestock	4.2	4.8	9.0	4.3	6.3	10.6	4.5	7.6	12.1	4.5	7.6	12.1	4.2	7.9	12.1	4.3	7.8	12.1
Zone Total Water	51.6	75.6	127.2	53.2	131.0	184.2	63.2	171.9	235.1	62.1	222.5	284.6	65.6	275.5	341.1	69.7	337.2	406.9

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Guadalupe River Basin are projected to decrease from the 1980 level of 10.7 thousand acre-feet by a projected maximum 36 percent by the year 2000 in the high case. In the year 2030, water requirements in the basin are projected to be 10.2 thousand acre-feet annually in the high case to irrigate about 10.5 thousand acres.

Zone 1 is projected to account for about 25 percent of total basin irrigation requirements in 2000 and 2030. Zone 2 is projected to account for about 75 percent of the total in the high case.

In Zone 2, 7.6 thousand acre-feet of irrigation water requirements is projected in 2000 and 2030.

Livestock

Livestock water needs in the basin are projected to increase from 9 thousand acre-feet in 1980 to 12.1 thousand acre-feet by 2030. In Zone 1, livestock water uses required 18 percent of the basin total livestock water need in 1980.

Mining

Mining water use in the Guadalupe River Basin is projected to total 2.6 thousand acre-feet annually in the year 2030. Nonmetal mining requirements are expected to more than double by 2030. The remainder of the basin's mining freshwater requirements will be used in the recovery of petroleum and natural gas.

Navigation

No additional freshwater requirement is anticipated for navigation other than that needed to maintain the Victoria Barge Canal.

Hydroelectric Power

Currently, there is 16.1 megawatts of installed capacity in the Guadalupe River Basin, including several units which are being reactivated. A substantial addition of hydroelectric capacity is planned for the basin based on studies by the Guadalupe-Blanco River Authority in cooperation with the Guadalupe Valley Electric Cooperative, DeWitt County Electric Cooperative, and New Braunfels Utilities. A 6,070-kilowatt hydroelectric unit is proposed for installation at Canyon Dam, and eight low-head hydroelectric plants are proposed in Guadalupe, Gonzales, DeWitt, and Victoria Counties with an aggregate capacity of 13,070 kilowatts. These proposed hydroelectric plants will have no effect on Canyon Lake operations for water supply purposes and will have no effect on the flows of the Guadalupe River.

Estuarine Freshwater Inflows

The Guadalupe River discharges into the Guadalupe estuary. Gaged freshwater inflows to meet marsh inundation and salinity needs for the Subsistence Alternative are estimated at 1.24 million acre-feet per year from the Guadalupe River Basin. In addition, 250 thousand acre-feet per year of ungaged inflow from the basin is needed for this alternative level (Table III-18-4). The estimated annual inflows to maintain commercial fishery harvests in the estuary (Harvest Maintenance Alternative) at no less than the average 1962 through 1976 harvests total 1.62 million acre-feet, with an additional 317 thousand acre-feet needed from ungaged portions of the basin (Table III-18-4). It is also established that the Fisheries Harvest Enhancement Alternative objective of maximizing the shrimp production in the estuary requires volumes of water from the Guadalupe River Basin equal to the annual inflow limit set at the average annual gaged inflow for the period 1941-1976. The gaged inflow need is approximately 1.8 million acre-feet from the basin (Table III-18-4). The ungaged inflow is estimated at 353 thousand acre-feet annually from the Guadalupe River Basin. Since the estimated inflow need equals the upper limit on inflow analyzed in this study, it is likely that additional freshwater inflow (consistent with salinity and marsh inundation limits) will increase the predicted shrimp harvest. An estimated 754 thousand acre-feet per year of gaged inflow from the Guadalupe River Basin is needed for the Biotic Species Viability Alternative in order to maintain salinities within the viability limits for organisms in the Guadalupe estuarine system (Table III-18-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Guadalupe River Basin to the year 2030 is 130.1 thousand acre-feet with the following amounts annually

Table III-18-4. Gaged River Inflow Needs of the Guadalupe Estuary Under Four Alternative Levels of Fisheries Productivity[1]

	Guadalupe River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability
January	86.4	116.4	279.6	42.8
February	96.2	136.9	196.8	47.5
March	80.3	111.6	156.5	56.2
April	134.1	162.2	152.4	83.8
May	138.1	255.8	240.6	82.4
June	104.0	193.5	182.1	59.2
July	57.6	57.6	57.6	45.6
August	80.6	80.6	80.6	59.5
September	207.8	207.8	207.8	109.5
October	104.0	104.0	118.1	75.0
November	76.9	101.4	76.9	42.4
December	76.5	91.9	76.5	50.3
Annual	1,240.7	1,619.7	1,825.5	754.2

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Combined gaged streamflow of Guadalupe River at Victoria and San Antonio River near Goliad.

available by aquifer: 42.9 thousand acre-feet from the Carrizo-Wilcox Aquifer, 38.2 thousand acre-feet from the Edwards (Balcones Fault Zone) Aquifer, 21.0 thousand acre-feet from the Gulf Coast Aquifer, 20.0 thousand acre-feet from the Sparta Aquifer, and 8.0 thousand acre-feet from the Queen City Aquifer. Annual amounts of yield for the Edwards-Trinity (Plateau) and Trinity Group Aquifers within the basin were not included because extensive withdrawals of natural recharge and recoverable storage from these aquifers would deplete available surface-water supplies and adversely affect recharge to the Edwards (Balcones Fault Zone) Aquifer. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual effective recharge of 38.6 thousand acre-feet per year. This reduction decreases the total ground-water availability within the basin in 2030 to 125.8 thousand acre-feet per year.

The projected annual ground-water use within the Guadalupe River Basin by decade from 1990 through 2030 is expected to be from 53.2 to 69.7 thousand acre-feet per year (Table III-18-3). The approximate average annual projected ground-water use within the basin is expected to be about 62.7 thousand acre-feet per year. Of the 62.7 thousand acre-feet of average annual projected use, about 54 percent is expected to be from the Edwards (Balcones Fault Zone) Aquifer, 18 percent from the Gulf Coast Aquifer, and 17 percent from the Carrizo-Wilcox Aquifer.

Surface-Water Availability and Proposed Development

Using only existing water supply sources, the Guadalupe River Basin is projected to experience water shortages by 1990. However, the proposed water development projects for this basin are projected to supply sufficient surface water to meet all anticipated surface-water needs, except irrigation, through 2030 (Table III-18-5, Figure III-18-2).

Zone 1

With existing and proposed supplies, a surface-water surplus in the year 2030 of 14.5 thousand acre-feet per year is estimated for Zone 1 of the basin (Table III-18-6, Figure III-18-3). This surplus is available for municipal and industrial purposes. Total surface water supplied to the zone is projected to be 58.3 thousand acre-feet per year in 2000 and 101.1 thousand acre-feet per year in 2030.

Table III-18-5. Water Resources of the Guadalupe River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	53.2	—	—	—	53.2	53.2	—	—	53.2	.0	.0	.0
Surface Water	240.8	—	27.0	.0	267.8	114.4	—	67.3	181.7	86.5	(.4)	86.1
Total	294.0	—	27.0	.0	321.0	167.6	—	67.3	234.9	86.5	(.4)	86.1
2000												
Ground Water	63.2	—	—	—	63.2	63.2	—	—	63.2	.0	.0	.0
Surface Water	400.8	—	34.1	.0	434.9	153.1	—	150.4	303.5	132.9	(1.5)	131.4
Total	464.0	—	34.1	.0	498.1	216.3	—	150.4	366.7	132.9	(1.5)	131.4
2010												
Ground Water	62.1	—	—	—	62.1	62.1	—	—	62.1	.0	.0	.0
Surface Water	443.6	—	42.7	.0	486.3	203.6	—	223.6	427.2	60.7	(1.6)	59.1
Total	505.7	—	42.7	.0	548.4	265.7	—	223.6	489.3	60.7	(1.6)	59.1
2020												
Ground Water	65.6	—	—	—	65.6	65.6	—	—	65.6	.0	.0	.0
Surface Water	494.6	—	51.3	.0	545.9	256.7	—	224.9	481.6	65.9	(1.6)	64.3
Total	560.2	—	51.3	.0	611.5	322.3	—	224.9	547.2	65.9	(1.6)	64.3
2030												
Ground Water	69.7	—	—	—	69.7	69.7	—	—	69.7	.0	.0	.0
Surface Water	494.6	—	61.9	.0	556.5	318.2	—	224.7	542.9	15.2	(1.6)	13.6
Total	564.3	—	61.9	.0	626.2	387.9	—	224.7	612.6	15.2	(1.6)	13.6

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
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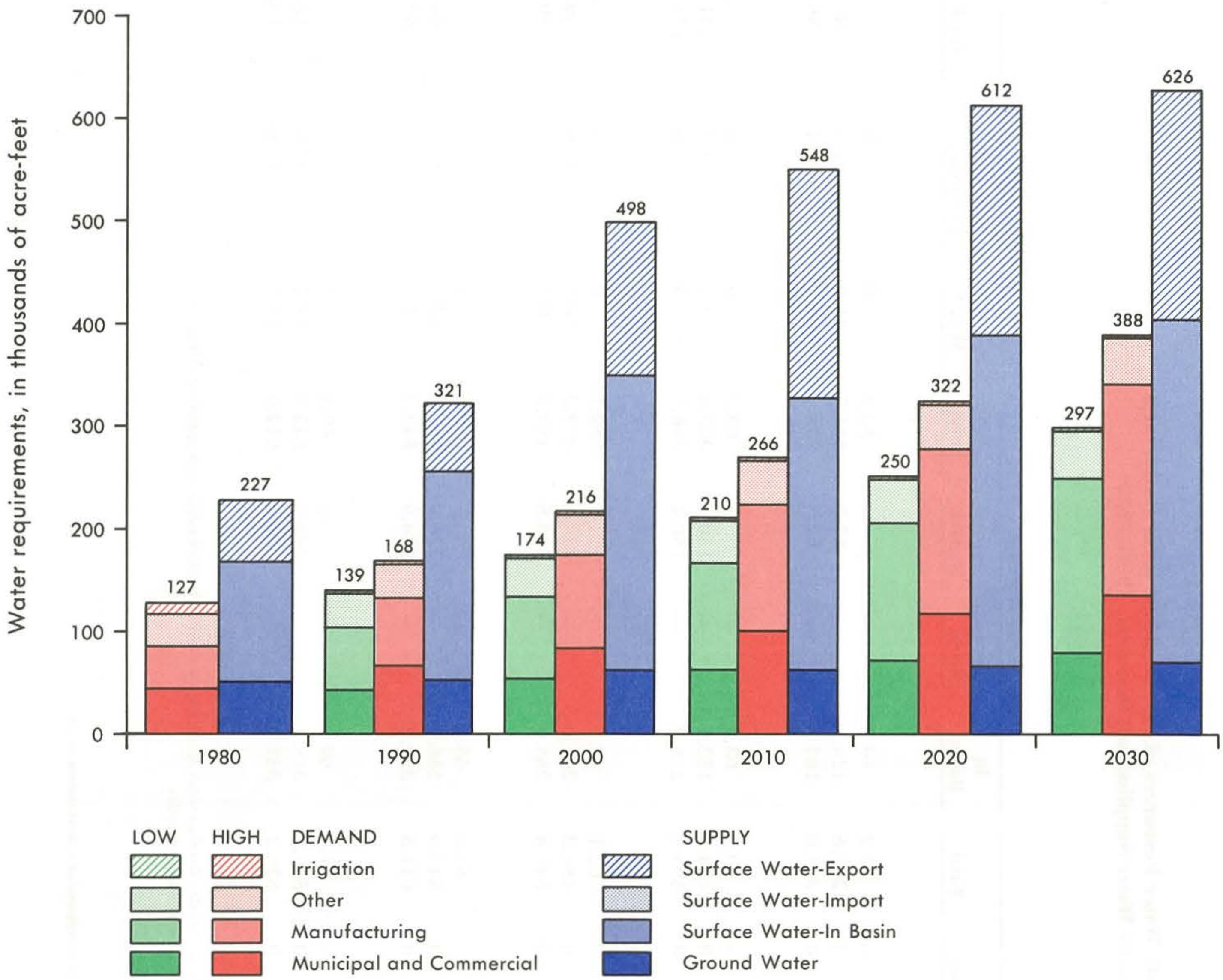

Figure III-18-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Guadalupe River Basin, 1980-2030

Although the entire zone has a net water surplus in 1990 with only existing reservoirs, surface-water shortages are projected for municipal purposes in areas upstream of Canyon Lake. It is anticipated that before the year 1990, Ingram Reservoir, or an equivalent project, will need to be constructed upstream from Canyon Lake. Ingram Reservoir will provide a dependable yield of 8.3 thousand acre-feet annually to supplement ground-water supplies for meeting projected municipal and manufacturing requirements in the Kerrville area.

The Guadalupe-Blanco River Authority and Upper Guadalupe River Authority have made a joint study of surface-water and ground-water development to meet the requirements of the Upper Guadalupe River Basin in Kerr, Kendall, and Comal Counties. Generally, the study concluded that an off-channel reservoir which could store water pumped from the Guadalupe River during periods of high flow would meet the requirements of Kerr County in the most cost effective manner. Also, the requirements of Kendall County and that portion of Comal County above Canyon Lake could be met by diversion from the Guadalupe River with some off-channel storage as needed. Further efforts by local interests will be necessary to implement this project, which would be an alternative to Ingram Reservoir.

Table III-18-6. Water Resources of the Guadalupe River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	31.2	—	—	—	31.2	31.2	—	—	31.2	.0	.0	.0
Surface Water	58.3	.0	.0	.0	58.3	8.2	12.9	10.4	31.5	27.2	(.4)	26.8
Total	89.5	.0	.0	.0	89.5	39.4	12.9	10.4	62.7	27.2	(.4)	26.8
2000												
Ground Water	41.2	—	—	—	41.2	41.2	—	—	41.2	.0	.0	.0
Surface Water	58.3	.0	.0	.0	58.3	12.2	14.6	11.5	38.3	20.3	(.3)	20.0
Total	99.5	.0	.0	.0	99.5	53.4	14.6	11.5	79.5	20.3	(.3)	20.0
2010												
Ground Water	38.0	—	—	—	38.0	38.0	—	—	38.0	.0	.0	.0
Surface Water	101.1	.0	.0	.0	101.1	30.4	15.2	13.6	59.2	42.3	(.4)	41.9
Total	139.1	.0	.0	.0	139.1	68.4	15.2	13.6	97.2	42.3	(.4)	41.9
2020												
Ground Water	40.5	—	—	—	40.5	40.5	—	—	40.5	.0	.0	.0
Surface Water	101.1	.0	.0	.0	101.1	42.1	17.6	14.9	74.6	26.9	(.4)	26.5
Total	141.6	.0	.0	.0	141.6	82.6	17.6	14.9	115.1	26.9	(.4)	26.5
2030												
Ground Water	43.5	—	—	—	43.5	43.5	—	—	43.5	.0	.0	.0
Surface Water	101.1	.0	.0	.0	101.1	52.9	19.0	14.7	86.6	14.9	(.4)	14.5
Total	144.6	.0	.0	.0	144.6	96.4	19.0	14.7	130.1	14.9	(.4)	14.5

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
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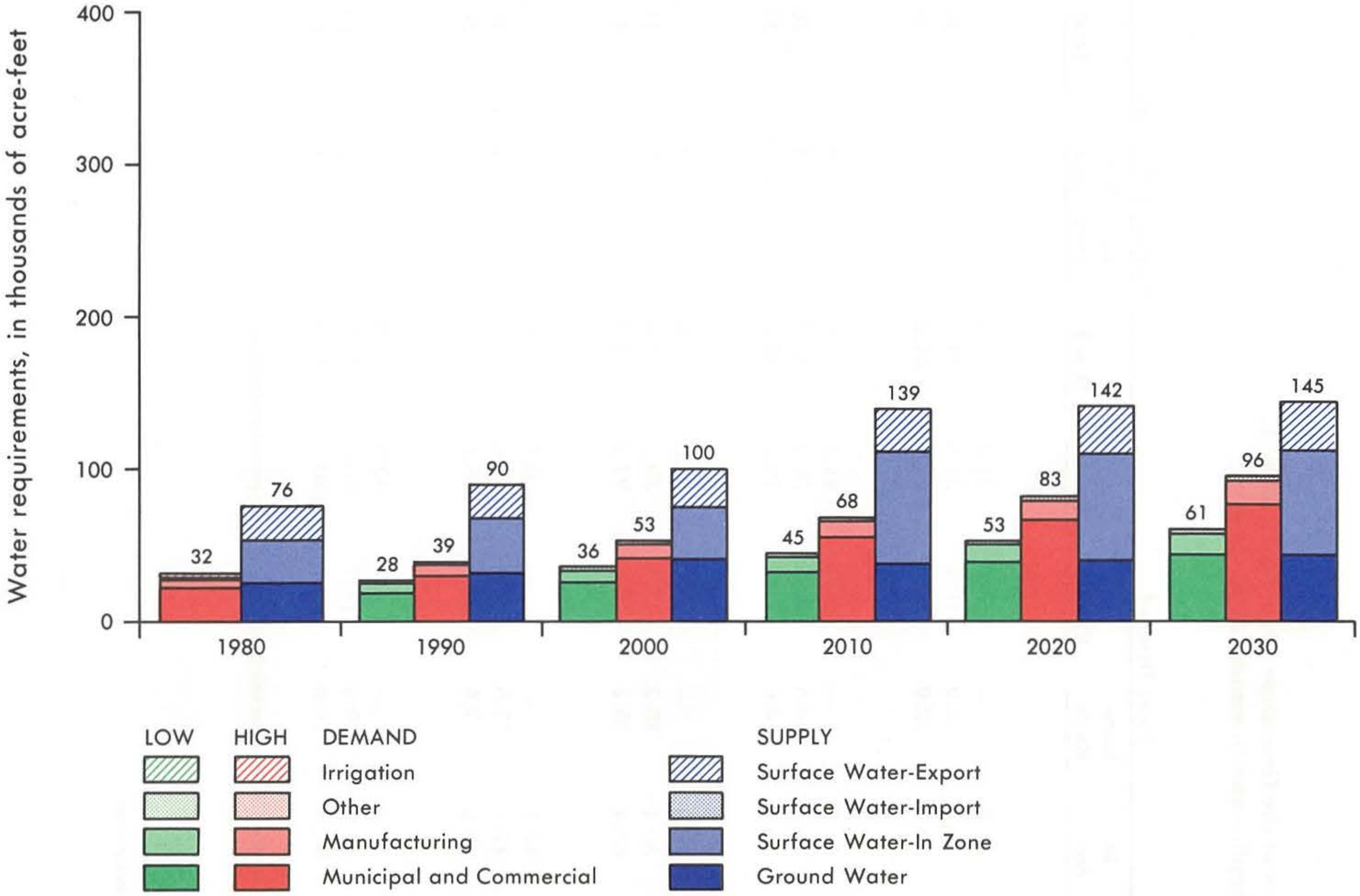

Figure III-18-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Guadalupe River Basin, Zone 1, 1980-2030

By the year 2010, projected surface-water needs in Zone 1 of the basin are projected to require additional surface-water supplies for Hays County municipal and manufacturing water needs to supplement ground-water supplies from the Edwards (Balcones Fault Zone) Aquifer. An alternative for meeting these needs is construction of the Cloptin Crossing Reservoir on the Blanco River by 2010. Cloptin Crossing Reservoir could meet anticipated needs in the upper basin through the year 2030. Cloptin Crossing, as authorized by Congress, will provide a dependable yield of 42.8 thousand acre-feet annually.

Lockhart Reservoir is an alternative source of surface water to provide supplemental municipal supplies for the City of Lockhart. Lockhart presently obtains its municipal supplies from the Carrizo-Wilcox Aquifer. Ground water in this area is of inferior quality and is highly corrosive. Lockhart Reservoir will provide a dependable yield of about 6.4 thousand acre-feet annually, which is sufficient to meet the projected needs of this area for the foreseeable future.

Zone 2

In Zone 2 of the basin, projected water requirements for all purposes other than irrigation can be met from the present through the year 2030 with supplies from existing and proposed surface-water projects (Table III-18-7, Figure III-18-4). An irrigation shortage of 1.2 thousand acre-feet per year occurs in year 2030 as a result of localized limited ground-water availability. In 2030, approximately 19.0 thousand acre-feet of the total 474.4 thousand acre-feet of available surface-water supply could be provided by sources in Zone 1 of the basin.

Table III-18-7. Water Resources of the Guadalupe River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	22.0	—	—	—	22.0	22.0	—	—	22.0	.0	.0	.0
Surface Water	182.5	12.9	27.0	.0	222.4	106.2	.0	56.9	163.1	59.3	.0	59.3
Total	204.5	12.9	27.0	.0	244.4	128.2	.0	56.9	185.1	59.3	.0	59.3
2000												
Ground Water	22.0	—	—	—	22.0	22.0	—	—	22.0	.0	.0	.0
Surface Water	342.5	14.6	34.1	.0	391.2	140.9	.0	138.9	279.8	112.6	(1.2)	111.4
Total	364.5	14.6	34.1	.0	413.2	162.9	.0	138.9	301.8	112.6	(1.2)	111.4
2010												
Ground Water	24.1	—	—	—	24.1	24.1	—	—	24.1	.0	.0	.0
Surface Water	342.5	15.2	42.7	.0	400.4	173.2	.0	210.0	383.2	18.4	(1.2)	17.2
Total	366.6	15.2	42.7	.0	424.5	197.3	.0	210.0	407.3	18.4	(1.2)	17.2
2020												
Ground Water	25.1	—	—	—	25.1	25.1	—	—	25.1	.0	.0	.0
Surface Water	393.5	17.6	51.3	.0	462.4	214.6	.0	210.0	424.6	39.0	(1.2)	37.8
Total	418.6	17.6	51.3	.0	487.5	239.7	.0	210.0	449.7	39.0	(1.2)	37.8
2030												
Ground Water	26.2	—	—	—	26.2	26.2	—	—	26.2	.0	.0	.0
Surface Water	393.5	19.0	61.9	.0	474.4	265.3	.0	210.0	475.3	.3	(1.2)	(.9)
Total	419.7	19.0	61.9	.0	500.6	291.5	.0	210.0	501.5	.3	(1.2)	(.9)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

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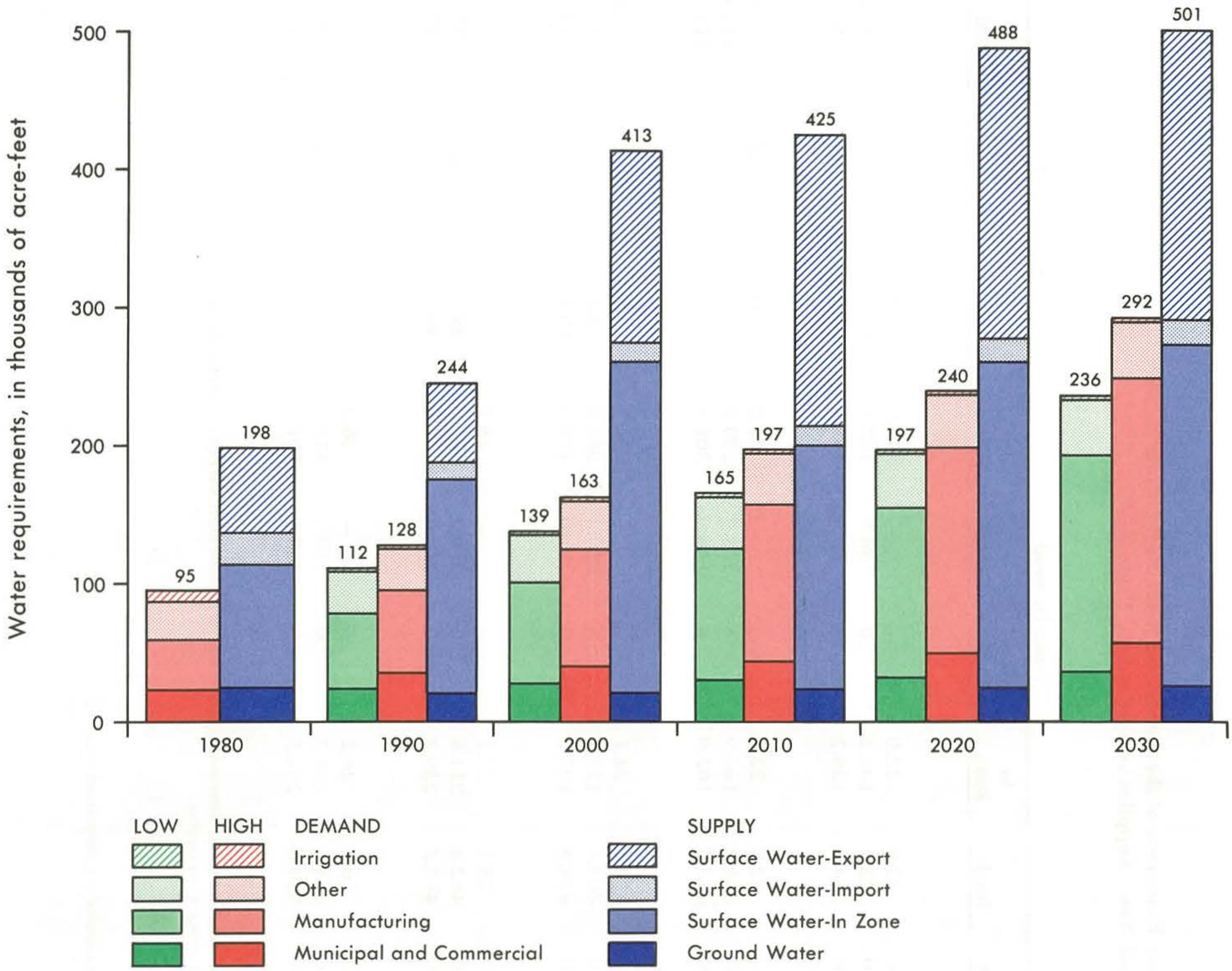

Figure III-18-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Guadalupe River Basin, Zone 2, 1980-2030

A program for limited withdrawals of the Edwards (Balcones Fault Zone) Aquifer may necessitate additional surface-water development in Zone 2 of the Guadalupe River Basin to meet the needs of the basin and the City of San Antonio. This development would include the use of supplies developed by the proposed Lindenau and Cuero Reservoirs. Analyses performed by the Department indicate developments in the Guadalupe River Basin could take place in the following order:

1. Construction by 1990 of Lindenau Reservoir on Sandies Creek in the Guadalupe River Basin and conveyance facilities to provide 56.9 thousand acre-feet annually to Applewhite Reservoir in the San Antonio River Basin.

2. Construction by 2000 of a low-flow diversion structure on the Guadalupe River near Cuero and pipeline facilities to pump excess flows from the Guadalupe River to Lindenau Reservoir. An increase in the capacity of conveyance facilities from Lindenau Reservoir to Applewhite Reservoir to convey 138.9 thousand acre-feet yearly by 2000 and 210.0 thousand acre-feet yearly by 2010.

3. Construction by 2020 of the Cuero Reservoir on the Guadalupe River near Cuero and a storage equalization channel between Cuero and Lindenau Reservoir.

Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such major interbasin transfers of water.

Water needs in the City of Victoria metropolitan area for municipal and manufacturing purposes in year 2020 are projected to be in excess of available surface-water supplies and could necessitate the development of additional water resources for the area. Potential alternatives to meet the needs of the Victoria area are the Lindenau and Cuero Reservoirs in the lower basin. Construction of Cuero Reservoir by 2020 would provide sufficient water to meet anticipated shortages through the year 2030.

Water Quality Protection

A water quality management plan for the Guadalupe River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $94.8 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Guadalupe River Basin with approximately $54.4 million required for Zone 1 and $40.4 million projected for Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Canyon Lake is the only reservoir in the basin having flood control as a project purpose. The reservoir provides 740.9 thousand acre-feet of controlled storage capacity of which 346.4 thousand acre-feet is allocated for flood control. Ingram Reservoir which would be owned by the Upper Guadalupe River Authority, would have 36.4 thousand acre-feet of flood-control storage as presently designed. Cloptin Crossing Reservoir, a Corps of Engineers project, would provide 119.9 thousand acre-feet of flood-control storage as presently authorized.

In the past, log jams in the lower part of the Guadalupe River Basin have caused considerable flooding to agricultural lands. The Corps of Engineers completed a project which involved removing the jams in 1975. The Guadalupe-Blanco River Authority has assumed responsibility for keeping the river free of log jams in the section cleared by the Corps of Engineers.

There is about 268 square miles of drainage area above 50 existing floodwater-retarding structures within the Guadalupe River Basin. As of October 1980, an additional 10 structures with a drainage area of 148 square miles were planned for construction. About one-third of the planned and existing structures are located in Zone 1, and the remaining two-thirds are located in Zone 2.

A study by the Corps is underway on Walnut Branch, Seguin, Texas.

19. SAN ANTONIO RIVER BASIN

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19. SAN ANTONIO RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The San Antonio River Basin is bounded on the north and east by the Guadalupe River Basin, and on the south and west by the Nueces River Basin and the San Antonio-Nueces Coastal Basin. Elevation ranges from about 2,000 feet at the headwaters of the Medina River in the northwest corner of Bandera County to about sea level at the confluence with the Guadalupe River near Tivoli. Total basin drainage area is 4,180 square miles. Major streams include the Medina River, Leon Creek, Salado Creek, Cibolo Creek, and the San Antonio River. For planning purposes, the San Antonio River Basin has been divided into two zones (Figure III-19-1).

Surface Water

The average annual runoff from 1955-70 was about 150 acre-feet per mile in the lower part of the basin, and from 1963-70 average annual runoff was about 185 acre-feet in the northern part of the basin near Boerne. Much of the runoff in the upper part of the basin enters the Edwards and associated limestones in the Balcones Fault Zone.

During 1941-70, low runoff rates occurred during 1950-56 and 1962-64, averaging 48 and 50 acre-feet per square mile, respectively. The lowest annual runoff rate was 23 acre-feet per square mile in 1956.

In the upper basin, flood plains of the Edwards Plateau are narrow and steep-sided. Rapid runoff from the shallow soils produce rapidly rising, high-velocity floods on the principal tributaries. Floods in the coastal plain region below San Antonio are slower-moving and overflow the wide, shallow flood plains. The San Antonio River Basin is impacted by hurricanes and other tropical weather disturbances at least once every two or three years.

The average concentration of dissolved solids in streams within the upper part of the San Antonio River Basin range from about 300 to 350 milligrams per liter (mg/l). Water stored in Medina Lake usually contains dissolved-solids concentrations of about 150 to 350 mg/l, and the quality of the river remains good downstream to the western edge of the San Antonio metropolitan area. Dissolved-solids concentrations of the main stem of the San Antonio River below San Antonio usually exceed 600 mg/l. The average dissolved-solids concentration of the river at Goliad is about 400 mg/l. Below Goliad, the chemical quality of the river does not change significantly.

Water quality of the upper reaches of the San Antonio River is relatively poor, particularily during periods of low flow. Under such conditions, flow consists predominantly of treated municipal wastewater from the City of San Antonio's three large sewage treatment plants which cannot be sufficiently assimilated without the development of acute water quality problems. The reach between Interstate Highway 410 and Falls City (70 river miles) is consistently stressed with low levels of dissolved oxygen and elevated levels of ammonia nitrogen, biochemical oxygen demand, nutrient compounds, and fecal coliform bacteria. Low dissolved oxygen levels have caused seven major fish kills within this reach since 1970. Water quality is also stressed in the lower portions of Leon Creek and the Medina River and can be attributed to the discharge of treated wastewater from the City of San Antonio Leon Creek Plant. Similar poor water quality conditions exist in the upper reaches of Cibolo Creek between Interstate Highway 35 and Shaefer Road (7 river miles) and result from the discharge of treated wastewater from the Cibolo Creek Municipal Authority Plant near Schertz.

Ground Water

The Edwards-Trinity (Plateau) Aquifer occurs in part of Kerr and Bandera Counties in the far western part of the San Antonio River Basin. Total thickness generally ranges from 400 to 500 feet. Well yields are generally small within the basin. Water in the aquifer generally contains between 500 to 3,000 mg/l total dissolved solids.

The Trinity Group Aquifer occurs in the northwestern part of the San Antonio River Basin. Most wells completed in the aquifer yield less than 100 gallons per minute (gpm). Water quality ranges from fresh to slightly saline.

The Edwards (Balcones Fault Zone) Aquifer extends across Comal, Bexar, and Medina Counties in the upper middle part of the San Antonio River Basin. Total thickness ranges from 400 to 600 feet. Yields of large-capacity wells average 1,500 gpm, but locally wells produce up to 9,000 gpm. Generally, the water contains less than 500 mg/l total dissolved solids.

The Carrizo-Wilcox Aquifer occurs in a wide band across the central part of the basin. Total thickness ranges from 800 to more than 2,000 feet. Yields of high-capacity

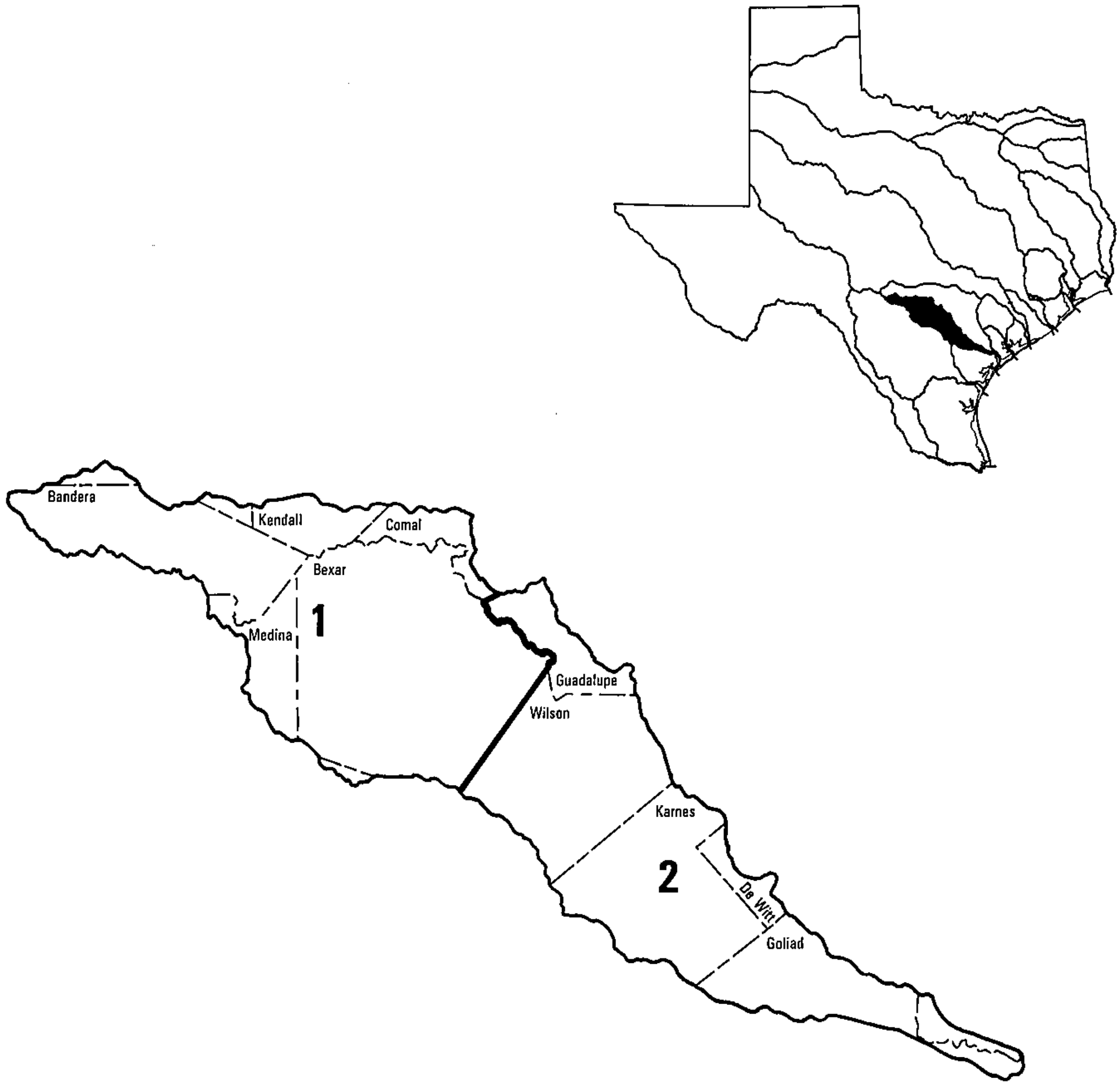

Figure III-19-1. San Antonio River Basin and Zones

wells average 900 gpm, but local wells produce up to 2,000 gpm. Water in the aquifer contains from less than 1,000 to as much as 3,000 mg/l total dissolved solids.

The Gulf Coast Aquifer underlies the lower part of the San Antonio River Basin. The aquifer extends to a maximum depth of 1,800 feet. Yields of large-capacity wells average 800 gpm but may reach 2,000 gpm. Water quality generally ranges from 500 to 1,500 mg/l total dissolved solids.

The Queen City Aquifer occurs in a narrow band across the middle part of the basin. Total thickness ranges up to about 500 feet. Yields of wells generally do not exceed 200 gpm. Water quality ranges from less than 1,000 to as much as 3,000 mg/l total dissolved solids.

The Sparta Aquifer also occurs in a narrow band across the middle part of the basin. Maximum thickness is approximately 100 feet. Well yields are usually less than 100 gpm. Water quality varies from less than 1,000 to about 10,000 mg/l total dissolved solids.

Over pumpage of the Trinity Group Aquifer in Bexar County near the downdip extent of the aquifer can cause gradual deterioration of ground-water quality because of saline-water encroachment. The same condition is true for the Carrizo-Wilcox Aquifer in western and northern Karnes County within the basin.

The potential for saline-water encroachment may be very great in the Edwards (Balcones Fault Zone) Aquifer within the basin. Since the aquifer is composed of fractured and faulted limestones with locally unpredictable secondary porosity and permeability, it is impossible to define or predict with any accuracy the aquifer's flow system on a local basis. Of great importance is the aquifer's regional flow system which generally consists of major natural recharge (inflow) in the Nueces River Basin, movement of water in the subsurface artesian zone northeastward beneath the Nueces and San Antonio River Basins, and major natural discharge (outflow) of water at Comal and San Marcos Springs in the Guadalupe River Basin. At the downdip extent of the aquifer, under natural conditions, ground-water quality deteriorates rapidly across the fresh and saline water interface. Therefore, a very large amount of saline waters occurs immediately adjacent to and southeast of the fresh water-bearing deposits of the aquifer. During the drought of the 1950's when water level elevations were at historical lows and when amounts of ground-water withdrawals from the aquifer were large, no significant saline-water encroachment was detected. However, what will happen to the aquifer's water quality if water level elevations are lowered below levels of the 1950's? Considering the aquifer's regional flow system, an extreme lowering of water levels below the 1950's level in the Nueces, San Antonio, and Guadalupe River Basins may cause a significantly large invasion of saline water which not only may contaminate municipal, industrial, and irrigation freshwater supplies but also any flows at Comal, San Marcos, and other springs which are located near the fresh and saline water interface of the aquifer.

In areas immediately adjacent to the Coast in Victoria and Refugio Counties, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage.

Population and Economic Development

The population of the San Antonio River Basin was reported at 1.05 million in 1980. San Antonio, the third largest city in the State, had a population of over 780 thousand in 1980.

Agriculture, mineral production, tourism, and government are the primary economic activities. The five military installations have a large federal government expenditure. Seven colleges within the City of San Antonio make education a major economic activity locally.

Water Use

Municipal water use in the San Antonio River Basin in 1980 totaled 232.9 thousand acre-feet. Ninety-seven percent of the total basin use occurred in Zone 1, with almost all of this use concentrated in Bexar County. The City of San Antonio and its environs were the largest users of municipal water in the basin.

Manufacturing industries in the basin used 14.3 thousand acre-feet of freshwater in 1980. Almost the entire quantity was used in Zone 1, and approximately 99 percent of the zone requirements occurred in Bexar County where the food and kindred products industry used approximately 64 percent of the total basin manufacturing freshwater requirement.

Manufacturing industries in the basin used 14.3 thousand acre-feet of fresh water in 1980. Almost the entire quantity was used in Zone 1, and approximately 99 percent of the zone requirements occurred in Bexar County where the food and kindred products industry used approximately 64 percent of the total basin manufacturing freshwater requirement.

In 1980, there was 3,344 megawatts of installed stream-electric power generating capacity in the San Antonio River Basin. During that year, ground-water withdrawals for stream-electric power plant cooling totaled 1.4 thousand acre-feet and surface-water consumption was 27.9 thousand acre-feet of which 17.8 thousand acre-feet was estimated net adjusted evaporation.

A total of 60.9 thousand acre-feet of water was used for irrigation in the entire basin in 1980. Of this amount, 36.3 thousand acre-feet was from ground-water sources and 24.6 thousand acre-feet was supplied from surface-water sources. The Edwards (Balcones Fault Zone) Aquifer supplies water for both Zones 1 and 2, while the Carrizo-Wilcox Aquifer supplies Zone 2. A portion of the surface-water irrigation was in the Mitchell Lake area, using treated effluent discharged by the City of San Antonio. In addition, water from Medina Lake was diverted for the Medina Irrigation project in the adjacent Nueces River Basin. A total of 51.8 thousand acre-feet of water was used in Zone 1 in 1980, of which nearly 61 percent was from ground-water sources. In Zone 2, 9.1 thousand acre-feet of water was used of which almost 53 percent was supplied from ground-water sources.

Estimated freshwater use for mining in the San Antonio River Basin totaled 1.0 thousand acre-feet in 1980. Most of the fresh water used for mining occurs in Bexar County for nonmetal production (sand and gravel, etc.) which constitutes approximately 41 percent of the total mining water use in the basin.

Livestock water use in 1980 totaled 5.1 thousand acre-feet in the basin, mostly for cattle production. Ground water supplied 1.2 thousand acre-feet and surface water 3.9 thousand acre-feet. In Zone 1, 1.9 thousand acre-feet of water was used, with 1.2 thousand acre-feet of surface water and 700 acre-feet of ground water. Livestock water use in Zone 2 totaled 3.2 thousand acre-feet (2,700 acre-feet of surface water, 500 acre-feet of ground water).

Return Flows

The heavily urbanized Bexar County area produced over 97 percent of the 145.6 thousand acre-feet of municipal and manufacturing return flows in the San Antonio River Basin in 1980.

Due to the soil types and the irrigation pattern, areas irrigated by ground water do not produce any significant volume of return flows. In 1980, a total of about 6 thousand acre-feet of return flows originated from surface-water irrigation in both zones of the basin.

Current Ground-Water Development

In 1980, approximately 285.8 thousand acre-feet of ground water was used in the San Antonio River Basin. Of this amount, 273.0 thousand acre-feet was used in Zone 1, and 12.8 thousand acre-feet in Zone 2. In Zone 1, 98 percent of the ground water used was from the Edwards (Balcones Fault Zone) Aquifer. In Zone 2, 57 percent of the ground water used was from the Carrizo-Wilcox Aquifer, and 33 percent was from the Gulf Coast Aquifer.

Of the 285.8 thousand acre-feet of ground water used in the basin, approximately 231.9 thousand acre-feet or 81 percent was used for municipal purposes, and 36.3 thousand acre-feet or 13 percent was used for irrigation purposes.

In 1980, large overdrafts of ground water from the Edwards (Balcones Fault Zone) Aquifer occurred in Zone 1 in Comal County due to excessive withdrawals for municipal purposes, and in Medina County due to excessive withdrawals for irrigation. No overdrafts of ground water occurred in 1980 in Zone 2 of the San Antonio River Basin.

Current Surface-Water Development

Major reservoirs in Zone 1 of the San Antonio River Basin include Medina Lake, Olmos Reservoir, Victor Braunig Lake, and Calaveras Creek Reservoir. Medina Lake, located on the Medina River in Bandera and Medina Counties, is owned and operated by the Bexar-Medina-Atascosa Counties Water Improvement District Number 1. Under existing permits, Medina Lake provides water for irrigation in the San Antonio and adjoining Nueces River Basins. Olmos Reservoir, located on Olmos Creek in Bexar County, is owned and operated by the City of San Antonio. This project is used as a floodwater-retention reservoir. Impounded floodwaters are stored only until releases can be made without damaging property in downstream areas. During periods when the reservoir is empty, the reservoir basin provides park and playground facilities. Victor Braunig Lake and Calaveras Creek Reservoir are located in Bexar County on Arroyo Seco and Calaveras Creek, respectively. These projects are owned by the City of San Antonio and operated by the City Public Service Board to supply cooling water for stream-electric power generation. Under existing permits, local runoff is supplemented by water pumped from the San Antonio River. Mitchell Lake is an 850-acre reservoir located south of the City of San Antonio in Bexar County and, until 1930, served as the only waste treatment facility for San Antonio. An existing Texas Water Quality Board discharge permit authorizes the discharge of domestic sewage effluent and other wastewaters into the lake, and further authorizes discharges from the lake under certain emergency conditions, based on the volume of water in the lake and rainfall conditions in the watershed. Although not considered a major reservoir, Mitchell Lake for many years has served a large role in the irrigation of land (as much as 4,000 acres) below and adjacent to it. Since 1980, however, no irrigation has taken place from Mitchell Lake.

There are no major existing reservoirs located in Zone 2 of the San Antonio River Basin.

Water Rights

The total quantity of surface water authorized or claimed for diversion and use in the San Antonio River Basin was 216,739 acre-feet as of December 31, 1983 (Table III-19-1). Authorizations and claims for municipal and industrial use amounted to a combined total of 120,773 acre-feet (Table III-19-2). Zone 1 has the largest quantity of authorized and claimed water in the basin with 204,957 acre-feet (Table III-19-2).

Table III-19-1. Authorized or Claimed Amount of Water, by Type of Right, San Antonio River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	56	82,531
Claims	1	518
Certified Filings	0	0
Certificates of Adjudication	137	133,690
Total Authorizations and Claims	194	216,739

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A Certificate of Adjudication is the final result after recognition of a valid right in the adjudication process, and is based on a permit, certified filing, or claim or any combination of the three.

Table III-19-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, San Antonio River Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	6	71,862	0	71,862
Industrial	3	48,911	0	48,911
Irrigation	161	79,403	11,181	90,584
Mining	2	766	0	766
Recreation	21	3,054	601	3,655
Recharge	1	961	0	961
Other	5	0	0	0
Total	194[1]	204,957	11,782	216,739

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

Water Quality

During periods of low flow, the San Antonio River below the City of San Antonio consists almost entirely of treated municipal and industrial effluents. Cibolo Creek, below U.S. Interstate Highway 35, has relatively heavy algal growths caused by nutrients derived from treated municipal wastewaters and agricultural runoff, and Leon Creek is effluent-dominated during periods of low flow. Uranium mining activities in Wilson and Karnes Counties are being closely monitored and regulated to prevent water quality degradation.

Flooding, Drainage, and Subsidence

Floods have damaged urban developments in the San Antonio area. Basin-wide flooding in 1957 resulted in $3.7 million in nonagricultural damages. In May 1965, the greater San Antonio area suffered an estimated $1.1 million in flood damages. In September 1967, Hurricane Beulah caused an estimated $3.3 million in agricultural damages and $2.9 million in nonagricultural damages.

The January 1968 flood caused $350 thousand in damages, the September 1973 flood caused an estimated $6.6 million in damages, the August and November 1974 flood caused $2.8 million in damages, and flooding of Apache Creek in February 1975 caused $75 thousand in damages to urban property in the greater San Antonio area. In May and June 1976, flooding along Martinez, San Pedro, and Apache Creeks produced damages in excess of $790 thousand.

In August 1978, Tropical Storm Amelia produced record level floods in Bandera County and the resulting Presidential disaster declaration brought more than $2 million in federal flood relief. During the period 1978-1981, 139 flood insurance claims were filed for $718 thousand in flood damages.

Presently, 36 cities have been designated as flood prone by the Federal Emergency Management Agency. Maps have been prepared for all the cities and unincorporated flood-prone areas in all but one county to show areas subject to inundation by the 100-year flood. Participation in the emergency phase of the National Flood Insurance Program includes seven cities which have adopted building standards for flood-plain construction. Twenty three cities have completed flood insurance rate studies and are participating in the Regular Phase of the Program. The City of San Antonio and Bexar County currently have rate studies in progress.

The San Antonio River Basin experiences only minor drainage problems, which are located primarily in the Rio Grande Plain land resource area. Narrow channels with insufficient capacities to carry storm runoff cause occasional ponding from overflow. Generally, these problems are confined to local areas and are alleviated by on-site and ground drainage facilities.

The amount and distribution of subsidence in the coastal areas of the San Antonio River Basin are unknown. The potential for subsidence and active faulting in the Kay Creek and Huff Oil Fields exists in southern Victoria County and northern Refugio County. However, the subsidence associated with petroleum and related saline-water withdrawals in these fields is probably less than 0.5 foot.

Recreation Resources

There are three reservoirs in the San Antonio River Basin with a combined surface area of 11.6 thousand acres. Medina Lake, with 5.6 thousand surface acres available for flat-water recreation, accounts for over 49 percent of the total surface area in the basin. Victor Braunig Lake (1.4 thousand surface acres) and Calaveras Lake (3.5 thousand surface acres) are both located in Bexar County and serve part of the recreational needs of the San Antonio metropolitan area.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the San Antonio River Basin is projected to increase 174 percent from 1980 to 2030 (Table III-19-3). Bexar County, containing the San Antonio metropolitan area, has 93.6 percent of the basin population. The county population more than doubled by 2030 will result in over 2.8 million people and a slight increase (to 94.7 percent) in the county's share of the total basin population.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the San Antonio River Basin are projected to increase from the 1980 level of 232.9 thousand acre-feet by a projected maximum of 78 percent by the year 2000. In the year 2030, water requirements are projected to range from 442.5 to 747.8 thousand acre-feet. Zone 1 is projected to account for 97 percent of the total.

A range of 11.3 to 16.6 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000.

Industrial

Manufacturing water requirements in 1980 were 14.3 thousand acre-feet in the San Antonio River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the San Antonio River Basin are projected to increase more than three times by the year 2030, to a potential high of 50.7 thousand acre-feet by 2030. The projected increase in manufacturing freshwater use in the San Antonio River Basin is greater than the State average (255 percent for 1980-2030, compared to 230 percent for the State).

Projected 2030 requirements in Bexar County are distributed among many different manufacturing groups. The heavier water-using industries include: agricultural chemicals, hydraulic cement, concrete, gypsum and plaster products, meat products, beverages, millwork, veneer, plywood and structural wood members, and petroleum refining.

Table III-19-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
San Antonio River Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			1,008.1			1,250.5			1,519.8			1,784.8			2,174.5			2,787.9
Municipal	225.1	1.0	226.1	264.0	58.9	322.9	262.9	134.8	397.7	265.1	200.8	465.9	264.8	301.6	566.4	275.3	449.2	724.5
Manufacturing	13.8	0.3	14.1	5.7	13.4	19.1	5.7	19.7	25.4	5.7	26.4	32.1	5.5	34.7	40.2	0.0	49.9	49.9
Steam Electric	1.4	27.9	29.3	0.0	29.3	29.3	6.8	29.3	36.1	12.4	29.3	41.7	0.0	47.4	47.4	0.0	53.0	53.0
Mining	0.5	0.0	0.5	0.6	0.0	0.6	0.6	0.1	0.7	1.6	0.2	1.8	2.6	0.4	3.0	3.6	0.5	4.1
Irrigation	31.5	20.3	51.8	12.3	17.9	30.2	12.3	16.8	29.1	13.5	17.3	30.8	13.4	17.4	30.8	9.7	22.3	32.0
Livestock	0.7	1.2	1.9	1.3	0.8	2.1	1.3	0.9	2.2	1.3	0.9	2.2	1.3	0.9	2.2	0.9	1.3	2.2
Zone Total Water	273.0	50.7	323.7	283.9	120.3	404.2	289.6	201.6	491.2	299.6	274.9	574.5	287.6	402.4	690.0	289.5	576.2	865.7
Zone 2																		
Population			46.3			61.0			71.2			78.7			88.4			100.1
Municipal	6.8	0.0	6.8	13.4	0.3	13.7	16.0	0.6	16.6	17.6	0.7	18.3	19.6	0.9	20.5	22.0	1.3	23.3
Manufacturing	0.2	0.0	0.2	0.3	0.0	0.3	0.4	0.0	0.4	0.5	0.0	0.5	0.6	0.0	0.6	0.8	0.0	0.8
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.5	0.0	0.5	0.5	0.0	0.5	0.6	0.0	0.6	0.6	0.0	0.6	0.6	0.0	0.6	0.7	0.0	0.7
Irrigation	4.8	4.3	9.1	4.8	4.2	9.0	4.7	4.4	9.1	5.0	4.4	9.4	5.0	4.4	9.4	3.4	6.0	9.4
Livestock	0.5	2.7	3.2	0.5	3.3	3.8	0.5	3.9	4.4	0.5	3.9	4.4	0.5	3.9	4.4	0.4	4.0	4.4
Zone Total Water	12.8	7.0	19.8	19.5	7.8	27.3	22.2	8.9	31.1	24.2	9.0	33.2	26.3	9.2	35.5	27.3	11.3	38.6
BASIN TOTALS																		
Population			1,054.4			1,311.5			1,591.0			1,863.5			2,262.9			2,888.0
Municipal	231.9	1.0	232.9	277.4	59.2	336.6	278.9	135.4	414.3	282.7	201.5	484.2	284.4	302.5	586.9	297.3	450.5	747.8
Manufacturing	14.0	0.3	14.3	6.0	13.4	19.4	6.1	19.7	25.8	6.2	26.4	32.6	6.1	34.7	40.8	0.8	49.9	50.7
Steam Electric	1.4	27.9	29.3	0.0	29.3	29.3	6.8	29.3	36.1	12.4	29.3	41.7	0.0	47.4	47.4	0.0	53.0	53.0
Mining	1.0	0.0	1.0	1.1	0.0	1.1	1.2	0.1	1.3	2.2	0.2	2.4	3.2	0.4	3.6	4.3	0.5	4.8
Irrigation	36.3	24.6	60.9	17.1	22.1	39.2	17.0	21.2	38.2	18.5	21.7	40.2	18.4	21.8	40.2	13.1	28.3	41.4
Livestock	1.2	3.9	5.1	1.8	4.1	5.9	1.8	4.8	6.6	1.8	4.8	6.6	1.8	4.8	6.6	1.3	5.3	6.6
Basin Total Water	285.8	57.7	343.5	303.4	128.1	431.5	311.8	210.5	522.3	323.8	283.9	607.7	313.9	411.6	725.5	316.8	587.5	904.3

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Steam-Electric Power Generation

Installed steam-electric power generating capacity will expand rapidly in the Bexar County area of the San Antonio River Basin as the V.H. Braunig, O.W. Sommers, and J.T. Deeley plants expand to full capacities. Projected water requirements to support this level of power generation will include water withdrawals of about 36.1 thousand acre-feet per year by the year 2000 (high case). Water requirements are projected to increase from 41.9 to 53.0 thousand acre-feet annually by 2030.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the San Antonio River Basin are projected to decrease from the 1980 level of 60.9 thousand acre-feet by a projected maximum 37 percent by the year 2000 in the high case, declining 40 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 33.3 to 41.4 thousand acre-feet annually, low and high case, respectively, to irrigate from 38.6 to 44.2 thousand acres.

Zone 1 is projected to account for about 76 and 77 percent of total basin irrigation requirements in 2000 and 2030, respectively. Zone 2 is projected to account for about 23 percent of the total.

Livestock

Future livestock water requirements within the basin are expected to increase from 5.1 thousand acre-feet in 1980 to 6.6 thousand acre-feet annually by 2030. Livestock water use in 2000 is expected to be 2.2 thousand acre-feet annually in Zone 1 and 4.4 thousand acre-feet annually in Zone 2.

Mining

Between 1980 and 2030, mining water use in the San Antonio River Basin is projected to increase from 1.0 thousand acre-feet to 4.8 thousand acre-feet. Much of the increase in basin requirements will be by nonmetal mining firms (limestone, sand and gravel, and clay) in Bexar County, while water use in the recovery of petroleum and natural gas is projected to decline as the potential quantities available for production decrease over the projection period.

Navigation

Currently, no navigation facilities which would require the use of regulated freshwater supplies are planned in the basin.

Hydroelectric Power

There are no planned hydroelectric power generating facilities in the basin.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the San Antonio River Basin to the year 2030 is 381.8 thousand acre-feet with the following amounts annually available by aquifer: 285.1 thousand acre-feet from the Edwards (Balcones Fault Zone) Aquifer, 70.1 thousand acre-feet from the Carrizo-Wilcox Aquifer, 13.0 thousand acre-feet from the Gulf Coast Aquifer, 10.0 thousand acre-feet from the Sparta Aquifer, and 3.6 thousand acre-feet from the Queen City Aquifer. Annual amounts of yield for the Edwards-Trinity (Plateau) and Trinity Group Aquifers within the basin were not included because extensive withdrawals of natural recharge and recoverable storage from these aquifers would deplete their spring flows and thereby reduce downstream available surface-water supplies and adversely affect recharge to the Edwards (Balcones Fault Zone) Aquifer. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual effective recharge of 43.4 thousand acre-feet per year. This reduction decreases the total ground-water availability within the basin in 2030 to 355.1 thousand acre-feet.

The projected annual ground-water use within the San Antonio River Basin by decade from 1990 through 2030 is expected to be from 303.4 to 323.8 thousand acre-feet per year (Table III-19-3). The approximate average annual projected ground-water use within the basin is expected to be about 313.9 thousand acre-feet per year. Of the 313.9 thousand acre-feet of average annual projected use, about 89 percent is expected to be from the Edwards (Balcones Fault Zone) Aquifer, and about seven percent is expected to be from the Carrizo-Wilcox Aquifer.

Surface-Water Availability and Proposed Development

The San Antonio River Basin is projected to experience water shortages before the year 1990 if no additional water supply sources are developed. Based upon proposed surface-water development, the San Antonio and Guadalupe River Basins could fully meet projected surface-water requirements in the San Antonio River Basin from the present through 2030 (Table III-19-4, Figure III-19-2). A surplus of surface water for municipal and industrial purposes is projected in all decades in both Zones 1 and 2 through the year 2030.

Zone 1

Zone 1 of the basin is projected, under the proposed surface-water plan in this report, to have an annual water surplus of 39.0 thousand acre-feet in 2000 and 28.2 thousand acre-feet in 2030 (Table III-19-5, Figure III-19-3). In 2030, a total of 564.9 thousand acre-feet of surface water is projected to be used in this zone, with an importation of 210.0 thousand acre-feet per year of surface water to the City of San Antonio from the Guadalupe River Basin.

Studies of the Edwards (Balcones Fault Zone) Aquifer have indicated that limitations on withdrawals of ground water from the aquifer will be needed to maintain spring flow in the Guadalupe River Basin at San Marcos Springs and to avoid possible degradation of water quality in the aquifer. Such pumpage limits will necessitate, at some future time, the curtailment of additional development by some users of the aquifer and must involve Bexar County, as municipalities and industry in Bexar County are the largest users of water from the Edwards. If economic growth in Bexar County is not to be inhibited by water shortages, then alternative water supplies must be developed from the most economically available sources. The most likely future water sources for Bexar County are surface-water supplies in the Guadalupe and San Antonio River Basins.

In 1982, the City Water Board of San Antonio was granted a permit by the Texas Water Commission to construct and operate the Applewhite Reservoir on the Medina River south of San Antonio. This reservoir, associated floodwater diversion works on Leon Creek, and pumping and treatment facilities will provide a maximum annual surface-water supply of 70.0 thousand acre-feet per year, with an average annual diversion of 50.0 thousand acre-feet of surface water to the City of San Antonio. However, the annual yield of the reservoir during the historical drought is only 15.0 thousand acre-feet. Development of the Applewhite Reservoir site will supplement existing ground-water supplies for San Antonio and provide a terminal storage facility for additional supplies of surface water for the city.

Projected water needs for the City of San Antonio exceed available supplies, including the proposed Applewhite Reservoir, by the year 1990. A likely alternative for meeting the shortages anticipated in 1990 for the City of San Antonio is the development of the Lindenau Reservoir project in the Guadalupe River Basin. This reservoir could supply the anticipated shortage for the City of San Antonio of 56.9 thousand acre-feet per year in 1990.

Additional surface water would need to be developed to meet projected year 2000 shortages for San Antonio. By the year 2000, flood-flow diversion facilities from the Guadalupe River to Lindenau Reservoir and associated pipelines to Applewhite Reservoir could be constructed to provide the needed waters. By the year 2030, additional surface water in excess of that available from the Lindenau and Applewhite sites would be needed. A likely alternative would be the development of the Goliad Reservoir and associated pumping facilities to San Antonio before the year 2020. Further engineering, environmental, and institutional studies will be required before the least-cost sizing and sequencing of these projects can be established.

Zone 2

An annual surface-water surplus of 133.0 thousand acre-feet in 2000 is projected to occur in Zone 2 of the

Table III-19-4. Water Resources of the San Antonio River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	303.4	—	—	—	303.4	303.4	—	—	303.4	.0	.0	.0
Surface Water	103.1	—	164.3	57.3	324.7	111.2	—	78.8	190.0	134.7	.0	134.7
Total	406.5	—	164.3	57.3	628.1	414.6	—	78.8	493.4	134.7	.0	134.7
2000												
Ground Water	311.8	—	—	—	311.8	311.8	—	—	311.8	.0	.0	.0
Surface Water	103.1	—	214.1	139.4	456.6	192.4	—	92.2	284.6	172.1	(.1)	172.0
Total	414.9	—	214.1	139.4	768.4	504.2	—	92.2	596.4	172.1	(.1)	172.0
2010												
Ground Water	323.8	—	—	—	323.8	323.8	—	—	323.8	.0	.0	.0
Surface Water	103.1	—	259.0	210.7	572.8	265.4	—	114.9	380.3	192.7	(.2)	192.5
Total	426.9	—	259.0	210.7	896.6	589.2	—	114.9	704.1	192.7	(.2)	192.5
2020												
Ground Water	313.9	—	—	—	313.9	313.9	—	—	313.9	.0	.0	.0
Surface Water	235.1	—	325.0	211.0	771.1	392.9	—	152.9	545.8	225.6	(.3)	225.3
Total	549.0	—	325.0	211.0	1085.0	706.8	—	152.9	859.7	225.6	(.3)	225.3
2030												
Ground Water	316.8	—	—	—	316.8	316.8	—	—	316.8	.0	.0	.0
Surface Water	235.1	—	401.0	210.0	846.1	568.0	—	238.3	806.3	41.7	(1.9)	39.8
Total	551.9	—	401.0	210.0	1162.9	884.8	—	238.3	1123.1	41.7	(1.9)	39.8

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

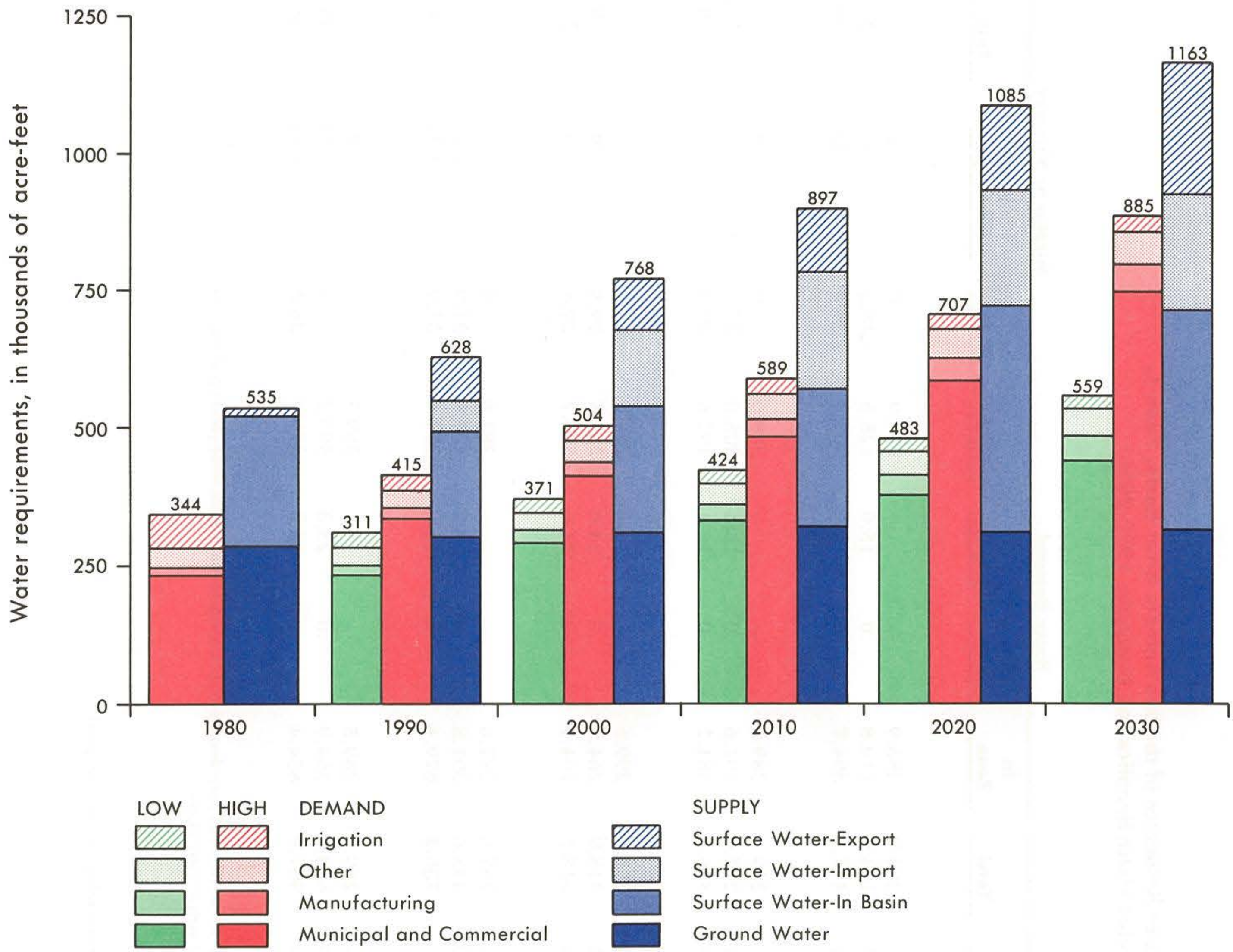

Figure III-19-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Antonio River Basin, 1980-2030

basin (Table III-19-6, Figure III-19-4) if all proposed water development is instituted. Of the 524.0 thousand acre-feet of surface water projected for 2030 to be available for this zone, a total of 392.0 thousand acre-feet of return flow from Zone 1 is available. Exports from this zone in 2030 are projected to be 213.0 thousand acre-feet of surface water to adjacent river and coastal basins, and 296.3 thousand acre-feet to Zone 1 of the basin.

The major reservoir proposed for construction in Zone 2 is the Goliad Reservoir project. The potential dam site is located on the San Antonio River several miles upstream from the City of Goliad in Goliad County. Preliminary capacity-cost studies of this project were initially performed by the U.S. Bureau of Reclamation for the United States Study Commission-Texas in 1960; and the project has been studied by the Department. The Goliad site is proposed for development by the year 2020 to meet needs in San Antonio and to provide water to the Nueces-Rio Grande Coastal Basin, particularly the City of Corpus Christi. Pipelines to convey water from Goliad to Lake Corpus Christi and to the City of San Antonio would need to be constructed prior to the year 2020. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major interbasin transfer of water.

Table III-19-5. Water Resources of the San Antonio River Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	283.9	—	—	—	283.9	283.9	—	—	283.9	.0	.0	.0
Surface Water	103.1	.0	4.0	56.9	164.0	110.8	.0	15.0	125.8	38.2	.0	38.2
Total	387.0	.0	4.0	56.9	447.9	394.7	.0	15.0	409.7	38.2	.0	38.2
2000												
Ground Water	289.6	—	—	—	289.6	289.6	—	—	289.6	.0	.0	.0
Surface Water	103.1	.0	5.0	138.9	247.0	191.6	.0	16.4	208.0	39.0	.0	39.0
Total	392.7	.0	5.0	138.9	536.6	481.2	.0	16.4	497.6	39.0	.0	39.0
2010												
Ground Water	299.6	—	—	—	299.6	299.6	—	—	299.6	.0	.0	.0
Surface Water	103.1	.0	5.8	210.0	318.9	264.5	.0	24.6	289.1	29.8	.0	29.8
Total	402.7	.0	5.8	210.0	618.5	564.1	.0	24.6	588.7	29.8	.0	29.8
2020												
Ground Water	287.6	—	—	—	287.6	287.6	—	—	287.6	.0	.0	.0
Surface Water	103.1	128.5	7.0	210.0	448.6	391.8	.0	25.0	416.8	31.9	(.1)	31.8
Total	390.7	128.5	7.0	210.0	736.2	679.4	.0	25.0	704.4	31.9	(.1)	31.8
2030												
Ground Water	289.5	—	—	—	289.5	289.5	—	—	289.5	.0	.0	.0
Surface Water	103.1	296.3	9.0	210.0	618.4	564.9	.0	25.3	590.2	28.3	(.1)	28.2
Total	392.6	296.3	9.0	210.0	907.9	854.4	.0	25.3	879.7	28.3	(.1)	28.2

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

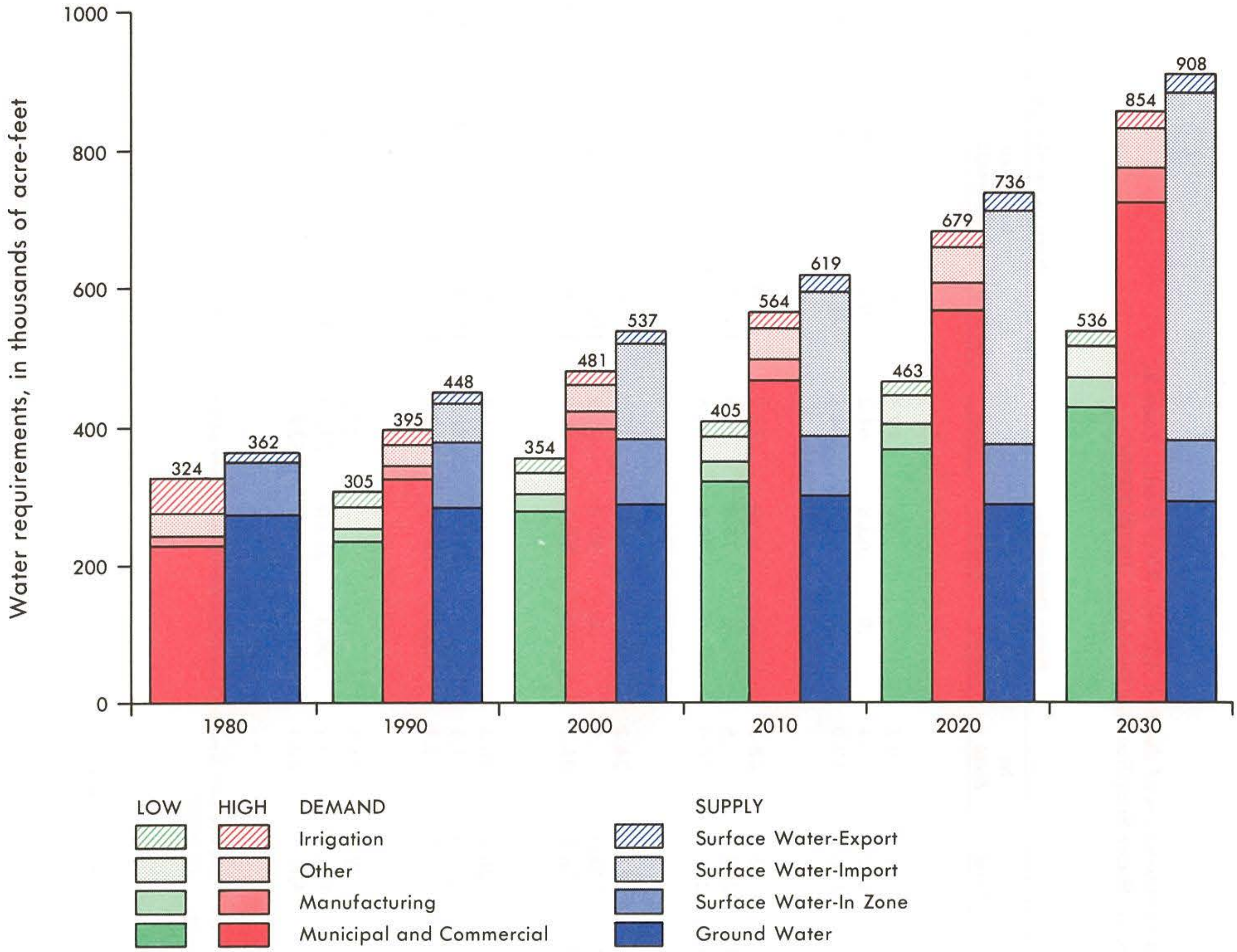

Figure III-19-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Antonio River Basin, Zone 1, 1980-2030

A potential surface-water development in Zone 2 of the San Antonio River Basin is the authorized Cibolo Reservoir. Hydrologic studies have determined that the firm annual yield of the Cibolo Reservoir project, under year 2000 conditions, will total approximately 22 thousand acre-feet. Approximately 2 thousand acre-feet of the yield of Cibolo Reservoir has been tentatively allocated to supply the projected water requirements of the Karnes County area, thus leaving 20 thousand acre-feet available annually for possible delivery to Bexar County.

Large volumes of ground water are available for development in certain areas of the Carrizo-Wilcox Aquifer south of Bexar County. Through the application of a mathematical model of the Carrizo-Wilcox Aquifer, it was concluded that approximately 40 thousand acre-feet could be pumped annually from the artesian zone of the aquifer in Wilson County, in the Guadalupe River Basin, over a 50-year period without dewatering the aquifer. However, severe declines in water levels which would occur under this development alternative could affect the availability of this part of the aquifer as a perpetual source of water for local uses. Subject to further study, the Carrizo-Wilcox Aquifer is not presently considered a suitable long-term water-supply source for large municipal and manufacturing demands in Bexar County.

Table III-19-6. Water Resources of the San Antonio River Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	19.5	—	—	—	19.5	19.5	—	—	19.5	.0	.0	.0
Surface Water	.0	.0	160.3	.4	160.7	.4	.0	63.8	64.2	96.5	.0	96.5
Total	19.5	.0	160.3	.4	180.2	19.9	.0	63.8	83.7	96.5	.0	96.5
2000												
Ground Water	22.2	—	—	—	22.2	22.2	—	—	22.2	.0	.0	.0
Surface Water	.0	.0	209.1	.5	209.6	.8	.0	75.8	76.6	133.1	(.1)	133.0
Total	22.2	.0	209.1	.5	231.8	23.0	.0	75.8	98.8	133.1	(.1)	133.0
2010												
Ground Water	24.2	—	—	—	24.2	24.2	—	—	24.2	.0	.0	.0
Surface Water	.0	.0	253.2	.7	253.9	.9	.0	90.3	91.2	162.9	(.2)	162.7
Total	24.2	.0	253.2	.7	278.1	25.1	.0	90.3	115.4	162.9	(.2)	162.7
2020												
Ground Water	26.3	—	—	—	26.3	26.3	—	—	26.3	.0	.0	.0
Surface Water	132.0	.0	318.0	1.0	451.0	1.1	128.5	127.9	257.5	193.7	(.2)	193.5
Total	158.3	.0	318.0	1.0	477.3	27.4	128.5	127.9	283.8	193.7	(.2)	193.5
2030												
Ground Water	27.3	—	—	—	27.3	27.3	—	—	27.3	.0	.0	.0
Surface Water	132.0	.0	392.0	.0	524.0	3.1	296.3	213.0	512.4	13.4	(1.8)	11.6
Total	159.3	.0	392.0	.0	551.3	30.4	296.3	213.0	539.7	13.4	(1.8)	11.6

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
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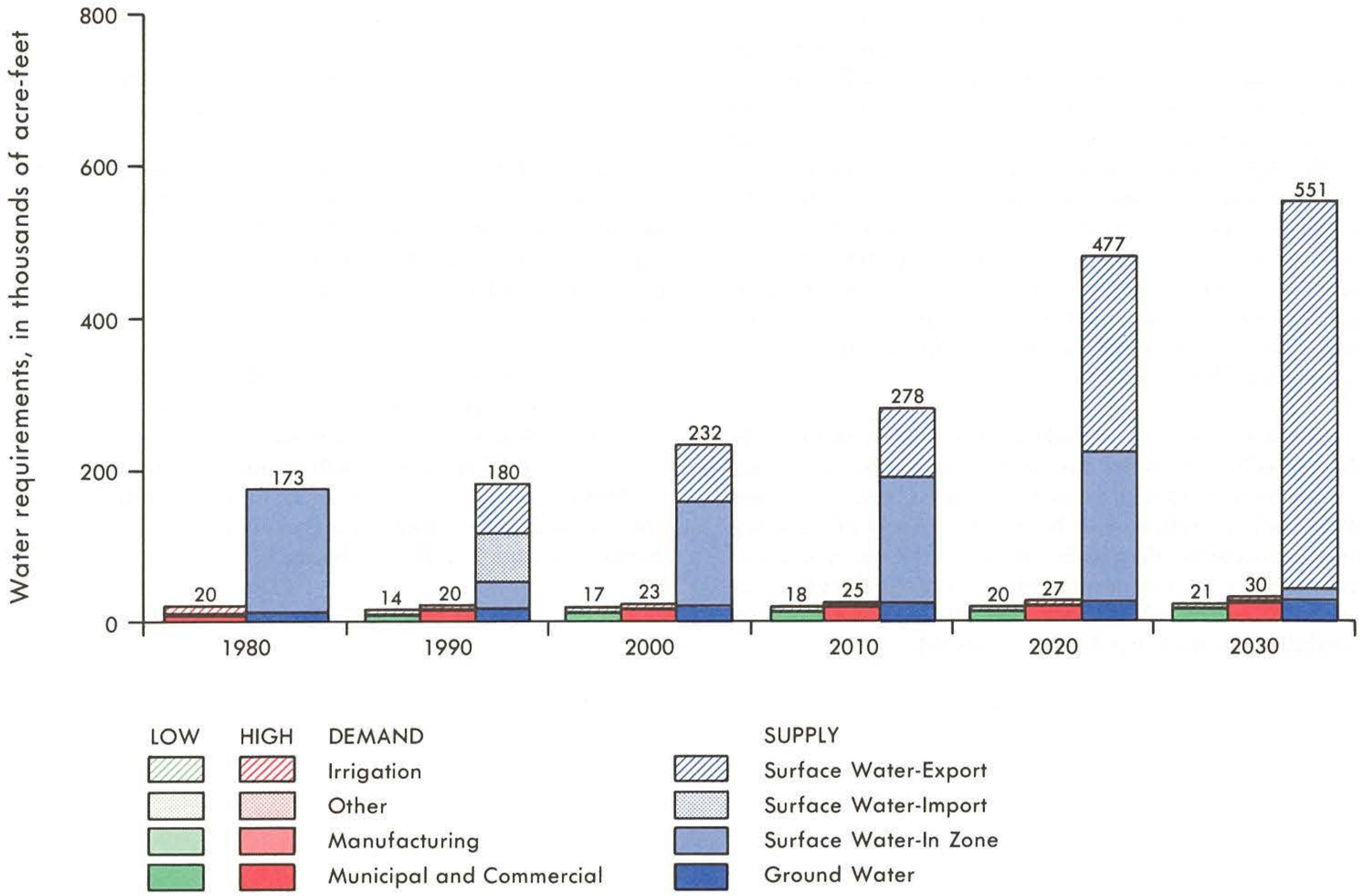

Figure III-19-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Antonio River Basin, Zone 2, 1980-2030

Water Quality Protection

A water quality management plan for the San Antonio River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. The plan serves as a basic element in the State's overall water quality strategy and provides guidance in establishing priorities for construction grants for waste-treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $437.0 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire San Antonio River Basin with approximately $413.4 million required for Zone 1 and $23.6 million projected for Zone 2. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

The San Antonio Channel Improvement project is perhaps the single most important project being accomplished in the basin with respect to flood control. The project provides for clearing, widening, deepening, and straightening the channel of the San Antonio River within and near the City of San Antonio as well as sections of San Pedro, Apache, Alazan, Martinez, and Six Mile Creeks.

When completed, the total length of improved channel will be nearly 35 miles, of which 14.4 miles is the San Antonio River channel. Estimated federal cost for the project is $46 million with an additional $1.3 million being cash contributions by local interests which are represented by the San Antonio River Authority. In addition to the financial contribution, local interests are providing the necessary right-of-ways and easements, modifying utilities, reconstructing five channel dams, constructing 14 new low-water crossings and 81 new bridges, and modifying five existing bridges totalling an estimated $48.9 million. This project is scheduled for completion in September 1989.

Olmos Dam, completed in 1926 on Olmos Creek by the City of San Antonio, does not normally impound water but serves to hold high peak discharges during flood flow. Water is later released to lessen the effects of flooding. Inspections of the dam indicated that work was needed on the structure to maintain the integrity of the dam for continued use of its 12,600 acre-feet of flood storage. This rehabilitation work has been completed.

The authorized Cibolo Reservoir, which will be located in Wilson County, will provide flood-control storage of 202.5 thousand acre-feet for flood protection along Cibolo Creek and the lower San Antonio River Basin.

In addition, the U.S. Soil Conservation Service (SCS) has constructed floodwater-retarding structures on several small streams in the basin. Forty-six of the planned 61 structures are complete. The study on Ecleto Creek has been approved for operation and will have a total of eleven structures when complete.

There are about 400 square miles of drainage area above 46 existing SCS floodwater-retarding structures within the San Antonio River Basin. As of October 1980, an additional 15 structures with a combined drainage area of 190 square miles were planned for construction. Both the planned and existing structures are divided fairly evenly between Zones 1 and 2 of the basin.

20. SAN ANTONIO-NUECES COASTAL BASIN

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20. SAN ANTONIO-NUECES COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The San Antonio-Nueces Coastal Basin is bounded on the north and east by the San Antonio River Basin and the Lavaca-Guadalupe Coastal Basin, and on the south and west by the Nueces River Basin and the Nueces-Rio Grande Coastal Basin. Runoff from the basin drains into Copano Bay, Mission Bay, St. Charles Bay, and Aransas Bay. Total basin drainage area is 2,652 square miles. For planning purposes, the San Antonio-Nueces Coastal Basin is treated as a single hydrologic unit (Figure III-20-1).

Surface Water

The average annual runoff in the basin during the 1941-70 period was about 102 acre-feet per square mile. The years of lowest flow during the 1941-70 period occurred from 1954 to 1956 and 1963 to 1964. The average annual runoff during the 1954-56 period was about eight acre-feet per square mile, reaching a low of six acre-feet per square mile in 1955. The average annual runoff during the 1963-64 period was 10 acre-feet per square mile, with a low of seven acre-feet per square mile in 1963. The lowest runoff rate (four acre-feet per square mile) occurred in 1950.

Flood problems associated with the San Antonio-Nueces Coastal Basin are similar to those experienced in other coastal basins. The terrain contributes to shallow flooding of long duration.

Records dating back to 1871 show that, on the average, a tropical storm or hurricane has affected the coastline of the San Antonio-Nueces Coastal Basin once every three years.

Runoff from the upper part of the basin is of good quality, and the average concentration of dissolved solids in flows of Medio and Blanco Creeks above Refugio is less than 250 milligrams per liter (mg/l). However, the main stem of the Mission River is usually highly saline for the entire length, principally as a result of runoff from oil fields in the Refugio area. Dissolved-solids concentrations in low flows of the river at Refugio often exceed 50,000 mg/l, and during dry years the concentration of dissolved solids has averaged between 30,000 and 45,000 mg/l. The average dissolved-solids concentration of the river below Refugio commonly exceeds 1,250 mg/l. Runoff to the Aransas River is of good quality, but is degraded locally by drainage from oil fields. Low flows frequently contain between 1,000 and 2,000 mg/l total dissolved solids. The discharge weighted average dissolved solids concentration of the river is estimated to be about 650 mg/l.

Ground Water

Except for the southern parts of Aransas and San Patricio Counties, the entire San Antonio-Nueces Coastal Basin is underlain by the Gulf Coast Aquifer. The aquifer extends to depths of 1,800 feet below land surface. The net water-bearing sand thickness ranges from 200 to 500 feet. Large-capacity well yields average about 500 gallons per minute (gpm); however, locally wells yield as much as 3,000 gpm. The ground water generally contains about 1,000 mg/l total dissolved solids, but ranges up to 3,000 mg/l total dissolved solids.

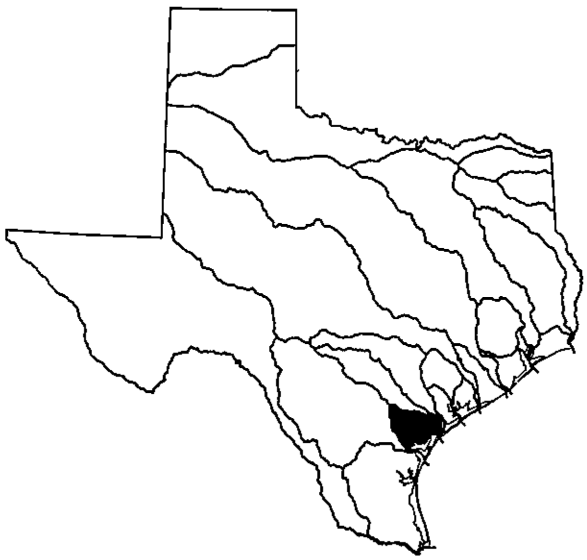
In areas immediately adjacent to the coast in Refugio, Aransas, San Patricio, and Nueces Counties within the basin, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage.

Population and Economic Development

The San Antonio-Nueces Coastal Basin had a population of 98.7 thousand in 1980. The economic structure of the coastal basin is diversified, with petroleum-related activities, agriculture, and tourism providing the base. Agricultural activities contribute over $76 million to the basin economy. Mineral production yields over $500 million annually to the area economy, principally from oil and gas, and to a lesser extent shell, stone, and clay.

Water Use

Municipal water use in 1980 in the San Antonio-Nueces Coastal Basin amounted to 14.2 thousand acre-feet. San Patricio County accounted for the greatest portion of the total use (45 percent), followed by Bee County (25 percent), Aransas County (20 percent), and Refugio County (10 percent). Cities accounting for significant portions of the total basin use were Rockport (11 percent), Beeville (16 percent), Aransas Pass (7 percent), Portland (11 percent), and Sinton (5 percent).



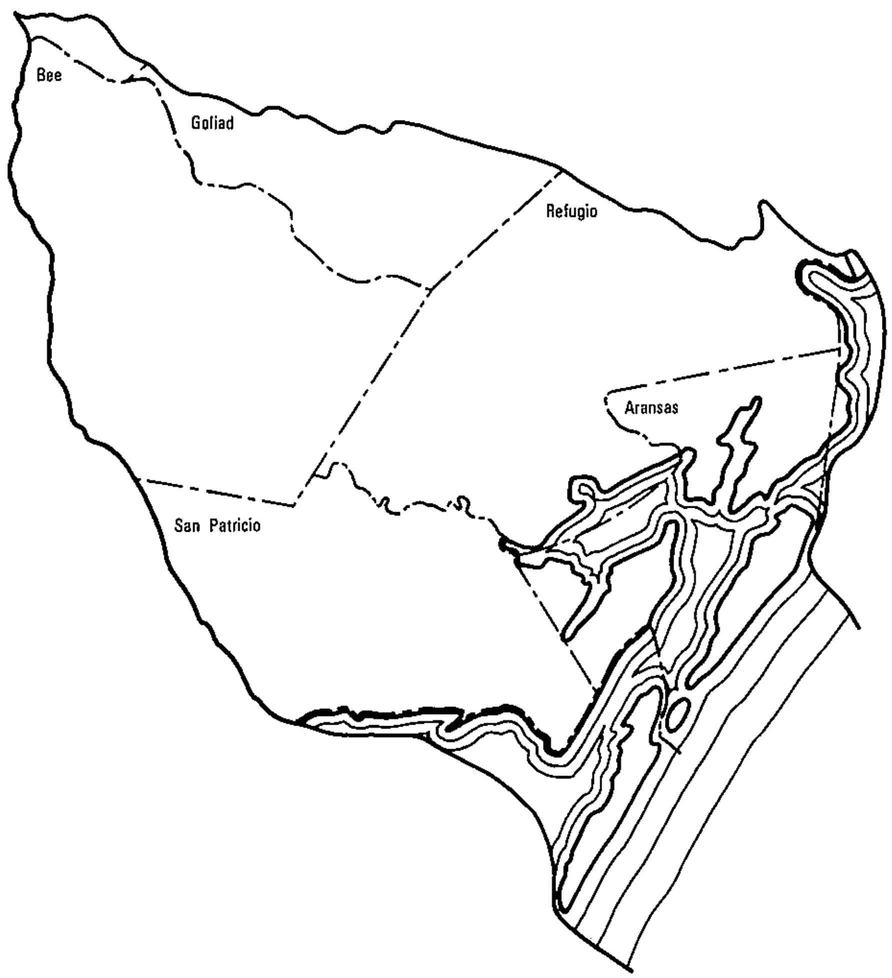


Figure III-20-1. San Antonio-Nueces Coastal Basin

Manufacturing industries in the basin used 14.5 thousand acre-feet of freshwater during 1980, concentrated in San Patricio County. Major water-using manufacturing industries within the basin include chemicals and allied product industries and primary metals industries.

In the San Antonio-Nueces Coastal Basin, 5.8 thousand acres was irrigated with 3.3 thousand acre-feet of water in 1980. All but about 0.1 thousand acres was irrigated from ground-water sources.

Estimated mining water use in the San Antonio-Nueces Coastal Basin totaled almost 900 acre-feet in 1980. Most of the fresh water was used for petroleum and natural gas production.

Livestock water use in the San Antonio-Nueces Coastal Basin in 1980 totaled 2.2 thousand acre-feet. The total livestock requirements were supplied by 400 acre-feet and 1.8 thousand acre-feet of ground-water and surface-water, respectively.

Navigation facilities in the San Antonio-Nueces Coastal Basin include the Gulf Intracoastal Waterway and its tributary waterways—the channels to Fulton, Rockport, and Aransas Pass, the Lydia Ann Channel, the Aransas Pass Entrance Channel, the La Quinta Channel, and a portion of the Corpus Christi Ship Channel. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the San Antonio-Nueces Coastal Basin totaled 11.3 thousand acre-feet. San Patricio County contributed the majority of the return flows, 66 percent.

Return flows from irrigation in the basin were estimated to be approximately 15 percent of the water applied for irrigation. Irrigation return flows in 1980 were estimated to be about 500 acre-feet. Much of these return flows were discharged near the Coast.

Current Ground-Water Development

Approximately 12.3 thousand acre-feet of ground water was used in 1980 in the San Antonio-Nueces Coastal Basin. All of the ground water used in the basin was from the Gulf Coast Aquifer.

Of the 12.3 thousand acre-feet of ground water used in the basin, about 7.8 thousand acre-feet or 63 percent was for municipal purposes, and 3.2 thousand acre-feet or 26 percent was used for irrigation purposes.

Significant overdrafts of ground water from the Gulf Coast Aquifer occurred in Aransas County due to withdrawals for municipal purposes, and in San Patricio County due to excessive withdrawals for municipal and irrigation purposes.

Current Surface-Water Development

There are no major reservoirs in the San Antonio-Nueces Coastal Basin. The San Patricio Municipal Water District (MWD) purchases raw and treated water from the City of Corpus Christi. The San Patricio MWD supplies water to industries and the Cities of Odem, Taft, Gregory, Portland, Ingleside, Port Aransas, Rockport, and Aransas Pass. The San Patricio MWD has a contractual agreement with the City of Corpus Christi to purchase up to 26 million gallons per day (gpd) of raw water and five million gpd of treated water, for a total of 34.7 thousand acre-feet annually.

In 1980, water use in the San Antonio-Nueces Coastal Basin totaled about 35.1 thousand acre-feet. Of this quantity, 22.8 thousand acre-feet was supplied from surface-water sources and 12.3 thousand acre-feet was supplied from ground-water sources. Almost all of the surface-water use was supplied by the San Patricio MWD, which delivered 17.3 thousand acre-feet of water to member cities and industries. The remaining major municipalities in the San Antonio-Nueces Coastal Basin, including Beeville, Sinton, Woodsboro, and Refugio obtained their water supplies from ground-water sources.

Water Rights

A total of 53,151 acre-feet of surface water was authorized or claimed for diversion and use in the San Antonio-Nueces Coastal Basin as of December 31, 1983 (Table III-20-1). Recreation uses accounted for nearly all of the basin total (99.2 percent) (Table III-20-2).

Water Quality

Residual effects of previous discharges of oil-field brines in unlined earthen pits and into the Mission River are expected to impact the quality of the river for some time. High pH, chloride, sulfate, and total dissolved-solids concentrations are the principal problems.

Flooding, Drainage, and Subsidence

Flood damages in the San Antonio-Nueces Coastal Basin usually result from the effects of hurricanes and

Table III-20-1. Authorized or Claimed Amount of Water, by Type of Right, San Antonio-Nueces Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	5	585
Claims	3	52,566
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	8	53,151

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-20-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, San Antonio-Nueces Coastal Basin

Type of Use	Number of Rights	Basin Total
Municipal	1	240
Industrial	0	0
Irrigation	4	166
Recreation	3	52,745
Total	8	53,151

hurricane related storms. Hurricane Carla caused considerable damage to the basin in 1971. Flood damages exceeded $2 million in Aransas County and amounted to $106 thousand and $195 thousand respectively, in Refugio and San Patricio Counties.

Hurricane Beulah was one of the most devastating events to occur in the basin in recent years. Flood losses within the basin totaled approximately $14 million. San Patricio County suffered the worst damages, with over $11 million in total flood damages. Aransas County suffered nonagricultural losses in excess of $1.5 million.

In 1970, Hurricane Celia produced extensive damages in this area of the Coast. Marine, as well as industrial, agricultural, and residential properties suffered great losses. Damages from Hurricane Celia totaled $14 million in San Patricio, Aransas, and Refugio Counties.

The basin suffered damages again in 1971 as a result of Hurricane Fern, although total damages from this hurricane were not as widespread as from Hurricane Beulah. Damages totaled $177 thousand in Aransas County, $400 thousand in Bee County, $302 thousand in Refugio County, and nearly $900 thousand in San Patricio County from Hurricane Fern.

September flooding in 1979 and Hurricane Allen in August 1980 brought two Presidential disaster declarations to the basin with over $2.1 million being expended by various federal agencies for flood relief. Flood insurance claims for 1979, 1980, and 1981 have totaled 996 for $5.3 million in flood damages.

The Federal Emergency Management Agency has designated 11 communities within the San Antonio-Nueces Coastal Basin as having one or more special flood-hazard areas. All eleven of these communities are participating in the National Flood Insurance Program. Flood insurance rate studies have been completed for nine communities. Insurance is available in the unincorporated portions of Aransas, Bee, Refugio, and San Patricio Counties. Aransas, Refugio and San Patricio Counties are participating in the Regular Phase of the Program and Bee County has a rate study underway.

Drainage problems in the San Antonio-Nueces Coastal Basin result from streams with insufficient channel capacities to carry storm runoff. Shallow depressions, ponds, and swales are covered with water for extended periods of time after heavy rains. Damage to crops often occurs as a result of numerous scattered depressions throughout the basin. Due to the low permeability of the soils in the area, on-site drainage facilities must be implemented to alleviate the problem.

Since 1918, more than 0.7 foot of subsidence has been measured at Refugio. This subsidence was caused by fresh ground-water withdrawals from the Gulf Coast Aquifer by Refugio, and petroleum and associated saline-water withdrawals from various oil and gas fields in and near Refugio. Fault activation and movement which can cause considerable damage to property are associated with subsidence. Damages caused by fault movement are very evident in urban areas of the Gulf Coastal Plain.

Recreation Resources

Mission River, Copano Creek, and the many smaller streams and ponds offer limited freshwater recreation opportunities in the San Antonio-Nueces Coastal Basin. These freshwater resources offer opportunities for boating and fishing. By comparison, coastal waters provide significantly more opportunities to the public, with both beach and shoreline areas as well as bay and Gulf waters available. Information from studies by the Texas Department of Water Resources and the Texas Parks and Wildlife Department shows an estimated 319.9 thousand sport fishing parties visited the Nueces and Mission-Aransas estuaries during 1976-1977. This recreation use generated an estimated total economic impact of over $60 million to regional and State economies.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the San Antonio-Nueces Coastal Basin is projected to increase 113 percent from 1980 to 2030 (Table III-20-3). The growth rate is expected to be 48 percent from 1980 to 2000 and 44 percent between 2000 and 2030.

San Patricio, Bee, and Aransas Counties are the three most populous counties in the basin. Although San Patricio County is expected to experience a 121 percent growth rate over the 1980-2030 period, its share of the total basin population is expected to increase slightly from 50 percent in 1980 to 52 percent in 2030. Bee County is expected to experience a 97 percent increase, yet decrease slightly in its share of total basin population. In contrast, Aransas County's share of total basin population is projected to grow from 14 percent to 20 percent, with a projected growth rate of 196 percent between 1980 and 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the San Antonio-Nueces Coastal Basin are projected to increase from the 1980 level of 14.2 thousand acre-feet by a projected maximum of 121 percent by the year 2000. In the year 2030, water requirements are projected to range from 27.9 to 45.4 thousand acre-feet. San Patricio County is projected to account for almost half of the total basin municipal requirements in the year 2000.

Industrial

Manufacturing water requirements in 1980 were 14.5 thousand acre-feet in the San Antonio-Nueces Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in San Antonio-Nueces Coastal Basin are projected to increase more than two and a half times by the year 2030, to a potential high of 40.7 thousand acre-feet by 2030. Manufacturing water requirements in the basin are expected to increase by 141-180 percent between 1980 and 2030, which is less than the statewide average of 178-230 percent.

In 1980, most of the manufacturing water use in the San Antonio-Nueces Coastal Basin occurred in San Patricio County.

Steam-Electric Power Generation

There are currently no plans to install steam-electric power generating capacity in San Antonio-Nueces Coastal Basin.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of

Table III-20-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
San Antonio-Nueces Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
San Antonio-Nueces Basin																		
Population			98.7			125.0			146.2			164.9			187.6			209.8
Municipal	7.8	6.4	14.2	6.2	20.2	26.4	6.6	24.8	31.4	6.5	29.0	35.5	7.2	33.2	40.4	7.4	38.0	45.4
Manufacturing	0.1	14.4	14.5	0.0	19.4	19.4	0.0	23.6	23.6	0.0	28.2	28.2	0.0	33.8	33.8	0.0	40.7	40.7
Steam Electric	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mining	0.8	0.1	0.9	0.9	0.1	1.0	1.0	0.2	1.2	0.9	0.0	0.9	0.6	0.1	0.7	0.4	0.0	0.4
Irrigation	3.2	0.1	3.3	4.2	0.7	4.9	4.2	0.8	5.0	4.3	0.8	5.1	4.3	0.8	5.1	4.3	0.8	5.1
Livestock	0.4	1.8	2.2	0.4	2.2	2.6	0.4	2.6	3.0	0.4	2.6	3.0	0.4	2.6	3.0	0.4	2.6	3.0
Basin Total Water	12.3	22.8	35.1	11.7	42.6	54.3	12.2	52.0	64.2	12.1	60.6	72.7	12.5	70.5	83.0	12.5	82.1	94.6

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the San Antonio-Nueces Coastal Basin are projected to increase from the 1980 level of 3.3 thousand acre-feet by a projected maximum 52 percent by the year 2000 in the high case, and in the low case. In the year 2030, water requirements in the Basin are projected to remain about 5.1 thousand acre-feet annually in the low and high cases to irrigate about 5.8 thousand acres.

Livestock

Livestock water needs within the basin are projected to increase from 2.2 thousand acre-feet in 1980 to 3.0 thousand acre-feet annually by 2030.

Mining

Mining water requirements, used mainly in the recovery of oil and natural gas in the San Antonio-Nueces Coastal Basin are projected to decrease from 0.9 thousand acre-feet in 1980 to 0.4 thousand acre-feet annually in 2030. This decrease in water demand is the result of declining potential quantities of oil and natural gas available for future production.

Navigation

Currently, no navigation facilities which would require the use of regulated freshwater supplies are planned in the basin.

Hydroelectric Power

There are no planned hydroelectric power generating facilities in the basin.

Estuarine Freshwater Inflows

The Mission and Aransas Rivers discharge from the San Antonio-Nueces Coastal Basin into the Mission-Aransas estuary. Estimates of freshwater inflow needs of the Mission-Aransas estuary are based on the Mission River gaged flows at Refugio and the total fisheries harvests for the Mission-Aransas and Nueces estuaries. The total fisheries harvests for the Mission-Aransas and Nueces estuaries are used because these two estuaries share a common outlet to the Gulf of Mexico.

Estimates of the gaged inflows needed to sustain the desired salinity limits for the Subsistence Alternative yield a 15.5 thousand acre-feet annual gaged inflow volume (Table III-20-4). The inflows needed annually, from the gaged portion of the Mission River (Table III-20-4), to maintain the average 1962 through 1976 commercial fisheries harvests (Fisheries Harvest Maintenance Alternative) for the combined Mission-Aransas and Nueces estuaries totals 19.4 thousand acre-feet. For the Harvest Enhancement Alternative, it is established that maximizing the finfish production in the Mission-Aransas and Nueces estuaries requires volumes of water from the contributing drainage areas of the estuary equal to the annual inflow limit set at the average (1941-1976) combined inflows of 368 thousand acre-feet per year, with an annual gaged inflow need of 42.7 thousand acre-feet from the Mission River Basin (Table III-20-4). Since the estimated freshwater inflow need equals the upper limit on inflow, it is likely that additional inflow (consistent with salinity limits) will increase the annual finfish harvest. The gaged inflow needed from the Mission River Basin for the Biotic Species Viability Alternative to maintain salinities within the viability limits for organisms in the Mission-Aransas estuarine system is estimated to be 2.8 thousand acre-feet annually (Table III-20-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the San Antonio-Nueces Coastal Basin through the year 2030 is 30.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the San Antonio-Nueces Coastal Basin by decade from 1990 through 2030 is expected to be from 11.7 to 12.5 thousand acre-feet per year (Table III-20-3). The approximate average annual projected ground-water use within the basin is expected to be about 12.2 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

Dependable surface-water supplies in the San Antonio-Nueces Coastal Basin are currently provided from

Table III-20-4. Gaged River Inflow Needs of the Mission-Aransas Estuary From the San Antonio-Nueces Coastal Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Mission River[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability
January	.7	.7	.7	.14
February	1.2	1.2	1.2	.07
March	.9	.9	.9	.13
April	1.5	1.5	3.9	.30
May	2.9	2.9	9.9	.61
June	1.8	1.8	6.3	.21
July	.8	2.8	2.8	.14
August	.8	1.8	9.1	.22
September	1.9	1.9	1.9	.36
October	1.2	1.2	1.2	.34
November	.9	.9	1.9	.16
December	.9	1.8	2.9	.12
Annual	15.5	19.4	42.7	2.80

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Gaged streamflow of Mission River at Refugio.

the Nueces River Basin. These supplies are projected to be insufficient to meet all anticipated needs after 2010. However, based upon proposed surface-water development, projected future surface-water requirements in the San Antonio-Nueces Coastal Basin can be fully satisfied for all purposes other than irrigation through the year 2030 (Table III-20-5, Figure III-20-2). An estimated 48.6 thousand acre-feet and 78.6 thousand acre-feet of surface water are proposed to be supplied annually to this basin through interbasin transfers from the San Antonio or Nueces River Basins or both in 2000 and 2030, respectively. A slight annual shortage for irrigation is estimated to occur in each decade from 1990 through 2030 due to insufficient ground water to meet all projected irrigation needs. This shortage is approximately 0.8 thousand acre-feet per year.

No major reservoirs are proposed in this coastal basin. Projected surface-water needs in the San Antonio-Nueces Coastal Basin can be supplied through existing reservoirs and conveyance facilities in the Nueces River Basin until the year 2020. By the year 2020, additional surface-water supplies will be needed. An alternative source proposed for meeting these needs is Goliad Reservoir on the San Antonio River. This reservoir could supply sufficient surface water to meet anticipated needs in the basin through the year 2030. Additional studies will need to be undertaken by State and local interests to assess the economic, engineering, and environmental feasibility of this project.

Water Quality Protection

A water quality management plan for the San Antonio-Nueces Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Corpus Christi metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $41.2 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire San Antonio-Nueces Coastal Basin in January 1980

Table III-20-5. Water Resources of the San Antonio-Nueces Coastal Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	11.7	—	—	—	11.7	11.7	—	—	11.7	.0	.0	.0
Surface Water	.0	—	.0	39.6	39.6	40.3	—	.0	40.3	.0	(.7)	(.7)
Total	11.7	—	.0	39.6	51.3	52.0	—	.0	52.0	.0	(.7)	(.7)
2000												
Ground Water	12.2	—	—	—	12.2	12.2	—	—	12.2	.0	.0	.0
Surface Water	.0	—	.0	48.6	48.6	49.3	—	.0	49.3	.0	(.7)	(.7)
Total	12.2	—	.0	48.6	60.8	61.5	—	.0	61.5	.0	(.7)	(.7)
2010												
Ground Water	12.1	—	—	—	12.1	12.1	—	—	12.1	.0	.0	.0
Surface Water	.0	—	.0	57.2	57.2	57.9	—	.0	57.9	.1	(.8)	(.7)
Total	12.1	—	.0	57.2	69.3	70.0	—	.0	70.0	.1	(.8)	(.7)
2020												
Ground Water	12.5	—	—	—	12.5	12.5	—	—	12.5	.0	.0	.0
Surface Water	.0	—	.0	67.0	67.0	67.8	—	.0	67.8	.0	(.8)	(.8)
Total	12.5	—	.0	67.0	79.5	80.3	—	.0	80.3	.0	(.8)	(.8)
2030												
Ground Water	12.5	—	—	—	12.5	12.5	—	—	12.5	.0	.0	.0
Surface Water	.0	—	.0	78.6	78.6	79.4	—	.0	79.4	.0	(.8)	(.8)
Total	12.5	—	.0	78.6	91.1	91.9	—	.0	91.9	.0	(.8)	(.8)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

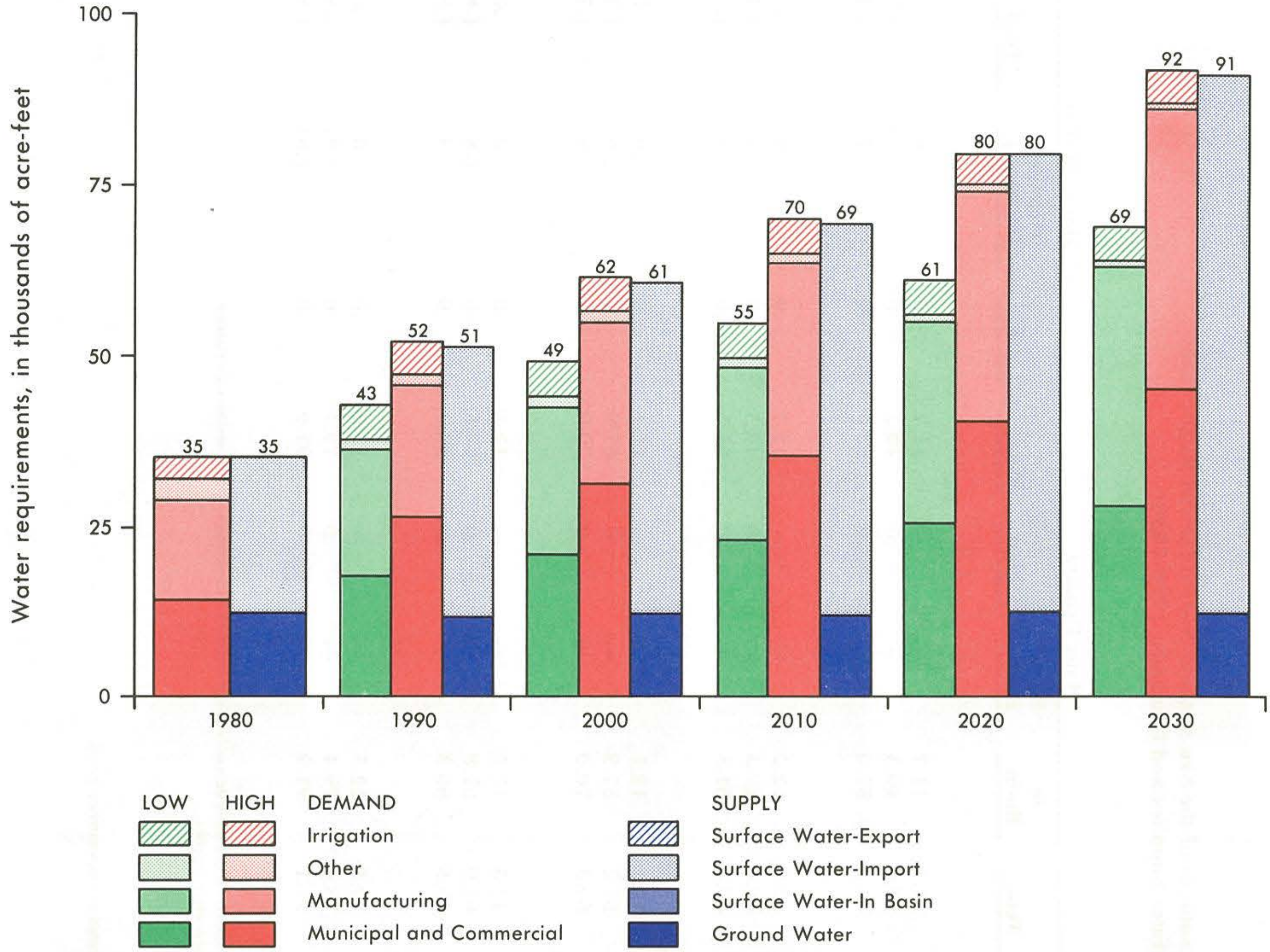


Figure III-20-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, San Antonio-Nueces Coastal Basin, 1980-2030

dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

Local projects have afforded some protection from flooding in the coastal areas of the basin; however, major hurricane protection is not available. Coastal urban areas will be studied by the U.S. Army Corps of Engineers to determine the feasibility of providing future hurricane flood protection. An additional study has been made on Chiltipin Creek to consider improvements for flood protection to the City of Sinton. As with all federal projects, benefits must justify costs, and local sponsors must be able to contribute their share of the project cost.

As federal efforts are uncertain at the present time, local flood-protection measures and flood-plain management measures and regulations seem to offer the best alternative for minimizing flood damages. Levees and drainage improvements can help correct flood problems affecting existing developments, and proper site selection and conformance to minimum building standards will reduce flood potential to new developments.

21. NUECES RIVER BASIN

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21. NUECES RIVER BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Nueces River Basin is bounded on the north and east by the Colorado, Guadalupe, and San Antonio River Basins and the San Antonio-Nueces Coastal Basin, and on the west and south by the Rio Grande Basin and the Nueces-Rio Grande Coastal Basin. Total basin drainage area is 16,950 square miles. The basin empties into Nueces Bay, an arm of Corpus Christi Bay. Principal streams include: the Atascosa River; the Frio River and its principal tributaries (San Miguel Creek, Hondo Creek, and the Sabinal, Dry Frio, and Leona Rivers); and the Nueces River. The Atascosa and Frio Rivers join the Nueces River above Lake Corpus Christi. For planning purposes, the Nueces River Basin is treated as a single hydrologic unit (Figure III-21-1).

Surface Water

In the Edwards Plateau area above the Balcones Fault Zone, the average annual runoff (1941-70) was 118 acre-feet per square mile. In the southwestern part of the basin, the average annual runoff during the 1962-1970 period was 74 acre-feet per square mile. In the eastern part of the basin, the average annual runoff between 1941 and 1970 was 88 acre-feet per square mile. The Balcones Fault Zone crosses the basin along an approximate east-west line from San Antonio to Del Rio, passing just north of Uvalde. A substantial part of the flows of the Nueces River and its principal tribuaries enter the fractured and cavernous limestone formations as they cross the fault zone. Low runoff rates between 1941 and 1970 occurred during four periods—1947-48, 1950-52, 1954-56, and 1962-66, and were 14, 16, 10, and 14 acre-feet per square mile in these periods, respectively. The lowest runoff in each period, in acre-feet per square mile, was 8 in 1948, 10 in 1952, 8 in 1955, and 5 in 1962.

The Edwards Plateau portion of the basin is known for extremely high peak discharges such as those experienced during the floods of June 1935 and September 1955. These floods produced some of the highest peak discharges ever recorded in drainage areas of comparable size in Texas. The gaging station at Laguna, Texas on the Nueces River recorded its maximum discharge of 307 thousand cubic feet per second and a gage height of 29.95 feet during the flood of September 24, 1955. This was the greatest known river stage since 1866.

Downstream from the Balcones Fault Zone, the Nueces River and its tributaries cross various permeable formations and have small channel capacities with wide flood plains. As flood peaks cross the fault zone, there are substantial reductions due to in-channel losses and losses to bank storage.

The lower part of the basin has been significantly affected by floods associated with hurricanes and tropical storms moving inland from the Coast. Records dating back to 1871 show that, on the average, a tropical storm or hurricane has affected the Nueces River Basin once every three years.

The average dissolved-solids concentrations of streams in the upper parts of the basin range from 150 to 400 milligrams per liter (mg/l). Higher concentrations have been observed during low-flow periods; however, water-quality data indicate that most streams in the basin contain relatively good-quality water.

Ground Water

The Edwards-Trinity (Plateau) Aquifer occurs in the upper part of the Nueces River Basin. Yields of wells are generally low. The water generally contains from 200 to 300 mg/l total dissolved solids.

The Trinity Group Aquifer occurs in the upper part of the Nueces River Basin. Well yields are commonly low. The quality of water in the aquifer is generally good, but deteriorates with depth. Total dissolved-solids concentrations range from less than 1,000 to about 3,000 mg/l.

The Edwards (Balcones Fault Zone) Aquifer occurs in a band across the upper middle part of the Nueces River Basin. Total thickness ranges from about 400 to 900 feet. Yields of large-capacity wells average about 900 gallons per minute (gpm), but locally wells produce up to 1,200 gpm. Water in the aquifer generally contains less than 500 mg/l total dissolved solids.

The Carrizo-Wilcox Aquifer occurs over most of the central part of the Nueces River Basin. Total thickness ranges up to 3,000 feet. Yields of high-capacity wells average about 700 gpm, but locally wells produce a maximum of about 1,200 gpm. The water generally contains less than 1,000 mg/l total dissolved solids, but is moderately saline locally.

The Gulf Coast Aquifer covers the lower part of the Nueces River Basin. The aquifer extends to a maximum

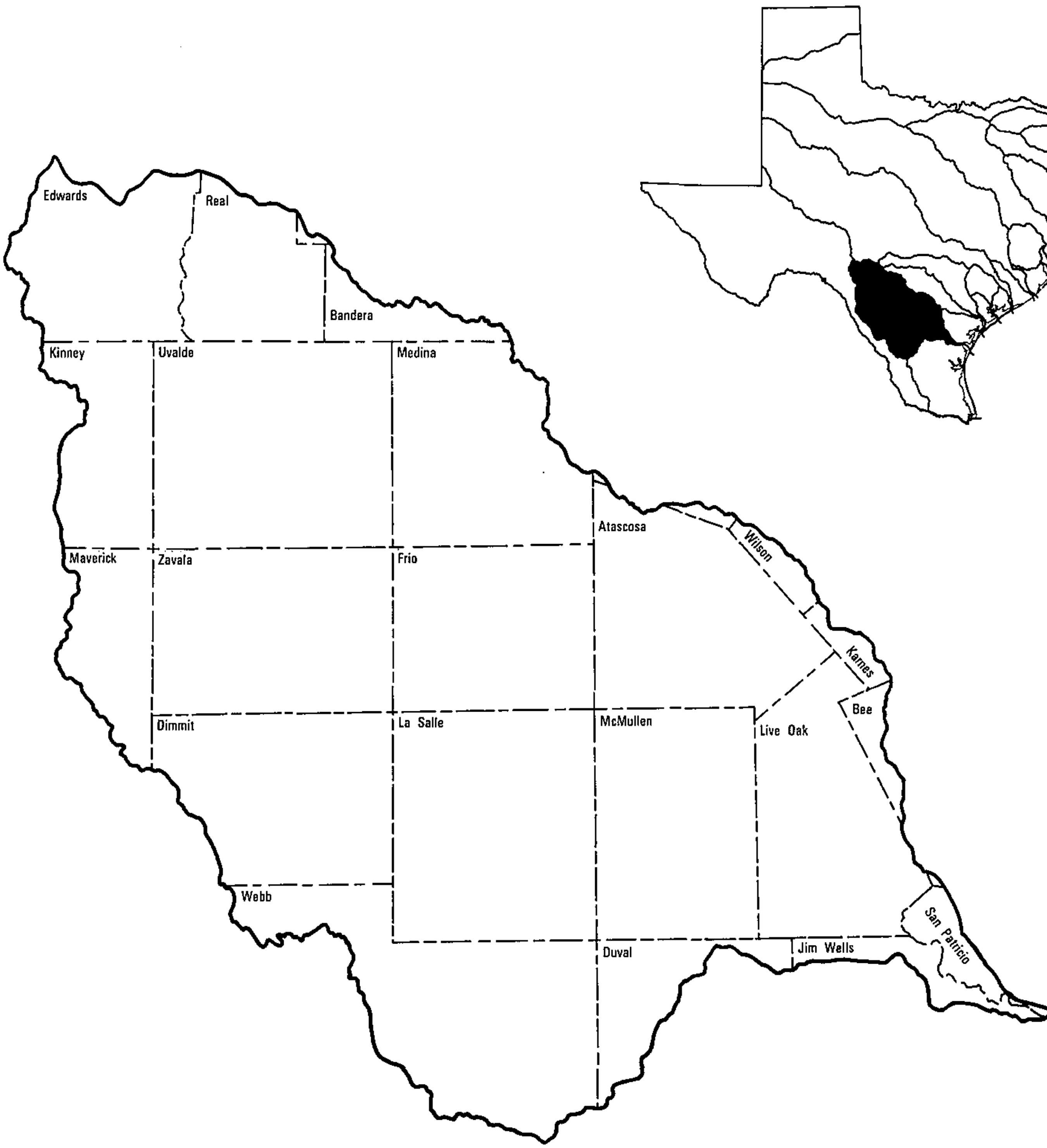

Figure III-21-1. Nueces River Basin

depth of about 1,600 feet. Yields of large-capacity wells average about 500 gpm, but locally wells produce up to 1,800 gpm. Water quality varies, but in most areas the water contains from 1,000 to 1,500 mg/l total dissolved solids.

The Queen City Aquifer occurs in a band across the middle of the Nueces River Basin. Total thickness ranges up to about 1,400 feet, but generally is considerably less. Well yields are generally low, but higher yields can be developed from properly constructed wells. Water quality ranges from less than 1,000 to 3,000 mg/l total dissolved solids.

The Sparta Aquifer also occurs in a band across the middle part of the Nueces River Basin. Total thickness ranges from about 50 to 200 feet. Yields of wells are generally low, but yields of more than 100 gpm can be developed from properly constructed wells. The water generally contains from less than 1,000 to over 10,000 mg/l total dissolved solids.

Over pumpage of the Trinity Group Aquifer in Uvalde and Medina Counties can cause gradual deterioration of ground-water quality because of saline-water encroachment. The same condition is true for the Carrizo-Wilcox Aquifer in central Webb, southeastern La Salle, central McMullen, northern Live Oak, and southwestern Karnes Counties within the basin. Saline-water encroachment adjacent to the downdip extents of these aquifers as well as the Queen City and Sparta Aquifers can be controlled by proper well location, completion, and pumpage.

The potential for saline-water encroachment may be very great in the Edwards (Balcones Fault Zone) Aquifer within the basin. Since the aquifer is composed of factured and faulted limestones with locally unpredictable secondary porosity and permeability, it is impossible to define or predict with any accuracy the aquifer's flow system on a local basis. Of great importance is the aquifer's regional flow system which generally consists of major natural recharge (inflow) in the Nueces River Basin, movement of water in the subsurface artesian zone northeastward beneath the Nueces and San Antonio River Basins, and major natural discharge (outflow) of water at Comal and San Marcos Springs in the Guadalupe River Basin. At the aquifer's downdip extent under natural conditions, ground-water quality deteriorates rapidly across the fresh-saline water interface. Therefore, a very large amount of saline water occurs immediately adjacent to and southeast of the fresh water-bearing deposits of the aquifer. During the drought of the 1950's when water-level elevations were at historical lows and when amounts of ground-water withdrawals from the aquifer were large, no significant saline-water encroachment was detected. However, what will happen to the aquifer's water quality if water-level elevations are lowered below the levels of the 1950's? Considering the aquifer's regional flow system, an extreme lowering of water levels below the 1950's level in the Nueces, San Antonio, and Guadalupe River Basins may cause a significantly large invasion of saline water which may contaminate not only municipal, industrial, and irrigation fresh water supplies but also any reduced flows at Comal, San Marcos, and other springs which are located near the fresh-saline water interface of the aquifer.

In areas immediately adjacent to the coast in Nueces and San Patricio Counties fresh water deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage.

Population and Economic Development

The population of the Nueces River Basin in 1980 was 153.5 thousand. Uvalde is the largest population center with over 14 thousand residents. Crystal City, Pearsall, Hondo, Carrizo Springs, and Cotulla all have populations of 9 thousand or less.

The economy of the Nueces River Basin is based on agriculture and mineral production. The Nueces River Basin contains the extensively irrigated agricultural area of the Winter Garden. In a few counties, hunting and tourism are significant economic activities, notably Uvalde County and Live Oak County where Lake Corpus Christi is located. Food processing is an important support industry in some counties.

Water Use

Municipal water use in 1980 in the Nueces River Basin totaled 30.4 thousand acre-feet. The most significant water-using areas are Uvalde County (20 percent), Nueces County (10 percent), Medina County (12 percent), and Atascosa County (13 percent). Twenty-two percent of the basin water use occurred in rural areas or in cities which had less than one thousand population. The City of Uvalde used the largest volume of water of any city in the basin, accounting for 16 percent of the basin municipal use.

A total of 2.5 thousand acre-feet of freshwater was used by manufacturing industries in the Nueces River Basin in 1980. Most of this water was used in the manufacture of food and kindred products, chemicals and allied products, and petroleum refining and related products.

In 1980, there was a total of 608 megawatts of installed steam-electric power generating capacity in the

Nueces River Basin. During 1980, almost 700 acre-feet of ground water was withdrawn and 3.0 thousand acre-feet of surface water consumed by these power plants.

Large quantities of ground water are pumped from both the Edwards (Balcones Fault Zone) and Carrizo-Wilcox Aquifers for irrigation use. In 1980, irrigation showed a total of about 277.4 thousand acres using 471.8 thousand acre-feet of water for irrigation in the Nueces River Basin. This includes irrigation in the Chacon Lake and Devine areas, which is supplied with water diverted from Medina Lake in the San Antonio River Basin. Of the total annual use, ground water supplied 397.5 thousand acre-feet. Surface water furnished 74.3 thousand acre-feet, including Medina Lake water used in the Chacon Lake and Devine areas.

In 1980, mining industries in the Nueces River Basin used 5.1 thousand acre-feet of freshwater. Mining of non-metals (primarily sulfur mining operations) used 1.7 thousand acre-feet. Mining water use associated with petroleum and natural gas production totaled 1.6 thousand acre-feet of freshwater. In situ uranium mining operations accounted for the remaining freshwater use in the basin.

Livestock water use in 1980 totaled 13.2 thousand acre-feet in the Nueces River Basin. Most of this total was used in the production of cattle. Ground water supplied approximately 4.6 thousand acre-feet and surface water supplied the remaining 8.6 thousand acre-feet.

Return Flows

In 1980, a total of 6.4 thousand acre-feet of municipal and manufacturing return flows originated in the Nueces River Basin. Nueces County accounted for 2.2 thousand acre-feet of the total in the basin.

In 1980, irrigation return flows in the basin were small, although approximately 10 thousand acre-feet of return flows resulted from the surface-water irrigation in the Chacon Lake and Devine project area.

Current Ground-Water Development

Approximately 437.0 thousand acre-feet of ground water was used in 1980 in the Nueces River Basin. Approximately, 63 percent of the ground water used was from the Carrizo-Wilcox Aquifer, 26 percent was from the Edwards (Balcones Fault Zone) Aquifer, and about 6 percent was from the Leona Formation, an alluvial aquifer in southern Uvalde and northwestern Zavala Counties.

Of the 437.0 thousand acre-feet of ground water used in the basin, 397.5 thousand acre-feet or 91 percent was used for irrigation purposes, and about 26.7 thousand acre-feet or 6 percent was used for municipal purposes.

Small to large overdrafts of ground water from the Carrizo-Wilcox Aquifer occurred in 1980 in Atascosa, Bexar, Frio, Medina, Wilson, and Zavala Counties, due primarily to withdrawals for irrigation purposes. A large overdraft of the Edwards (Balcones Fault Zone) Aquifer occurred in Medina County, due primarily to withdrawals for irrigation.

Current Surface-Water Development

Lake Corpus Christi and Choke Canyon Reservoir are the largest existing reservoirs in the Nueces River Basin. The Lower Nueces River Water Supply District owns Lake Corpus Christi and the City of Corpus Christi operates the reservoir. Choke Canyon Reservoir is jointedly owned by the Nueces River Authority and the City of Corpus Christi.

The City of Corpus Christi is the largest purchaser of water from the Lake Corpus Christi. Water released from the reservoir for the Corpus Christi area is treated, settled, filtered, and pumped from the river at Calallen, some 35 miles downstream from Lake Corpus Christi. The city also delivers both treated and untreated water to Reynolds Metals Company and the San Patricio Municipal Utility District. The San Patricio Municipal Water District supplies water to industries and the Cities of Odem, Taft, Gregory, Portland, Ingleside, Rockport, and Port Aransas, all located in the adjacent San Antonio-Nueces Coastal Basin. In addition, the city sells raw water to the City of Mathis, the Celanese Corporation at Bishop in Zone 1 of the adjacent Nueces-Rio Grande Coastal Basin, and Suntide Refinery near Corpus Christi in the Nueces River Basin. The Alice Water Authority purchases water from the city at Lake Corpus Christi for municipal use. In 1980, about 109.5 thousand acre-feet of water was sold through the Corpus Christi system and exported from Lake Corpus Christi to adjoining coastal basins. Contracts and appropriate water rights permits have been consummated whereby the City of Corpus Christi will increase the current commitment by serving the future surface-water need of the City of Beeville in the San Antonio-Nueces Coastal Basin and the South Texas Water Authority in the Nueces-Rio Grande Coastal Basin, Zone 1.

The water demands placed on Lake Corpus Christi are rapidly approaching the annual dependable supply which the reservoir will yield. The City of Corpus Christi and the Nueces River Authority are co-sponsors of the recently completed Choke Canyon Reservoir on the Frio River. Choke Canyon Reservoir, when filled and fully operational, and Lake Corpus Christi will be operated as a system in order to optimize the dependable annual firm yields.

In 1980, ground-water and surface-water use in the Nueces River Basin totaled 526.7 thousand acre-feet, with ground water the major water-supply source. Although irrigation water is provided primarily from ground-water sources, water for irrigation purposes in the basin is diverted from Lake Medina in the San Antonio River Basin. In 1980, about 38.4 thousand acre-feet was diverted from this source into the Nueces River Basin. In addition, Upper Nueces Reservoir, located on the Nueces River in Zavala County, is an important source of irrigation water for the Winter Garden area.

Municipal and manufacturing water use in 1980 amounted to 32.9 thousand acre-feet within the Nueces River Basin. Ground-water sources provided over 88 percent of the water supply to meet this demand. Surface-water use in 1980 for municipal and manufacturing supplies amounted to only 3.8 thousand acre-feet. A major portion of this demand was supplied from Lake Corpus Christi as a municipal water supply for the portion of the City of Corpus Christi lying within the Nueces River Basin.

Water Rights

A total of 721,643 acre-feet of surface water was authorized or claimed for diversion and use in the Nueces River Basin as of December 31, 1983 (Table III-21-1). Irrigation uses accounted for 265,331 acre-feet (36.8 percent) of the basin total, followed by municipal and industrial uses which totaled 222,211 and 228,930 acre-feet, respectively (Table III-21-2).

Water Quality

The Nueces River Basin has relatively good quality surface water. The quality in the less inhabited upper reaches of the basin is excellent. Tributaries originating in the northern part of the basin lose substantial amounts of water when crossing the recharge zone of the Edwards (Balcones Fault Zone) Aquifer. As a result, streamflows in the Nueces River Basin downstream from the recharge zone consist almost entirely of storm runoff. Above Lake Corpus Christi runoff from oil-field areas and agricultural runoff have increased dissolved-solids concentrations of the Nueces River in the past; however, most of these problems have been alleviated.

Flooding, Drainage, and Subsidence

Most of the damage from floodwaters in the Nueces River Basin is chiefly to crops, pasture land, and associated agricultural properties. In the upper basin, limited urban damage occurs in Uvalde, Utopia, and D'Hanis from localized flooding produced by intense thunderstorm activity. Several smaller communities suffer from occasional flood problems. Hondo Creek has caused flooding problems in the area around the City of Hondo in Medina County, and localized flooding occurs in Devine and Lytle.

Table III-21-1. Authorized or Claimed Amount of Water, by Type of Right, Nueces River Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	111	169,253
Claims	168	123,019
Certified Filings	54	110,218
Certificates of Adjudication	8	319,153
Total Authorizations and Claims	341	721,643

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-21-2. Authorized or Claimed Amount of Water, by Type of Use, in Acre-Feet, Nueces River Basin

Type of Use	Number of Rights	Basin Total
Municipal	21	222,211
Industrial	3	228,930
Irrigation	307	265,331
Mining	3	22
Recharge	3	2,290
Recreation	13	2,859
Total	341[1]	721,643

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

Flood problems in Crystal City are extremely serious. Numerous floods over the years have produced substantial damage to residential developments located within the flood plains of Turkey Creek and the Nueces River. A flood on October 9, 1959 flooded 107 homes in Crystal City. It is possible for large magnitude floods to block major highways and evacuation routes, thus isolating the city.

Minor flooding in urban areas during the period 1978-1981 produced 22 flood insurance claims for $136 thousand in flood damages.

Flood-prone areas have been identified by the Federal Emergency Management Agency in 25 incorporated cities. Maps showing areas subject to inundation by the 100-year flood have been prepared for most of the cities within the basin, and work is currently underway to map flood-prone areas in the counties. Presently, 18 cities have adopted flood plain management standards for participation in the National Flood Insurance Program. Atascosa, Duval, Kinney, McMullen, Medina, Real, Uvalde, and Zavala Counties have also chosen to participate in the program. Flood insurance rate studies have been completed for eight cities and two counties in the basin and a study is completed in Uvalde. As funds and time permit, additional studies will be conducted within the basin.

Drainage problems in the Nueces River Basin are largely restricted to the Rio Grande Plains land-resource area. The natural surface drainageways, which are principally small channels, shallow depressions, ponds, and swales, are insufficient to carry intense storm runoff. Since surface depressions are common in the area, cultivated fields often include areas of standing water which damage field crops. The soils have low permeability, and surface drainage is required to protect agricultural investments from damage.

The amount and distribution of subsidence in the coastal areas of the Nueces River Basin are unknown. The potential for subsidence and active faulting in the Saxet Oil and Gas Field exists in Nueces County. However, the subsidence associated with petroleum and related saline-water withdrawals in this area within the basin is probably less than 0.5 foot.

Recreation Resources

Lake Corpus Christi (21.9 thousand surface acres), Choke Canyon Reservoir (26.0 thousand surface acres), and the Upper Nueces Reservoir (300 surface acres) in Zavala County are the only three reservoirs of 5.0 thousand acre-feet capacity or more in the Nueces River Basin. Lake Corpus Christi is located in San Patricio, Jim Wells, and Live Oak Counties and serves the recreational needs of the Corpus Christi metropolitan area. Among the other major freshwater recreation resources located within the basin are the Frio, Atascosa, and Nueces Rivers.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Nueces River Basin is projected to increase 102 percent from 1980 to 2030 (Table III-21-3). An increase of 41 percent is expected by the year 2000, then an additional 43 percent increase is expected by 2030. Atascosa County, which is the most populous with 16 percent of the basin total in 1980, is expected to experience a 113 percent increase in population by 2030. Uvalde County, currently the second most populous county in the basin, is anticipated to grow by 227 percent and become the largest county with 21 percent of the basin population by 2030.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Nueces River Basin are projected to increase from the 1980 level of 30.4 thousand acre-feet by a projected maximum of 77 percent by the year 2000 (high case). In the year 2030, water requirements are projected to range from 52.9 to 77.1 thousand acre-feet.

Industrial

Manufacturing water requirements in 1980 were 2.5 thousand acre-feet in the Nueces River Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Nueces River Basin are projected to increase more than three times by the year 2030, to a potential high of 8.5 thousand acre-feet by 2030 (high case). Most of the present manufacturing water requirements are associated with the

Table III-21-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Nueces River Basin

River Basin Zone & Category of Use	1980			1990			2000			2010			2020			2030		
	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total	Ground Water	Surface Water	Total
Nueces Basin																		
Population			153.5			186.4			216.4			248.1			279.5			309.3
Municipal	26.7	3.7	30.4	39.4	5.4	44.8	47.7	6.0	53.7	54.8	6.9	61.7	61.5	8.2	69.7	67.4	9.7	77.1
Manufacturing	2.4	0.1	2.5	1.8	1.6	3.4	2.4	2.1	4.5	3.0	2.6	5.6	3.7	3.2	6.9	4.7	3.8	8.5
Steam Electric	0.7	3.0	3.7	6.1	3.0	9.1	11.5	3.0	14.5	17.0	3.0	20.0	22.5	3.0	25.5	19.2	11.8	31.0
Mining	5.1	0.0	5.1	5.9	0.0	5.9	6.7	0.0	6.7	8.4	0.1	8.5	10.3	0.1	10.4	11.4	0.6	12.0
Irrigation	397.5	74.3	471.8	153.6	125.8	279.4	144.9	133.6	278.5	147.3	156.5	303.8	144.9	158.9	303.8	91.0	212.9	303.9
Livestock	4.6	8.6	13.2	6.4	9.2	15.6	6.9	11.1	18.0	6.4	11.6	18.0	6.5	11.5	18.0	4.3	13.7	18.0
Basin Total Water	437.0	89.7	526.7	213.2	145.0	358.2	220.1	155.8	375.9	236.9	180.7	417.6	249.4	184.9	434.3	198.0	252.5	450.5

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year

basin's economy—chemicals, processed fruits and vegetables, and petroleum refining. By 2030, the chemical industry is predicted to require the majority of basin water use.

Steam-Electric Power Generation

The development of near-surface lignite deposits in the McMullen County area of the Nueces River Basin will contribute significantly to growth in steam-electric power generating capacity through the year 2000. Beyond 2000, growth will continue but at a slower pace. Two cases of future electricity demand were used to develop projections of steam-electric power generating water use. From 1980 to 2000, rapid expansion is projected to occur—a growth of 292 percent. By 2030, water requirements are projected to range from 23.2 to 31.0 thousand acre-feet.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Nueces River Basin are projected to decrease from the 1980 level of 471.8 thousand acre-feet by a projected maximum 41 percent by the year 2000 in the high case, declining 55 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 239.0 to 303.9 thousand acre-feet annually, low and high case, respectively, to irrigate from 277.4 to 345.8 thousand acres.

Livestock

Livestock water use in 1980 (13.2 thousand acre-feet) is expected to increase to 18.0 thousand acre-feet by 2030 (Table III-21-3).

Mining

Mining water requirements in the Nueces River Basin are expected to increase from 5.1 thousand acre-feet in 1980 to 12.0 thousand acre-feet by 2030 (Table III-21-3). Nonmetal mining water use is expected to decrease from 32 percent of the total mining water use in 1980 to 20 percent of the basin total in 2030. Metal mining, which was 33 percent of the 1980 total basin water use, is projected to increase to 57 percent of the total basin use.

Navigation

No additional navigation projects which would require regulated freshwater supplies are planned in the Nueces River Basin.

Hydroelectric Power

Hydroelectric power generation is not a project purpose in the authorized Choke Canyon Reservoir.

Estuarine Freshwater Inflows

The Nueces River discharges into the Nueces estuary. Estimates of fresh water inflow needs of the Nueces estuary are based on Nueces River flows at the Mathis gaging station and the total fisheries harvests of the Nueces and Mission-Aransas estuaries. The total fisheries harvests of the Nueces and Mission-Aransas estuaries are used because these two estuaries share a common outlet to the Gulf of Mexico. An annual inflow of 356 thousand acre-feet per year of gaged inflows is estimated as needed to sustain inundation processes and desired salinity regimes for this estuarine system (Subsistence Alternative) (Table III-21-4). Based upon relationships derived among the 1962 through 1976 commercial fishery harvests and seasonal inflows, a 397 thousand acre-feet per year estimate of gaged Nueces River inflows (Table III-21-4) is necessary to meet the objective of the Fisheries Harvest Maintenance Alternative of maintaining fishery harvests of the Nueces and Mission-Aransas estuaries at no less than their mean historical levels, as well as meeting salinity bounds and inundation needs. It is also estimated that the Fisheries Harvest Enhancement Alternative objective of maximizing finfish production in the Nueces and Mission-Aransas estuaries requires volumes of water from the Nueces River

Table III-21-4. Gaged River Inflow Needs of the Nueces Estuary From the Nueces River Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Nueces River Basin[2]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability
January	6.5	6.5	6.5	4.6
February	7.2	7.2	7.2	4.4
March	7.9	7.9	7.9	8.0
April	21.5	21.5	21.5	21.2
May	72.8	72.8	66.7	22.0
June	30.5	30.5	50.1	10.8
July	19.8	34.5	84.2	3.6
August	12.2	20.4	50.6	6.3
September	129.2	129.2	129.2	16.1
October	30.8	30.8	30.8	13.1
November	11.2	27.2	42.9	3.4
December	6.2	8.1	52.5	4.1
Annual	355.8	396.6	550.1	117.6

[1]All inflows are mean monthly values in thousand acre-feet.
[2]Gaged streamflow of Nueces River near Mathis.

Basin equal to an annual inflow set at the average 1941 through 1976 annual combined gaged and ungaged inflow of 604 thousand acre-feet from the basin, with the annual gaged inflow from the basin being 550 thousand acre-feet (Table III-21-4). Additional inflow from the Nueces River Basin is likely to increase the estimated finfish harvest (consistent with marsh inundation and salinity limits). An estimated 118 thousand acre-feet per year of gaged inflow is needed from the Nueces River Basin for the Biotic Species Viability Alternative to maintain salinities within the viability limits for organisms in the Nueces estuarine system (Table III-21-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Nueces River Basin to the year 2030 is 361.1 thousand acre-feet with the following amounts annually available by aquifer: 216.9 thousand acre-feet from the Carrizo-Wilcox Aquifer, 101.7 thousand acre-feet from the Edwards (Balcones Fault Zone) Aquifer, 20.0 thousand acre-feet from the Sparta Aquifer, 14.0 thousand acre-feet from the Gulf Coast Aquifer, and 8.5 thousand acre-feet from the Queen City Aquifer. Annual amounts of yield for the Edwards Trinity (Plateau) and Trinity Group Aquifers within the basin were not included, because extensive withdrawals of natural recharge and recoverable storage from these aquifers would deplete available surface-water supplies and adversely affect recharge to the Edwards (Balcones Fault Zone) Aquifer. In the year 2030, the yield of the Carrizo-Wilcox Aquifer within the basin would be reduced to the aquifer's average annual effective recharge of 78.7 thousand acre-feet per year. This reduction decreases the total ground-water availability within the basin in 2030 to 222.9 thousand acre-feet per year. Consequently, the total ground-water use projected for the basin in 2030 also has been reduced.

The projected annual ground-water use within the Nueces River Basin by decade from 1990 through 2030 is expected to be from 198.0 to 249.4 thousand acre-feet per year (Table III-21-3). The approximate average annual projected ground-water use within the basin is expected to be about 223.5 thousand acre-feet per year. Of the 223.5 thousand acre-feet of approximate average annual projected use, about 53 percent is expected to be from the Carrizo-Wilcox Aquifer, 38 percent from the Edwards (Balcones Fault Zone) Aquifer, and 4 percent from the Gulf Coast Aquifer.

Surface-Water Availability and Proposed Development

Available water resources in the Nueces River Basin are not sufficient to meet all projected surface-water needs beginning after the year 2000 (Table III-21-5, Figure III-21-2). The estimated surface-water shortages amount to 16.8 thousand acre-feet and 137.5 thousand acre-feet per year in 2000 and 2030, respectively, with 81.4 thousand acre-feet and 151.8 thousand acre-feet of these shortages for irrigated agriculture. The municipal and industrial surface-water requirements are projected to be fully satisfied through the year 2030. Surface-water supplies available to the basin amount to some 304.0 thousand acre-feet in year 2030. This volume exceeds the surface-water needs within the basin by approximately 101.5 thousand acre-feet. However, a commitment to supply municipal and manufacturing needs in adjacent coastal basins places an additional demand on the basin of 239.0 thousand acre-feet in 2030. The irrigation water demand in the basin exceeds surface-water supplies available for irrigation by some 75.1 thousand acre-feet in 1990 increasing to 151.8 thousand acre-feet in year 2030. This shortage occurs due to the limited availability of ground-water resources.

Existing reservoirs in the Nueces River Basin can supply projected surface-water needs for municipal and manufacturing purposes in the basin through the year 2030. However, surface-water needs for the City of Corpus Christi in the Nueces-Rio Grande Coastal Basin and for parts of San Patricio County in the San Antonio-Nueces Coastal Basin supplied from the major Nueces River reservoirs, Choke Canyon and Corpus Christi, are projected to exceed the yield of these reservoirs by the year 2020. An alternative source proposed for additional surface-water resources is Goliad Reservoir in the San Antonio River Basin. Water conveyed from the Goliad project through pipelines could provide sufficient water to meet all municipal and manufacturing water needs in the San Antonio-Nueces Coastal Basin through the year 2030. Additional studies will have to be performed by the Department and regional interests to examine the engineering alternatives and the economic, environmental, and institutional considerations that would be involved in such a major inter-basin transfer of water.

The potential Cotulla Reservoir project in La Salle County might assist in meeting some of these demands and in redistributing additional developable supplies within the basin. However, detailed studies will be required to fully evaluate the effect of this alternative upon existing water rights in the basin.

Additional potential reservoirs in the basin are the Montell and Sabinal Reservoirs on the Upper Nueces and Sabinal Rivers, respectively. These projects would be used primarily to increase recharge to the Edwards Aquifer by storing flood flows for later release into the aquifer recharge zone. Flood control benefits would also occur.

Water Quality Protection

A water quality management plan for the Nueces River Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Corpus Christi metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $41.8 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Nueces River Basin in January 1980 dollars and are subject to revision as new data becomes available. The list of projects, with project costs for 1982-1989, at 1980 prices, are shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

No major reservoirs exist, nor are any planned by the year 2000, that would provide flood-control storage. The only structural flood-control measures have been in the form of channel rectifications and levee systems.

Under the Small Flood Control Project Authority of the U.S. Army Corps of Engineers, flood damage prevention projects have been completed at Pleasanton, Poteet, and Three Rivers, Texas.

There are no U.S. Soil Conservation Service (SCS) floodwater-retarding structures within the Nueces River Basin. As of October 1980, four structures were planned for construction in the basin under the SCS program.

Table III-21-5. Water Resources of the Nueces River Basin, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Basin	Intra-Basin	Return Flow	Import	Total	In Basin	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	213.2	—	—	—	213.2	213.2	—	—	213.2	.0	.0	.0
Surface Water	252.0	—	8.5	15.0	275.5	100.1	—	159.6	259.7	90.9	(75.1)	15.8
Total	465.2	—	8.5	15.0	488.7	313.3	—	159.6	472.9	90.9	(75.1)	15.8
2000												
Ground Water	220.1	—	—	—	220.1	220.1	—	—	220.1	.0	.0	.0
Surface Water	252.0	—	10.2	16.4	278.6	108.9	—	186.5	295.4	64.6	(81.4)	(16.8)
Total	472.1	—	10.2	16.4	498.7	329.0	—	186.5	515.5	64.6	(81.4)	(16.8)
2010												
Ground Water	236.9	—	—	—	236.9	236.9	—	—	236.9	.0	.0	.0
Surface Water	252.0	—	11.8	24.6	288.4	133.4	—	215.7	349.1	35.4	(96.1)	(60.7)
Total	488.9	—	11.8	24.6	525.3	370.3	—	215.7	586.0	35.4	(96.1)	(60.7)
2020												
Ground Water	249.4	—	—	—	249.4	249.4	—	—	249.4	.0	.0	.0
Surface Water	252.0	—	13.2	25.0	290.2	137.7	—	237.7	375.4	13.1	(98.3)	(85.2)
Total	501.4	—	13.2	25.0	539.6	387.1	—	237.7	624.8	13.1	(98.3)	(85.2)
2030												
Ground Water	198.0	—	—	—	198.0	198.0	—	—	198.0	.0	.0	.0
Surface Water	252.0	—	14.8	37.2	304.0	202.5	—	239.0	441.5	14.3	(151.8)	(137.5)
Total	450.0	—	14.8	37.2	502.0	400.5	—	239.0	639.5	14.3	(151.8)	(137.5)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

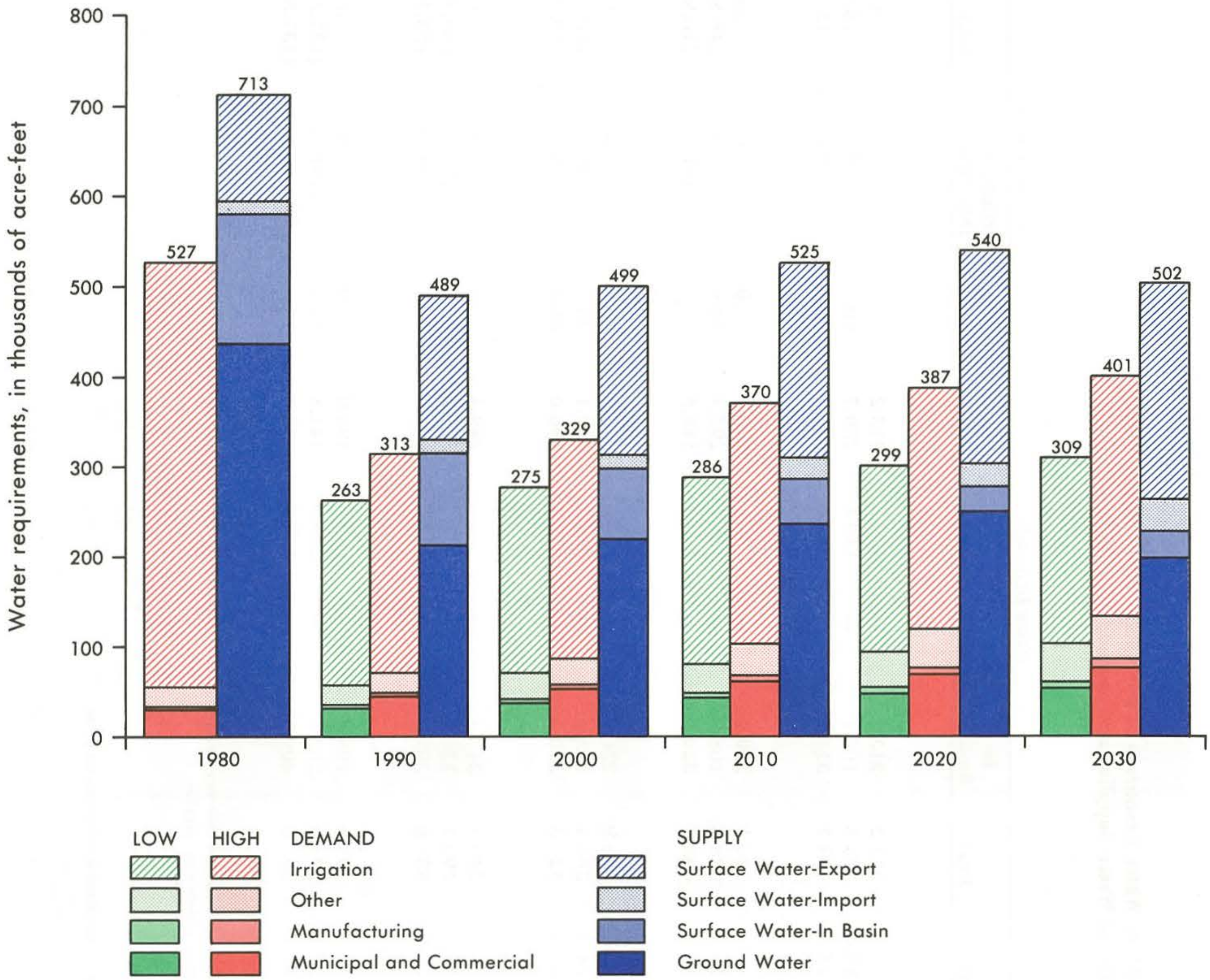

Figure III-21-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Nueces River Basin, 1980-2030

22. NUECES-RIO GRANDE COASTAL BASIN

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22. NUECES-RIO GRANDE COASTAL BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Nueces-Rio Grande Coastal Basin is bounded on the north by the Nueces River Basin on the west and south by the Rio Grande Basin. Maximum elevation in the basin is about 900 feet in southeastern Webb County. The total drainage area is 10,442 square miles. Runoff from the basin drains into Laguna Madre, Baffin Bay and Oso Bay. For planning purposes, the Nueces-Rio Grande Coastal Basin has been divided into two zones (Figure III-22-1).

Surface Water

Average annual runoff during the 1968-74 period was 23 acre-feet per square mile within the 480 square-mile drainage area west of Falfurrias. The runoff declines in the area west of Alice. Runoff increases toward the north and east, but in all areas is less than 50 acre-feet per square mile. Most streams are intermittent, except in tidally affected reaches.

The Nueces-Rio Grande Coastal Basin is characterized by flat terrain and narrow stream channels that flood frequently. The upper part of the basin is generally agricultural, and poor drainage results in considerable damage to croplands. Near the coast, the threat of a hurricane tidal surge is significant. The lower basin, commonly referred to as the Valley, is more highly urbanized. Hurricanes and hurricane-produced rainstorms have caused considerable flooding.

The average dissolved-solids concentrations of streams in the inland part of the basin range from about 100 to 3,000 milligrams per liter (mg/l). During low-flow periods, dissolved-solids concentrations as high as 28,400 mg/l have been recorded in the lower reaches of some streams. High salinity is partly due to oil-field activities, but primarily due to tidal effects. Most streams in the basin contain relatively good-quality water.

Ground Water

The Gulf Coast Aquifer underlies the entire Nueces-Rio Grande Coastal Basin, except for eastern parts of Cameron, Nueces, and Willacy Counties. The aquifer extends to a maximum depth of about 2,500 feet. Yields of large-capacity wells average about 300 gallons per minute (gpm), but locally wells produce up to 2,000 gpm. The quality of water in the aquifer varies widely, but generally the water contains 1,000 to 1,500 mg/l total dissolved solids. In much of the eastern part of the basin, saline water overlies usable fresh water in the aquifer.

In Jim Wells, Nueces, Kleberg, Kenedy, Willacy, and Cameron Counties within the basin, freshwater deposits of the Gulf Coast Aquifer are surrounded by extensive deposits containing saline waters. The potential for saline-water encroachment is very great, but can be controlled by proper well location, completion, and pumpage. The City of Alice has supplemented its ground-water supply with surface water because of deterioration of ground-water quality due to saline-water encroachment. The City of Brownsville uses water from the Rio Grande because saline-water encroachment has affected its well field. Currently, there are plans to supplement or replace ground-water pumpage with water from the Nueces River at Aqua Dulce, Banquete, Driscoll, Bishop, and Kingsville, because saline-water encroachment is causing serious deterioration of ground-water quality.

Population and Economic Development

There were 853.4 thousand people living in the 11 counties in the Nueces-Rio Grande Coastal Basin in 1980. Corpus Christi, with an in-basin population of 221,100 people, is the largest population center in the area. Other population centers are the Brownsville-San Benito-Harlingen and the McAllen-Pharr-Edinburg Standard Metropolitan Statistical Areas.

Agriculture and oil and gas production provide the foundation for the area's economy. Irrigation is a major factor in the high level of agricultural production in the basin.

Water Use

Municipal water use in the Nueces-Rio Grande Coastal Basin totaled 172.9 thousand acre-feet in 1980. The City of Corpus Christi accounted for almost 33 percent of the basin total; cities in the Lower Rio Grande Valley (Zone 2) used almost 46 percent of the total municipal use in this area.

Use of freshwater by manufacturing industries in the basin in 1980 totaled 32.2 thousand acre-feet. Most of this water use occurred in the manufacturing of food and kindred products, chemicals and allied products, primary

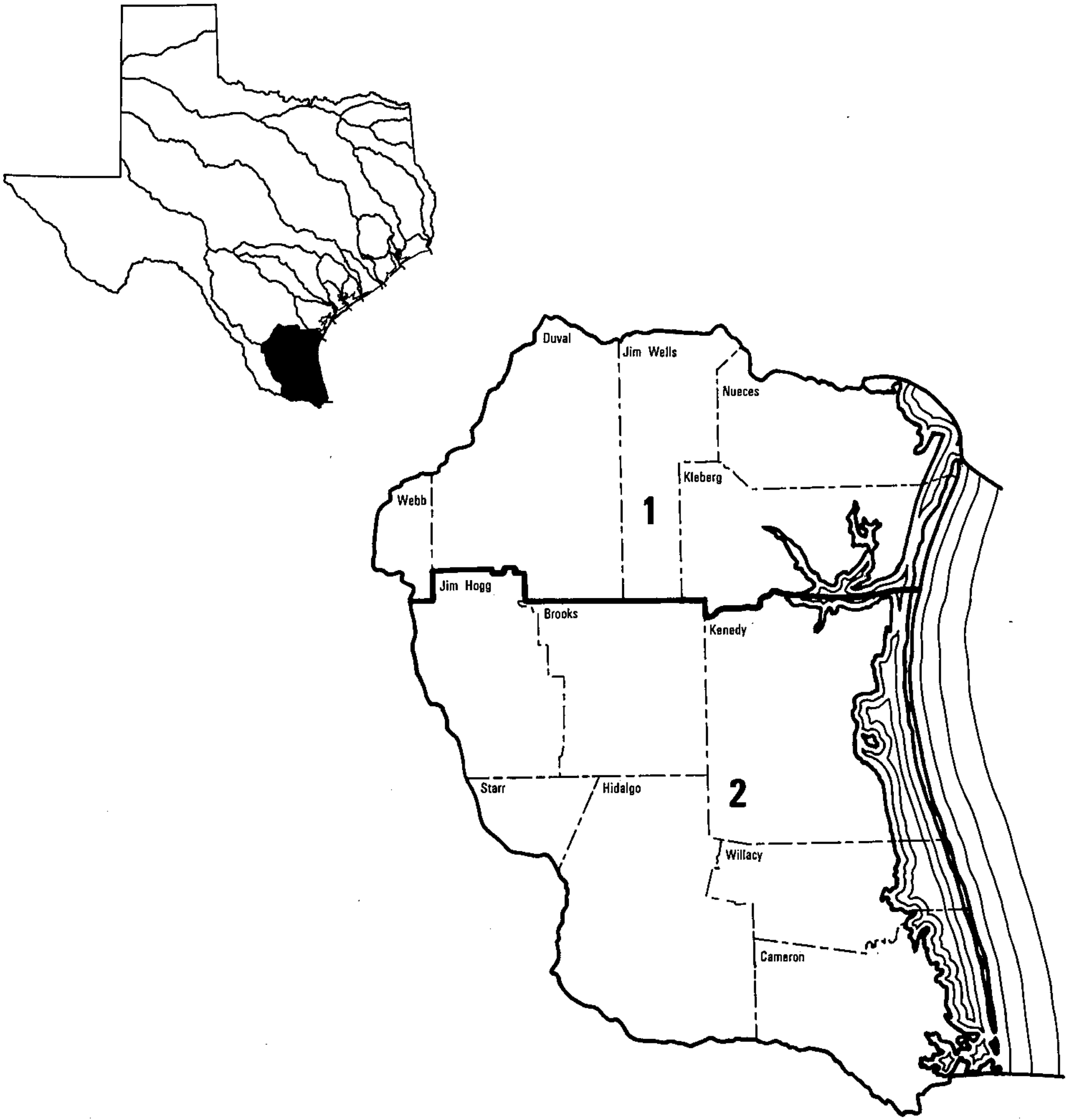

Figure III-22-1. Nueces-Rio Grande Coastal Basin and Zones

metals, and petroleum refining and related products. Most of the basin use, 84 percent, is centered in Nueces County with the Lower Rio Grande Valley industries using much of the remaining 16 percent.

In addition to the 1,138 megawatts of installed steam-electric power generating capacity in the Nueces-Rio Grande Coastal Basin which uses saline water for cooling, there was 413 megawatts of power generation capacity cooled by freshwater in 1980, all in Zone 2. During 1980, these plants consumed 5.6 thousand acre-feet of fresh surface water.

In 1980, about 747.9 thousand acres was irrigated in the basin using almost 1.3 million acre-feet of water. Zone 1 of the basin had about 10.2 thousand irrigated acres using 5.8 thousand acre-feet of water. Almost all irrigation water in Zone 1 was ground water. Zone 2 includes most of the Lower Rio Grande Valley where irrigation is highly developed. In 1980, 737.7 thousand acres was irrigated using almost 1.3 million acre-feet of water. Most of the water supply was surface-water diverted from the Rio Grande.

Mining industries in the Nueces-Rio Grande Coastal Basin used 3.1 thousand acre-feet of freshwater in 1980. Withdrawals of freshwater for mining purposes totaled 2.5 thousand acre-feet in Zone 1, and almost 600 acre-feet in Zone 2. Mining water use in the basin results primarily from petroleum and natural gas production, which was concentrated in Zone 1.

Livestock water use in the basin in 1980 totaled 8.4 thousand acre-feet, about 81 percent of which was supplied from surface-water sources. Zone 1 use totaled 3.5 thousand acre-feet of water and Zone 2 use amounted to 4.8 thousand acre-feet.

Navigation facilities in the Nueces-Rio Grande Coastal Basin include a portion of the Corpus Christi Ship Channel, the Corpus Christi Inner Harbor, the Gulf Intracoastal Waterway and its tributary waterways—the Port Mansfield Channel, Harlingen Channel, Port Isabel Small Boat Basin and Channel, Brazos Island Harbor, and the Brownsville Ship Channel. These marine navigation facilities have no regulated freshwater requirements.

Return Flows

In 1980, municipal and manufacturing return flows in the Nueces-Rio Grande Coastal Basin totaled 70.8 thousand acre-feet.

Of the total of 747.9 thousand acres irrigated in the Nueces-Rio Grande Coastal Basin in 1980, 737.7 thousand acres was located in the Lower Rio Grande Valley region in Zone 2. Except for small amounts of water obtained from resacas or local streams, most of the surface water used for irrigation in Zone 2 is diverted from the Rio Grande Basin. Even though return flows from surface-water irrigation are substantial, high salinity makes them unsuitable for reuse in most areas.

Current Ground-Water Development

In 1980, approximately 39.2 thousand acre-feet of ground water was used in the Nueces-Rio Grande Coastal Basin. Of this amount, 21.8 thousand acre-feet was used in Zone 1, and 17.4 thousand acre-feet was used in Zone 2. All of the ground water used in both zones of the basin was from the Gulf Coast Aquifer.

Of the 39.2 thousand acre-feet of ground water used in the basin, approximately 19.3 thousand acre-feet or 49 percent was for municipal purposes, and about 14.8 thousand acre-feet or 38 percent was for irrigation purposes.

A small overdraft of ground water from the Gulf Coast Aquifer occurred in 1980 in Hidalgo County within Zone 2, due to withdrawals for municipal and irrigation purposes.

Current Surface-Water Development

Existing major reservoirs in Zone 1 of the Nueces-Rio Grande Coastal Basin are Alice Terminal Reservoir and Barney M. Davis Cooling Reservoir. The Alice Water Authority purchases raw water from the City of Corpus Christi for municipal and manufacturing use. Raw water is pumped from Lake Corpus Christi to Alice Terminal Reservoir. In 1980, the Alice Water Authority purchased 3.2 thousand acre-feet of water from Corpus Christi. The remaining major reservoir in Zone 1, Barney M. Davis, is a cooling pond for Central Power and Light Company's Barney Davis steam-electric power plant located adjacent to the Laguna Madre near Corpus Christi. Saline water is withdrawn from Laguna Madre for cooling of the plant condensers. After retention in the Barney Davis cooling pond, the water is returned to Laguna Madre.

The City of Corpus Christi's principal water supply is Lake Corpus Christi in the Nueces River Basin. Water for the Corpus Christi area is treated, settled, filtered, and pumped at the Cunningham and Stevens Filtration Plants at Calallen, some 35 miles downstream from Lake Corpus Christi. The city also delivers up to 34.7 thousand acre-feet of water annually to the San Patricio Municipal Water District in the San Antonio-Nueces Coastal Basin. In 1980, the city and surrounding municipalities and industries in Zone 1 of the Nueces-Rio Grande Coastal Basin used almost 87.0 thousand acre-feet of water from the Nueces River Basin.

Water requirements within Zone 1 of the Nueces-Rio Grande Coastal Basin, particularly within the City of Corpus Christi, are growing rapidly. To insure that future water supplies are available for the Coastal Bend area, the City of Corpus Christi and the Nueces River Authority jointly sponsored the construction of Choke Canyon Reservoir on the Frio River. Deliberate impoundment began in 1982. Water-supply contracts with the U.S. Bureau of Reclamation for construction of the reservoir have been finalized. Choke Canyon Reservoir and Lake Corpus Christi will be operated as a system in order to optimize the yields of the two reservoirs.

In 1980, the total surface- and ground-water use within Zone 1 was 117.0 thousand acre-feet. Municipal and manufacturing water uses accounted for most of the 1980 water use in Zone 1.

The Cities of Benavides, San Diego, Orange Grove, Premont, Kingsville, and Bishop obtained their water supply from the Gulf Coast Aquifer. However, surface-water supplies for Kingsville and other communities are being sought due to declining water levels and the inferior chemical quality of ground water in much of the basin.

There are three major surface-water reservoirs in Zone 2 of the Nueces-Rio Grande Coastal Basin: Delta Lake, Valley Acres Reservoir, and Loma Alta Reservoir. The reservoirs are used for temporary storage and regulation of water diverted from the Rio Grande Basin.

Delta Lake, located in east-central Hidalgo County, has a capacity of 25.0 thousand acre-feet and is owned and operated by Hidalgo and Willacy Counties Water Control and Improvement District No. 1. Valley Acres Reservoir, north of Mercedes in eastern Hidalgo County, has a capacity of 7.8 thousand acre-feet and is owned and operated by the Valley Acres Water District. Water is diverted into this reservoir from the North Floodway. Loma Alta Reservoir, northeast of Brownsville, has a capacity of 26.5 thousand acre-feet and is owned and operated by the Brownsville Navigation District. Currently, only a small part (700 acre-feet) of Loma Alta Reservoir is in operation.

In Cameron, Willacy, and Hidalgo Counties, there are 24 additional reservoirs with capacities of less than 5.0 thousand acre-feet, most of which are used for off-channel storage of irrigation water. Some are off-channel reservoirs, while the remainder are on arroyos, resacas, drainage ditches, and floodways.

Except for runoff which is captured in resacas, farm ponds, drainage facilities, etc., all of the surface water used in Zone 2 of the Nueces-Rio Grande is diverted from the Rio Grande Basin, principally for use in Cameron, Willacy, and Hidalgo Counties.

In 1980, surface-water use for municipal and manufacturing purposes in Zone 2 totaled 88.5 thousand and 4.7 thousand acre-feet, respectively. Irrigation supplied by surface water totaled in excess of 1,264.2 thousand acre-feet in 1980 in Zone 2. Because virtually all surface water used in Zone 2 is supplied from the Rio Grande, and users of these waters are governed by allotments based upon court decree and rules of the Texas Water Rights Commission, current water uses and problems within Zone 2 of the Nueces-Rio Grande are described in the discussion of the Rio Grande Basin.

Water Rights

The total amount of surface water authorized or claimed for diversion and use in the Nueces-Rio Grande Coastal Basin was 154,962 acre-feet as of December 31, 1983 (Table III-23-1). Irrigation accounted for 101,315 acre-feet, or 65.4 percent, and recreation use represented 43,077 acre-feet, or 27.8 percent of total basin authorized or claimed quantities of water. The basin percentages of water claimed or authorized for use in Zones 1 and 2 were 9 and 91 percent, respectively (Table III-23-2).

Water Quality

Water quality data in the Nueces-Rio Grande Coastal Basin are limited because most streams, except the Arroyo Colorado, are intermittent. Los Olmos Creek, which has an intermittent base flow of about 0.1 ft^3/s, generally contains about 2,500 mg/l total dissolved solids. In the Lower Rio Grande Valley, the Arroyo Colorado and the North Floodway carry flood flows from the Rio Grande as well as irrigation return flows. Pesticide residues have been a recurring problem in the Arroyo Colorado.

Flooding, Drainage, and Subsidence

Hurricane-related flooding has caused severe damage in the Nueces-Rio Grande Coastal Basin. Hurricanes Carla (1961), Beulah (1967), Celia (1970), Fern (1971), and Allen (1980) caused severe agricultural and nonagricultural property losses. During the years 1978, 1979, and

Table III-22-1. Authorized or Claimed Amount of Water, by Type of Right, Nueces-Rio Grande Coastal Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	45	122,579
Claims	28	32,383
Certified Filings	0	0
Certificates of Adjudication	0	0
Total Authorizations and Claims	73	154,962

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

1981, additional flooding caused 548 flood insurance claims to be filed for $1.9 million in flood damages.

The Federal Emergency Management Agency has designated 45 communities in the Nueces-Rio Grande Coastal Basin as having one or more potential flood-hazard areas. Forty-four of these are participating in the National Flood Insurance Program. Thirty-four cities have completed flood insurance rate studies and are participating in the Regular Phase of the Program. The unincorporated portions of Nueces, Jim Wells, Duval, Kleberg, Jim Hogg, Brooks, Hidalgo, Willacy, and Cameron Counties have insurance available to their residents. Nueces, Cameron, Hidalgo and Kleberg Counties are in the Regular Phase of the Program and rate studies are underway in Jim Wells, Kenedy, and Willacy Counties to determine elevations of a 100-year frequency flood.

Table III-22-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Nueces-Rio Grande Coastal Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Total
Municipal	5	7,500	2,870	10,370
Industrial[2]	1	0	200	200
Irrigation	63	1,333	99,982	101,315
Recreation	6	5,577	37,500	43,077
Total	73[1]	14,410	140,552	154,962

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.
[2]Does not include 4 authorized diversions of saline water in Zone 1 amounting to 1,514,200 acre-feet/year and 2 authorized diversions of saline water in Zone 2 amounting to 480,000 acre-feet/year.

There are substantial drainage problems in the Nueces-Rio Grande Coastal Basin, particularly in the northern part of Cameron County, in the area east and south of Raymondville, and in the irrigated areas of Hidalgo, Willacy, and Cameron Counties.

Subsidence and fault movement are very evident within the basin in the Saxet Oil and Gas Field in the Clarkwood area west of Corpus Christi. The maximum amount of subsidence within the field since 1930 has been about 6.2 feet. Since discovery in 1930, the Saxet Field has produced about 1.0 trillion cubic feet of gas, more than 86 million barrels of crude oil and hydrocarbon liquids, and probably more than 1.5 billion barrels of saline ground water. Although rates and amounts of fault movement are unknown, movement of the Saxet Fault is probably correlative with rates of subsidence, which since 1942 have ranged from 0.086 to 0.133 foot per year. Movement of the Saxet Fault has damaged highways, railroads, streets, buildings, and a stadium in and near Clarkwood.

Recreation Resources

Major freshwater recreation resources in the Nueces-Rio Grande Coastal Basin include Delta Lake (2.4 thousand surface acres) and Valley Acres Reservoir (900 surface acres). These surface-water impoundments are in the southern part of the basin in Cameron and Hidalgo Counties. Other freshwater recreation opportunities available in the basin include shoreline activities along the streams and ponds in the region. At the eastern boundary of the basin, the coastal waters of Laguna Madre provide recreation opportunities to the public within both beach and shoreline areas as well as bay and Gulf waters.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Nueces-Rio Grande Coastal Basin is projected to increase 231 percent, from 853 thousand in 1980 to 2.83 million in 2030 (Table III-22-3). A 70 percent increase is expected by 2000, accelerating to 95 percent between 2000 and 2030.

All counties, except Kenedy County are expected to gain in population. Hidalgo County is expected to have the largest growth rate, 398 percent, and by 2030 its population will represent 49.2 percent of the total basin population.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Nueces-Rio Grande Coastal Basin are projected to increase from the 1980 level of 172.9 thousand acre-feet by a projected maximum of 108 percent by the year 2000 (high case). In the year 2030, water requirements are projected to range from 410.1 to 693.8 thousand acre-feet. Zone 1 is projected to account for 30 to 31 percent of total basin municipal requirements in 2000; in 2030, Zone 1 is projected to account for 26 percent of the total in both the low and high case.

A range of 298.5 to 513.6 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2030.

Industrial

Manufacturing water requirements in 1980 were 32.2 thousand acre-feet in the Nueces-Rio Grande Coastal Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Nueces-Rio Grande Coastal Basin are projected to increase more than two times by the year 2030, to a potential high of 81.2 thousand acre-feet by 2030 (high case).

Zone 1 (Nueces County) accounted for 84 percent of the total basin use in 1980 and is expected to decrease its share of basin manufacturing water requirements to 78 percent by 2030.

Steam-Electric Power Generation

Both fresh and saline water requirements for steam-electric power generation are projected to increase steadily in the Nueces-Rio Grande Coastal Basin. Water consumption by plants using freshwater for cooling is projected to be 5.6 thousand acre-feet annually by 2000 and 15.4 to 20.0 thousand acre-feet annually by 2030. Zone 2 required 96 percent of the total basin water requirement in 1980, and is projected to need 50 percent by 2030. Where saline water is used for cooling, freshwater will also be needed at plants to provide water for boiler feedwater makeup, and sanitary and maintenance uses.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Nueces-Rio Grande Coastal Basin are projected to increase from the 1980 level of 1.3 million acre-feet by a projected maximum seven percent by the year 2000 in the high case, increasing four percent in the low case. In the year 2030, water requirements in the Basin are projected to range from 1.1 to 1.4 million acre-feet annually, low and high case, respectively, to irrigate from 0.75 to 0.81 million acres.

Zone 2 is projected to account for about 99 percent of total basin irrigation requirements in 2000 and 2030. Zone 1 is projected to account for only one percent of the total.

Table III-22-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a]
Nueces-Rio Grande Coastal Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			333.1			387.0			426.5			487.8			589.6			711.0
Municipal	12.7	65.1	77.8	8.2	88.0	96.2	8.8	99.3	108.1	9.3	114.3	123.6	10.0	139.4	149.4	10.7	169.5	180.2
Manufacturing	0.6	26.6	27.2	2.7	31.5	34.2	2.6	38.1	40.7	2.7	43.6	46.3	2.7	51.4	54.1	2.7	61.0	63.7
Steam Electric	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2	0.2	3.3	0.1	3.4	6.6	0.1	6.7	9.8	0.2	10.0
Mining	2.4	0.1	2.5	2.1	0.5	2.6	2.1	0.5	2.6	2.3	0.6	2.9	2.6	0.6	3.2	2.8	0.6	3.4
Irrigation	5.5	0.3	5.8	8.4	0.4	8.8	8.5	0.4	8.9	8.6	0.4	9.0	8.6	0.4	9.0	8.6	0.4	9.0
Livestock	0.6	2.9	3.5	0.6	3.6	4.2	0.6	4.3	4.9	0.6	4.3	4.9	0.6	4.3	4.9	0.6	4.3	4.9
Zone Total Water	21.8	95.2	117.0	22.0	124.2	146.2	22.6	142.8	165.4	26.8	163.3	190.1	31.1	196.2	227.3	35.2	236.0	271.2
Zone 2																		
Population			520.3			764.2			1,025.6			1,317.4			1,693.2			2,117.3
Municipal	6.6	88.5	95.1	16.8	166.5	183.3	20.5	231.5	252.0	21.5	300.7	322.2	21.9	390.4	412.3	20.1	493.5	513.6
Manufacturing	0.2	4.7	4.9	0.0	6.6	6.6	0.0	8.8	8.8	0.0	11.2	11.2	0.0	14.1	14.1	0.0	17.5	17.5
Steam Electric	0.0	5.4	5.4	0.0	5.4	5.4	0.0	5.4	5.4	0.0	6.9	6.9	0.0	8.5	8.5	0.0	10.0	10.0
Mining	0.4	0.2	0.6	0.4	0.2	0.6	0.3	0.3	0.6	0.3	0.3	0.6	0.2	0.4	0.6	0.2	0.4	0.6
Irrigation	9.3	1,264.2	1,273.5	3.2	1,366.9	1,370.1	3.2	1,353.1	1,356.3	3.2	352.3	1,355.5	3.2	1,350.8	1,354.0	3.2	1,349.3	1,352.5
Livestock	0.9	3.9	4.8	1.2	4.5	5.7	1.3	5.3	6.6	1.3	5.3	6.6	1.3	5.3	6.6	1.3	5.3	6.6
Zone Total Water	17.4	1,366.9	1,384.3	21.6	1,550.1	1,571.7	25.3	1,604.4	1,629.7	26.3	676.7	1,703.0	26.6	1,769.5	1,796.1	24.8	1,876.0	1,900.8
BASIN TOTALS																		
Population			853.4			1,151.2			1,452.1			1,805.2			2,282.8			2,828.3
Municipal	19.3	153.6	172.9	25.0	254.5	279.5	29.3	330.8	360.1	30.8	415.0	445.8	31.9	529.8	561.7	30.8	663.0	693.8
Manufacturing	0.8	31.3	32.2	2.7	38.1	40.8	2.6	46.9	49.5	2.7	54.8	57.5	2.7	65.5	68.2	2.7	78.5	81.2
Steam Electric	0.0	5.6	5.6	0.0	5.6	5.6	0.0	5.6	5.6	3.3	7.0	10.3	6.6	8.6	15.2	9.8	10.2	20.0
Mining	2.8	0.3	3.1	2.5	0.7	3.2	2.4	0.8	3.2	2.6	0.9	3.5	2.8	1.0	3.8	3.0	1.0	4.0
Irrigation	14.8	1,264.5	1,279.3	11.6	1,367.3	1,378.9	11.7	1,353.5	1,365.2	11.8	1,352.7	1,364.5	11.8	1,351.2	1,363.0	11.8	1,349.7	1,361.5
Livestock	1.5	6.8	8.4	1.8	8.1	9.9	1.9	9.6	11.5	1.9	9.6	11.5	1.9	9.6	11.5	1.9	9.6	11.5
Basin Total Water	39.2	1462.1	1501.3	43.6	1,674.3	1,717.9	47.9	1,747.2	1,795.1	53.1	1,840.0	1,893.1	57.7	1,965.7	2,223.4	60.0	2,112.0	2,172.0

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Livestock

Livestock water requirements within the basin are projected to increase from 8.4 thousand acre-feet in 1980 to 11.5 thousand acre-feet annually in 2030. Livestock water use is expected to be 4.9 thousand acre-feet per year in Zone 1 and 6.6 thousand acre-feet annually in Zone 2 by 2030.

Mining

Mining water requirements in the Nueces-Rio Grande Coastal Basin are projected to increase 29 percent between 1980 and 2030 (from 3.1 thousand acre-feet to 4.0 thousand acre-feet annually).

Mining water requirements for fuels are expected to decrease to 1.0 thousand acre-feet in 2030, compared to 2.5 thousand acre-feet in 1980. The remaining mining water requirements in the Nueces-Rio Grande Coastal Basin are for nonfuels.

Navigation

No navigation facilities requiring freshwater resources for their operation are planned in the Nueces-Rio Grande Coastal Basin.

Hydroelectric Power

There are no hydroelectric power generating facilities planned in the Nueces-Rio Grande Coastal Basin.

Estuarine Freshwater Inflows

The drainage from the Nueces-Rio Grande Coastal Basin discharges into the Laguna Madre estuarine system. Estimates of freshwater inflow needs of the Laguna Madre estuarine system are based on the total gaged flows of San Fernando (at Alice) and Los Olmos (near Falfurrias) Creeks for Baffin Bay and Upper Laguna Madre, and the total gaged flow of the Arroyo Colorado (near Harlingen) and the North Floodway (near Sebastian) for the lower Laguna Madre.

Estimates of the annual gaged inflows needed to sustain the desired salinity limits for the Subsistence Alternative yield 4.2 thousand acre-feet and 177.7 thousand acre-feet of gaged inflow into Baffin Bay and lower Laguna Madre, respectively (Table III-22-4). The inflows needed annually from the gaged portion of the drainage area of Baffin Bay and lower Laguna Madre (Table III-22-4) to maintain the average 1962 through 1976 commercial fisheries harvest (Fisheries Harvest Maintenance Alternative) total 5.9 thousand acre-feet and 278.8 thousand acre-feet, respectively. For the Harvest Enhancement Alternative, it is estimated that maximizing the finfish commercial harvest in upper Laguna Madre and the shrimp harvest offshore of the lower Laguna Madre requires volumes of water from the contributing areas of the estuary equal to the annual inflow limit set at the average 1941-1976 annual combined inflows of 689 thousand acre-feet, with the annual gaged inflow need of 8.8 thousand acre-feet from the Baffin Bay drainage area (Table III-22-4) and 283 thousand acre-feet from the lower Laguna Madre drainage basin. The inflows needed annually to maintain the desired species salinity limits for the Biotic Species Viability Alternative are estimated to be 710 thousand acre-feet of gaged inflow into Baffin Bay and 136.8 thousand acre-feet of gaged inflow into the lower Laguna Madre (Table III-22-4).

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

The approximate annual ground-water yield within the Nueces-Rio Grande Coastal Basin through the year 2030 is 115.0 thousand acre-feet. This amount of annual ground-water supply is from the Gulf Coast Aquifer which is the only fresh to slightly saline water-bearing formation within the basin.

The projected annual ground-water use within the Nueces-Rio Grande Basin by decade from 1990 through 2030 is expected to be from 43.6 to 60.0 thousand acre-feet per year (Table III-22-3). The approximate average annual projected ground-water use within the basin is expected to be about 52.5 thousand acre-feet per year.

Surface-Water Availability and Proposed Development

The Nueces-Rio Grande Coastal Basin, Zone 1, currently receives surface water from the Nueces River Basin under existing water rights and contracts. Sufficient water supplies are estimated to be available from existing reservoirs in the Nueces River Basin to meet all demands for surface water in Zone 1 of the Nueces-Rio Grande Coastal Basin through 2030 except for irrigation (Table III-22-5, Figure III-22-2). No additional reservoirs are proposed for

Table III-22-4. Gaged River Inflow Needs of the Laguna Madre Estuary From the Nueces-Rio Grande Coastal Basin Under Four Alternative Levels of Fisheries Productivity[1]

	Baffin Bay and Upper Laguna Madre[2]				Lower Laguna Madre[3]			
Month	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability	Ecosystem Subsistence	Fisheries Harvest Maintenance	Finfish Harvest Enhancement	Biotic Species Viability
January	.13	.08	.13	.05	10.35	10.35	26.15	9.21
February	.08	.11	.26	.06	10.52	10.52	23.18	5.88
March	.25	.23	.07	.01	11.55	11.55	18.93	9.36
April	.08	.39	.88	.18	15.69	15.69	15.69	15.45
May	.48	1.29	2.74	.10	16.54	16.54	16.54	15.98
June	.61	.55	1.24	.01	16.40	23.38	16.40	13.64
July	.36	1.02	1.05	.01	12.65	17.25	12.65	8.09
August	.58	.57	.78	.01	10.99	19.86	10.99	6.94
September	.97	.97	.98	.15	25.96	68.59	62.50	15.88
October	.16	.20	.41	.01	19.48	57.50	52.40	15.04
November	.46	.42	.21	.06	13.86	13.86	13.86	11.27
December	.07	.11	.07	.06	13.73	13.73	13.73	10.07
Annual	4.23	5.94	8.82	.71	177.72	278.83	283.01	136.81

[1]The upper and lower portions of the estuary are separated by the "land cut." All inflows are mean monthly values in thousand of acre-feet.
[2]Combined gaged streamflow of San Fernando Creek at Alice and Los Olmos Creek near Falfurrias.
[3]Combined gaged streamflow of Arroyo Colorado near Harlingen and North Floodway near Sebastian.

Table III-22-5. Water Resources of the Nueces-Rio Grande Coastal Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	22.0	—	—	—	22.0	22.0	—	—	22.0	.0	.0	.0
Surface Water	.0	.0	.0	119.9	119.9	120.3	.0	.0	120.3	(.3)	(.1)	(.4)
Total	22.0	.0	.0	119.9	141.9	142.3	.0	.0	142.3	(.3)	(.1)	(.4)
2000												
Ground Water	22.6	—	—	—	22.6	22.6	—	—	22.6	.0	.0	.0
Surface Water	.0	.0	.0	137.9	137.9	138.2	.0	.0	138.2	(.2)	(.1)	(.3)
Total	22.6	.0	.0	137.9	160.5	160.8	.0	.0	160.8	(.2)	(.1)	(.3)
2010												
Ground Water	26.8	—	—	—	26.8	26.8	—	—	26.8	.0	.0	.0
Surface Water	.0	.0	.0	158.4	158.4	158.7	.0	.0	158.7	(.2)	(.1)	(.3)
Total	26.8	.0	.0	158.4	185.2	185.5	.0	.0	185.5	(.2)	(.1)	(.3)
2020												
Ground Water	31.1	—	—	—	31.1	31.1	—	—	31.1	.0	.0	.0
Surface Water	.0	.0	.0	190.7	190.7	191.6	.0	.0	191.6	(.8)	(.1)	(.9)
Total	31.1	.0	.0	190.7	221.8	222.7	.0	.0	222.7	(.8)	(.1)	(.9)
2030												
Ground Water	35.2	—	—	—	35.2	35.2	—	—	35.2	.0	.0	.0
Surface Water	.0	.0	.0	231.2	231.2	231.4	.0	.0	231.4	(.1)	(.1)	(.2)
Total	35.2	.0	.0	231.2	266.4	266.6	.0	.0	266.6	(.1)	(.1)	(.2)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions

Intra-Basin: A transfer of water among zones within a river basin.

Import: A transfer of water from another river basin.

Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.

Export: A transfer of water to another river basin.

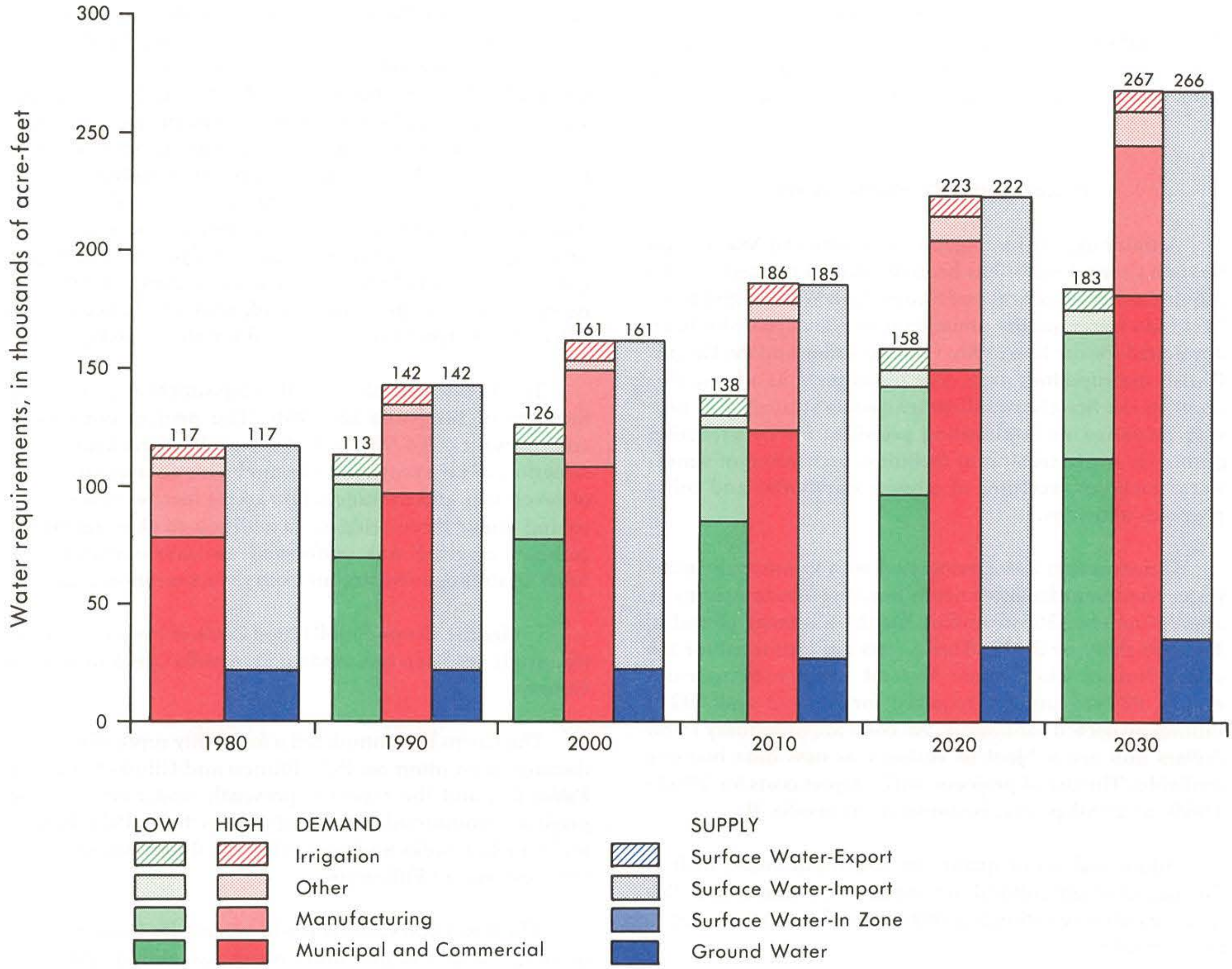

Figure III-22-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Nueces-Rio Grande Coastal Basin, Zone 1, 1980-2030

Zone 1. Annual surface-water requirements for municipal and almost all industrial purposes in the zone can be satisfied through water transfer from the Nueces River Basin under existing water rights. Minor mining shortages of less than 1.0 thousand acre-feet per year are projected to occur through 2030. The basin irrigation shortage amounts to only 100 acre-feet annually from the present to 2030 and is due to limited ground-water availability.

Water supplies and requirements of Zone 2 of the basin are considered with Zone 2 of the Rio Grande Basin.

Projected surface-water needs in Zone 2 of the basin exceed available surface-water supplies from the lower Rio Grande Basin by the year 1990. Studies by the International Boundary and Water Commission, U.S. Section, indicate that relatively little additional yield can be developed from another major reservoir on the Rio Grande. Thus, it is unlikely that projected shortages in surface-water needs for the basin can be met from water development on the Rio Grande Basin. Alternative sources for water for municipal and manufacturing purposes include Lake Texana in the Lavaca River Basin and potential reservoirs in the Guadalupe and San Antonio River Basins. These surface-water sources, however, may be prohibitively expensive due to the construction and operating costs of water conveyance and storage facilities.

Water Quality Protection

A water quality management plan for the Nueces-Rio Grande Coastal Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. Areawide water quality management plans have also been developed for the Lower Rio Grande Valley and the Corpus Christi metropolitan area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $365.6 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Nueces-Rio Grande Coastal Basin with approximately $274.3 million required for Zone 2 and $91.3 million projected for Zone 1. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Flood Control Measures

There are no reservoirs with flood-control storage in the basin. Flood control has been accomplished largely through channel rectification and construction of floodways. In 1955, the U.S. Army Corps of Engineers completed work on channel improvements on San Diego Creek in the City of Alice. The project consists of an earthen levee on the right bank of the creek, two concrete floodwall sections on the right bank forming a part of the levee system, riprap bank-slope protection, scour protection under the U.S. Highway 281 bridge, and sodding and seeding of levee and channel slopes. The project consisted of approximately 3.41 miles of stream channel, 16,332 feet of levee, and 1,843 feet of concrete floodwall. Major floods in recent years have indicated the need for additional study and reexamination of the project, particularly with respect to the possible extension of the existing levee, construction of additional levees, and evaluation of flood-control needs in the Lattas Creek area within the City of Alice. Funds have been requested for these studies.

The Corps completed a flood-protection project for the City of Kingsville in 1956. The project consists of enlargement of 14,955 feet of Tranquitas Creek and construction of an excavation channel with an average depth of seven feet and average width of 80 feet, with concrete paving under three bridges. In addition to channel enlargement, clearing was performed on approximately 3.5 miles of stream downstream from the excavation channel.

Under the Corps' Small Flood Control Project Authority a study has been initiated on Petronilla Creek in Nueces County.

The Corps has completed a feasibility report for flood-damage prevention on Palo Blanco and Cibolo Creeks at Falfurrias, and the report is presently under review. The project recommends diverting waters from Palo Blanco and Cibolo Creeks and conveying the floodwaters around the west side of Fulfurrias.

The lower Rio Grande Basin project for flood control, drainage, and land treatment measures, authorized by the Water Resources Development Act of 1974, is discussed in the section addressing the Rio Grande Basin.

There is about 299 square miles of drainage area above 18 U.S. Soil Conservation Service floodwater-retarding structures within the Nueces-Rio Grande Coastal Basin. As of October 1980, one additional structure with a drainage area of 42 square miles was planned for construction. All of the existing and planned structures are in Zone 1.

23. RIO GRANDE BASIN

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23. RIO GRANDE BASIN

BACKGROUND AND CURRENT CONDITIONS

Physical Description

The Rio Grande originates in southern Colorado, flows southerly across New Mexico, and enters Texas about 20 miles northwest of El Paso. It forms the international boundary between the United States and Mexico from El Paso to the Gulf of Mexico. Elevation of the streambed at the New Mexico-Texas state line is approximately 3,800 feet and the total basin drainage area is 182,215 square miles, of which 88,968 square miles is in the United States and 48,259 square miles is in Texas. The Pecos and Devils Rivers are the principal tributaries of the Rio Grande in Texas. The Rio Grande Basin has been divided into three zones for planning purposes; Zone 2 of the Nueces-Rio Grande Coastal Basin has been added in the supply and demand computations (Figure III-23-1).

Surface Water

The average annual runoff from 1941-70 was approximately 29 acre-feet per square mile in Texas and Mexico. Amounts and rates of runoff vary widely throughout the Rio Grande Basin. Reservoirs, numerous diversions, and substantial return flows also modify the flows of the main stem throughout its length. Upstream development has progressively reduced the flow of the Rio Grande as it enters Texas. The average annual flow of the Rio Grande at El Paso for the period 1890-1940 was 699.6 thousand acre-feet. From 1941-70, the annual flow averaged 375.4 thousand acre-feet. The lowest runoff rate of the basin above Laredo from 1941-70 occurred during 1950-53 and 1955-56; each period averaged 14 acre-feet per square mile.

Localized flooding from heavy rainstorms and inadequate drainage is a serious problem in the El Paso area. Downstream, the City of Presidio experiences problems associated with flooding of Cibolo Creek, although a levee on the Rio Grande provides some protection. Developments in the flood plain in Del Rio, Eagle Pass, and Laredo are subject to damages from infrequent river flooding but more serious flooding of local tributaries.

The completion of several major flood-control reservoirs and an extensive levee and floodway system in the Lower Valley area have lessened flooding along the main stem of the Rio Grande. Flooding remains a severe problem in areas not protected by levees, and flooding could occur during severe storms associated with hurricanes.

As the Rio Grande enters Texas at El Paso, total dissolved-solids concentrations vary from 500 to over 3,000 milligrams per liter (mg/l); the long-term discharge-weighted average concentration is about 800 mg/l. Lowest concentrations occur in the spring and summer when reservoirs in New Mexico are releasing water, and highest levels occur in winter during low-flow periods. Discharge-weighted average chloride and sulfate concentrations at this point are about 130 mg/l and 260 mg/l, respectively.

Diversions for irrigation and municipal use at the American Canal in Texas and the Acequia-Madre Canal in Mexico remove most of the flow of the Rio Grande which reaches Texas. Below El Paso, most of the flow consists of treated municipal wastewater from El Paso and irrigation return flows. While these flows are relatively high in dissolved solids, they are periodically diluted by local storm runoff. As a result, the long-term discharge-weighted dissolved-solids concentrations have averaged about 2,100 mg/l and annual discharge-weighted concentrations have ranged from less than 300 mg/l to over 4,400 mg/l. Water quality improves as inflows of good quality water enter downstream. At Langtry, annual discharge-weighted average dissolved-solids concentrations are about 500 mg/l and sulfate and chloride levels are around 200 and 50 mg/l, respectively. Dissolved-solids levels increase somewhat due to the inflow of the more saline Pecos River, but water quality in the International Amistad Reservoir above Del Rio, Texas is still very good, with dissolved-solids concentrations commonly between 500 to 650 mg/l.

Tributaries in this reach of the Rio Grande Basin to Amistad Dam include the Devils River, Alamito Creek, and the Pecos River on the American side and the Rio Conchos on the Mexican side. The Devils River and Alamito Creek are of excellent quality, with total dissolved solids normally under 500 to 600 mg/l. By contrast, the Pecos River is a major source of salt in the Rio Grande Basin and the Rio Conchos has been identified as a source of pesticides to the Rio Grande.

The Pecos River drains a substantial part of the far West Texas portion of the Rio Grande Basin. Natural discharge of highly saline ground water into the Pecos River in New Mexico keeps total dissolved-solids levels in the water in and above Red Bluff Reservoir very high. Except during floods, the flow of the Pecos River for a considerable distance downstream from Red Bluff Reservoir consists principally of releases and some seepage from the reservoir. As a result, total dissolved solids in this reach vary between 2,700 and 15,000 mg/l and exceed 7,500 mg/l 50 percent of the time.

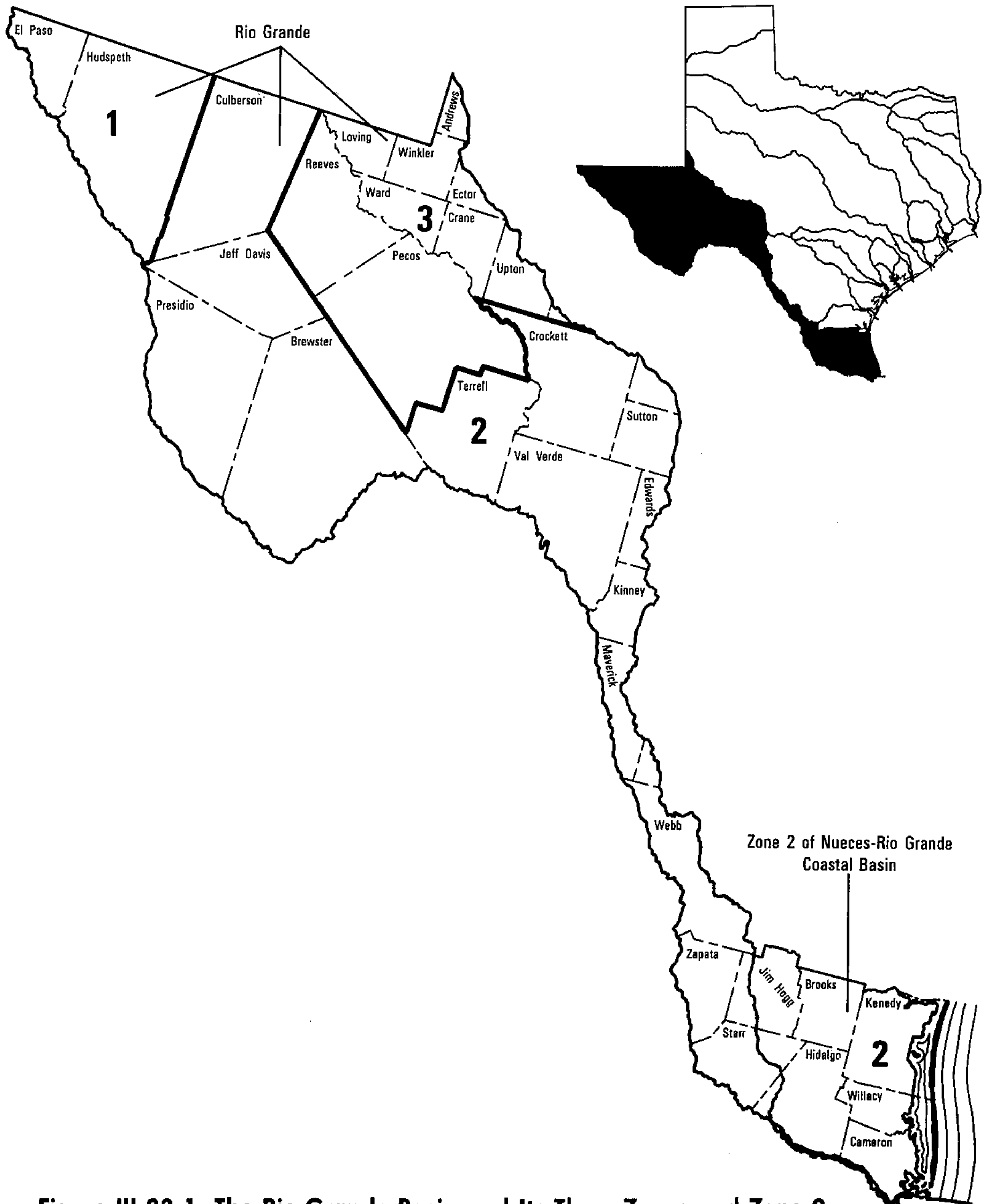

Figure III-23-1. The Rio Grande Basin and Its Three Zones and Zone 2 of the Nueces-Rio Grande Coastal Basin

Additional inflow from saline water-bearing aquifers below Red Bluff Dam, irrigation return flows, and runoff from old oil fields continue to degrade water quality between the dam and the vicinity of Girvin in northern Pecos County. In this area, annual discharge-weighted average concentrations of total dissolved solids exceed 14,000 mg/l.

Below Girvin, water quality improves substantially as runoff and ground water from limestone aquifers in Crockett, Terrell, and Val Verde Counties dilute the highly mineralized Pecos River streamflows. By the time the Pecos River reaches the Rio Grande near Langtry, in Val Verde County, the discharge-weighted average dissolved-solids concentration is about 1,600 mg/l, 570 mg/l chloride, and 325 mg/l sulfate. The water throughout the Pecos River watershed is very hard, with calcium carbonate concentrations often exceeding 200 mg/l.

Between International Amistad and International Falcon Reservoirs, water quality improves to a discharge-weighted average dissolved-solids level of 500 mg/l. Sulfate and chloride concentrations average about 150 mg/l and 85 mg/l, respectively. Major tributaries in this reach include (on the American side) Chacon Creek, Los Olmos Creek, Eight Mile Creek and La Joga Creek, all of which are slightly saline, and Sycamore Creek near Del Rio. On the Mexican side, the Rio San Diego, Rio San Rodrigro, and Rio Escondido flow into the Rio Grande near Eagle Pass. The quality of these tributaries is very good.

International Falcon Reservoir provides water of very good quality for the municipalities, irrigators, and industries of the Lower Rio Grande Valley, although the quality varies in response to extended wet or dry periods.

Saline irrigation return flows entering the Rio San Juan in Mexico increase dissolved-solids concentrations of the Rio Grande as it passes through the Valley. Also, the Morillo Drain in Mexico formerly conveyed saline irrigation return flows to the lower Rio Grande. In July 1969, this drain was diverted through a 75-mile long canal directly to the Gulf of Mexico. Preliminary analyses indicate that this has resulted in a significant improvement in the quality of the Rio Grande in the Valley area.

Ground Water

The Alluvium and Bolson Deposits Aquifer underlies much of the upper part of the Rio Grande Basin. Total thickness ranges to more than 5,000 feet, but the deepest known occurrence of fresh water is about 1,400 feet. Yields of high-capacity wells generally range from 1,000 to 1,500 gallons per minute (gpm), although individual wells produce up to 3,000 gpm. Water quality ranges from fresh to moderately saline.

The Edwards-Trinity (Plateau) Aquifer underlies a large area in the middle part of the Rio Grande Basin. The thickness of the limestone section ranges up to 1,000 feet. The sand is usually less than 100 feet thick. Well yields range up to 3,000 gpm. Water quality ranges from fresh to slightly saline.

The Carrizo-Wilcox Aquifer occurs in the lower middle part of the Rio Grande Basin. Total saturated thickness of the aquifer ranges from approximately 200 to 700 feet, with net saturated sand thickness ranging from 100 to 500 feet. Yields of wells range up to 500 gpm. Water quality ranges from fresh to slightly saline.

The Gulf Coast Aquifer occurs in the lower part of the Rio Grande Basin. Maximum thickness of the aquifer, where it contains fresh to slightly saline water, ranges up to 500 feet, with a net sand thickness of 30 to 40 percent. Yields of large-capacity wells range up to 2,000 gpm, but most wells average 500 gpm. Water quality ranges from fresh to slightly saline, with salinity increasing rapidly downdip.

The Bone Spring and Victorio Peak Limestones Aquifer occurs in the northeast corner of Hudspeth County in the upper part of the Rio Grande Basin. Yields of wells vary considerably, ranging from 160 to 2,240 gpm. Water quality ranges from about 1,000 to 8,000 mg/l total dissolved solids.

The Capitan Limestone Aquifer occurs along the Culberson-Hudspeth County line in the upper part of the Rio Grande Basin. The aquifer is productive to a depth of approximately 1,000 feet. Wells yield up to about 350 gpm. Water quality ranges from 850 to 1,500 mg/l total dissolved solids.

The Marathon Limestone Aquifer occurs in a small area in northwestern Brewster County in the upper part of the Rio Grande Basin. Total thickness ranges from 350 to 900 feet, but most wells are less than 250 feet deep. Well yields range up to 300 gpm. Water quality usually ranges from 500 to 1,000 mg/l total dissolved solids.

Igneous Rocks comprise an aquifer which occurs in the upper part of the Rio Grande Basin near Alpine and Marfa. Thickness varies considerably and wells locally exceed 1,000 feet in depth. Reported well yields vary from 375 to 1,000 gpm. Water quality ranges from fresh to moderately saline.

The Rustler Aquifer occurs in the upper part of the Rio Grande Basin mostly in Reeves County. Total thickness ranges up to a maximum of 500 feet. Yields of acidized wells range from 300 to 1,000 gpm. Water quality is generally poor, ranging from 2,000 to more than 6,000 mg/l total dissolved solids.

The Santa Rosa Aquifer occurs in the eastern part of the upper Rio Grande Basin. Thickness ranges up to about 300 feet. Most wells yield less than 300 gpm, but individual well yields exceed 1,000 gpm. Total dissolved-solids concentrations range from less than 100 to more than 4,100 mg/l, usually exceeding 1,000 mg/l.

Continued decline of water levels in the Alluvium and Bolson Deposits, and Gulf Coast Aquifers in the Rio Grande Basin will increase the threat of vertical and lateral saline-water encroachment into the freshwater bearing zones. Land-surface subsidence is also a potential problem near the Coast due to declines in artesian pressure in the Gulf Coast Aquifer. Excessive withdrawals of water from the Cenozoic Alluvium in the Reeves-Pecos County area have caused a change in direction of ground-water movement which has resulted in water of inferior quality moving into the aquifer from the Pecos River. Serious and steady ground-water quality deterioration is occurring in the Hueco Bolson due to heavy pumpage for municipal and industrial water needs in El Paso County and Juarez, Mexico. Because of this saline-water encroachment, El Paso will probably need additional freshwater supplies before the year 2000.

Population and Economic Development

The population of the Rio Grande Basin was reported at 780.9 thousand in 1980. El Paso is by far the largest city in the Rio Grande Basin with a 1980 population of 425.3 thousand. It is followed in population size by Laredo, Del Rio, Eagle Pass, and Pecos.

The economy of the area is based on mineral production, wholesale and retail trade, agriculture, agribusiness, and manufacturing. The economies of many of the border counties are centered around international trade and tourism with Mexico. Hunting and water-oriented recreation, principally at International Amistad and International Falcon Reservoirs, round out the basin economy.

Water Use

Total municipal freshwater use in the Rio Grande Basin was 175.9 thousand acre-feet in 1980. Zone 1 used almost 59 percent of the basin total, almost entirely concentrated in El Paso County. Zone 2, including the Cities of Eagle Pass, Laredo, and Del Rio, accounted for almost 32 percent of the basin total use. Zone 3, including Pecos, Monahans, Fort Stockton, and Kermit, accounted for more than nine percent.

Freshwater use by manufacturing industries in the basin in 1980 was 10.2 thousand acre-feet. Ninety-four percent of this amount was used in the El Paso area in Zone 1 and six percent of the total was used in Zones 2 and 3. Collectively, the petroleum refining industry and the primary metals industry accounted for approximately 59 percent of the total manufacturing freshwater use in the basin during 1980.

In 1980, there was 1,387 megawatts of steam-electric power generating capacity in the Rio Grande Basin. Most of this capacity was located in the western part of the basin. During 1980, over 13.0 thousand acre-feet of ground water was withdrawn and about 1.7 thousand acre-feet of fresh surface water was consumed in steam-electric power plant operations.

According to 1980 irrigation data, a total of 921.7 thousand acre-feet of water was applied to 338.2 thousand acres in the Rio Grande Basin, approximately 51 percent of which was from ground-water sources. This does not include diversions from the Rio Grande into the Nueces-Rio Grande Coastal Basin for Valley irrigation. The major portion of ground-water irrigation was located in Pecos, Reeves, Hudspeth, Culberson, and Jeff Davis Counties. Ground water is used to supplement surface-water supplies in El Paso and Hudspeth Counties along the Rio Grande flood plain in years when surface water is in short supply. About 186.8 thousand acres was irrigated in 1980 using about 451.1 thousand acre-feet of surface water. This acreage was concentrated in the El Paso and Maverick County project areas and in Starr County.

In 1980, mining freshwater use in the Rio Grande Basin totaled 51.3 thousand acre-feet. Nonmetal mining operations accounted for 92 percent of the total mining water use. Ground-water withdrawals for petroleum and natural gas production occur principally in Zone 3, with Winkler County being the major user of freshwater for this purpose.

In 1980, livestock water use in the Rio Grande Basin was 16.2 thousand acre-feet. Livestock water use in 1980 was 1.2 thousand acre-feet in Zone 1, 11.0 thousand acre-feet in Zone 2, and 4.0 thousand acre-feet in Zone 3.

On the American side of the Rio Grande, there is 41.1 megawatts of hydroelectric power generating capacity with an additional 66 megawatts to begin operation at Amistad Dam in mid-1983.

Return Flows

In 1980, municipal and manufacturing return flows in the Rio Grande Basin totaled 65.0 thousand acre-feet, of which El Paso County accounted for about 63 percent.

Irrigation return flows in the Rio Grande Basin vary greatly among regions of the basin. In the Dell City area, irrigation from ground water produces no significant return flows. In the remainder of Zone 1, return flows from the El Paso and Hudspeth Valley irrigation areas amount to about 10 percent or less of the water applied for irrigation. Return flows from the El Paso Valley area are reused in Hudspeth County; thus, no usable return flows leave Zone 1. About 20 thousand acre-feet are reused within Zone 1.

Return flows in Zone 2 originate in areas using surface-water supplies, such as the Maverick Irrigation District, the Lower Rio Grande Valley, and smaller areas in Starr, Zapata, Webb, and Val Verde Counties. About 50 thousand acre-feet of return flows originated in these areas in 1980. At least one-half of this amount reenters the river and can be reused downstream.

Irrigation in Zone 3 of the basin is concentrated in Pecos and Reeves Counties. Irrigation return flows in Zone 3 are negligible due to high evapotranspiration losses and recirculation.

Current Ground-Water Development

In 1980, approximately 667.9 thousand acre-feet of ground water was used in the Rio Grande Basin. Of this amount about 241.5 thousand acre-feet was used in Zone 1, about 147.6 thousand acre-feet was used in Zone 2, and about 278.8 thousand acre-feet was used in Zone 3. Within Zone 1, about 55 percent of the ground water used in 1980 was from the Bone Spring and Victorio Peak Limestones Aquifer, and about 43 percent used was from the Alluvium and Bolson Deposits Aquifer. About 70 percent of the ground water used in 1980 in Zone 2 was from the Alluvium and Bolson Deposits Aquifer. Also, about 16 percent of the ground water used in Zone 2 was from the Edwards-Trinity (Plateau) Aquifer. Within Zone 3 in 1980, approximately 64 percent of the ground water used was from the Alluvium and Bolson Deposits Aquifer, and about 27 percent of the use was from the Edwards-Trinity (Plateau) Aquifer.

Of the 667.9 thousand acre-feet of ground water used within the basin, about 470.6 thousand acre-feet or 70 percent was for irrigation purposes, about 111.8 thousand acre-feet or 17 percent was for municipal purposes, and about 50.9 thousand acre-feet or 8 percent was for mining purposes.

Large ground-water withdrawals for municipal and manufacturing purposes have caused significant removal of ground water from storage in the El Paso area. Current and historical annual withdrawals from the Hueco and Mesilla Bolsons in the El Paso area of Zone 1 are estimated to be 4 to 5 times greater than the aquifers' average annual natural recharge. Also within Zone 1 of the basin, withdrawals for irrigation purposes from the Bone Spring and Victorio Peak Limestones Aquifer in northwestern Hudspeth County are estimated to be seven to eight times greater than the annual natural recharge.

Within Zone 2, a small overdraft of ground water from the Alluvium and Bolson Deposits Aquifer within the Salt Basin in Culberson County occurred in 1980, due primarily to irrigation in the Van Horn area.

Small to large overdrafts of ground water from the Cenozoic Alluvium in Pecos and Reeves Counties within Zone 3 of the Rio Grande Basin occurred in 1980, due primarily to withdrawals for irrigation purposes.

Current Surface-Water Development

Allocation of the surface waters of the Rio Grande Basin is governed by two interstate compacts and two international treaties. The United States and Mexico signed a treaty in 1906 providing for the delivery of 60 thousand acre-feet of Rio Grande water annually by the United States to Mexico in the El Paso-Juarez Valley above Fort Quitman, Texas. The Rio Grande Compact, approved by the Legislatures of Colorado, New Mexico, and Texas in 1939, allocated the uncommitted waters of the Rio Grande above Fort Quitman, Texas. A treaty between the United States and Mexico, signed in 1944 and ratified by Congress in 1945, dealt with the division of waters of the Rio Grande and two other international rivers. The section pertaining to the Rio Grande allocated the waters from Fort Quitman, Texas to the Gulf of Mexico. This treaty also allowed for as many as three major storage reservoirs to be constructed within this reach of the basin to provide for water supply, flood control, and the generation of hydroelectric power. The International Boundary and Water Commission administers the responsibilities and obligations set forth by the treaty. The waters from the drainage area of the Pecos River were allocated by the Pecos River Compact, entered into by Texas and New Mexico in 1948 and approved and adopted by the Texas Legislature in 1949.

There are no major reservoirs in Zone 1 of the Rio Grande Basin; however, the City of El Paso, the U.S. Section of the International Boundary and Water Commission, the U.S. Bureau of Reclamation, and water districts in El Paso and Hudspeth Counties have substantial investments in canals, diversion facilities, and small storage and regulating reservoirs.

Deliveries of surface water to Zone 1 are provided for by the Rio Grande Compact and are made through the facilities of the Rio Grande Project of New Mexico-Texas. The Rio Grande Project was designed by the Bureau of Reclamation to provide irrigation water for 90.6 thousand acres in the Elephant Butte Irrigation District in the Rincon and Mesilla Valleys of New Mexico and 69.0 thousand acres in the El Paso County Water Improvement District No. 1 in the Mesilla and El Paso Valleys of Texas. Although the local share of the original costs of the Rio Grande Project have now been repaid by the Texas and New Mexico local sponsors, the Bureau of Reclamation continues to administer the Project water supply and to deliver water allotments (based on acre-feet per acre) to the headgates of the Elephant Butte and El Paso County Districts. The Hudspeth County Conservation and Reclamation District No. 1 (18.3 thousand acres), which is located within the lower part of the El Paso Valley, is not part of the Rio Grande Project but has secondary rights to excess flows of the Rio Grande (through a contract with the Rio Grande Project) and drainage waters in excess of project needs. Deliveries to Mexico, as provided for in the 1906 treaty, are in proportion to deliveries from Elephant Butte Reservoir, in New Mexico, under provisions of the Rio Grande Compact, and incremental flows of the Rio Grande above the diversion point to Mexico in the El Paso-Juarez Valley.

The Rio Grande Compact provides for scheduled annual deliveries of water from Colorado to New Mexico, thence to Texas, but allows for annual accrued credits and/or debits. Article VI of the Compact provides that beginning with the year following the effective date of the Compact (May 31, 1939), all credits and debits of Colorado and New Mexico will be computed for each calendar year, provided that in a year of actual spills (Elephant Butte Reservoir spills) no annual credits nor debits are computed for that year.

In the case of Colorado, no annual debit nor accrued debit is to exceed 100 thousand acre-feet, except as either or both may be caused by holdover storage of water in reservoirs constructed after 1937 in the drainage area of the Rio Grande above Lobatos, Colorado. Colorado is to retain water in storage at all times to the extent of any accrued debit.

In the case of New Mexico, the accrued debit is not to exceed 200 thousand acre-feet at any time, except as such debit may be caused by holdover storage in reservoirs constructed after 1929 in the drainage area of the Rio Grande Basin between Lobatos, Colorado and San Marcial, New Mexico. New Mexico is to retain water in reservoir storage to the extent of its accrued debit. In computing annual accrued credits or debits, New Mexico is not to be charged with any greater debit in any one year than the sum of 150.0 thousand acre-feet and all gain in reservoir storage in such year. The deliveries by New Mexico, are in effect deliveries to Elephant Butte Reservoir in New Mexico, which supplies water for the Rio Grande Project, New Mexico-Texas.

Other provisions of the Compact include the right of the Compact Commission, by "unanimous" action, to authorize release of water being held in storage by reason of accrued debits of Colorado or New Mexico. Also, during the month of January of any year, the Commissioner for Texas may demand of Colorado and New Mexico, and the Commissioner for New Mexico may demand of Colorado, release of water from reservoirs constructed after 1929 up to the amount of accrued debits of Colorado and New Mexico, respectively. Such releases are to be made at the greatest practicable rate under prevailing conditions, and in proportion to the total debit of each, and in amounts limited by their accrued debits, sufficient to bring the quantity of usable water in project storage to 600 thousand acre-feet by March 1 of the year and to maintain 600 thousand acre-feet of storage until April 13 such that a normal release of 790 thousand acre-feet may be made from project storage in that year. As indicated, the accrued water debit for Colorado, as computed by Compact rules, was 674.6 thousand acre-feet as of December 31, 1980, although Colorado does not officially concur with conclusions as to its indebtedness because of the litigation before the Supreme Court of the United States which is held in obeyance as long as Colorado meets its annual delivery obligation. The computed accrued debit of New Mexico was 148.0 thousand acre-feet as of December 31, 1980.

The discharge of the Rio Grande at the gaging station at El Paso, Texas provides an indication of the amount of Rio Grande water available to Texas. The wide variations in annual flow and the steady decline in available supply beginning in about 1943 (as compared to records dating back to 1895) is significant.

Exclusive of the water delivered to Mexico, most of the Rio Grande water passing the El Paso station is used for irrigation, with the remaining supply used principally by the City of El Paso. In 1980, the city used 19.9 thousand acre-feet of Rio Grande water.

In recent years, the City of El Paso has acquired ownership to about 2.0 thousand acres of water-right land and has gradually contracted for about 3.5 thousand acres of surface water rights belonging to individuals under the administration of the El Paso County Water Improvement District No. 1. The amount of surface-water rights from which the city can receive the Rio Grande Project water allocation per acre now slightly exceeds 5.5 thousand acres in both the Mesilla and El Paso Valleys in Texas. The amount of surface water received annually by the city is calculated by the number of acres (5.5 thousand) times the annual allotment (acre-feet per acre) determined annually by the Bureau of Reclamation Rio Grande Project.

The four existing major reservoirs in Zone 2, include San Esteban Lake, International Amistad Reservoir, Casa Blanca Lake, and International Falcon Reservoir.

San Esteban Lake on Alamito Creek in Presidio County had a capacity of 18.8 thousand acre-feet at one time but is now heavily silted. Ownership has changed several times since the reservoir was constructed in 1911. At the present time, it is the property of a private estate. Because of insufficient local runoff, the lake is dry most of the time. Records of the Texas Department of Water Resources indicate the owner holds a water right to use the lake for recreation purposes only.

International Amistad Reservoir, located on the main stem of the Rio Grande in Val Verde County, is the second of two multipurpose reservoirs constructed under the 1944 treaty between the United States and Mexico. Completed in 1968, the reservoir has a total controlled capacity of 5,128.0 thousand acre-feet, of which 3,383.7 thousand acre-feet is conservation storage and 1,744.2 thousand acre-feet is allocated to flood control. The United States is assigned 56.2 percent of the conservation storage and Mexico 43.8 percent. The United States (Texas) share of conservation storage is thus 1,901.7 thousand acre-feet.

Casa Blanca Lake, on Chacon Creek in Webb County, was completed in 1951. This reservoir, which has a capacity of 20.0 thousand acre-feet, is owned and operated by Webb County for recreation and irrigation of a golf course.

International Falcon Reservoir, located on the main stem of the Rio Grande in Starr and Zapata Counties, was completed in 1953. It was the first major reservoir constructed under the 1944 treaty between the United States and Mexico. The reservoir has a total controlled capacity of 3,177.1 thousand acre-feet, of which 2,667.6 thousand acre-feet is allocated to conservation storage and 509.5 thousand acre-feet is allocated to flood control. The United States is assigned 58.6 percent of the conservation storage capacity and Mexico 41.4 percent. Thus, the United States (Texas) share of conservation storage is 1,563.2 thousand acre-feet.

Detailed reservoir operation studies of the combined Amistad-Falcon Reservoir system have been performed by the Texas Department of Water Resources and the International Boundary and Water Commission in order to determine both the firm yields of the reservoirs and the yield when operated as a system. Such studies have been performed using historical hydrologic sequences covering the periods 1900-56 and 1900-70 and water demands as supplied by the Texas Department of Water Resources.

Anzalduas Diversion Dam, while not considered a major reservoir, is a vital project for diversion of municipal, industrial, and irrigation supplies in the Lower Rio Grande Valley as well as providing flood-relief measures. This project was completed by the International Boundary and Water Commission in 1960 on the main channel of the Rio Grande in Hidalgo County, subsequent to joint approval between the United States and Mexico in 1951.

Both Amistad and Falcon Reservoirs are operated by the International Boundary and Water Commission as a system for flood-control purposes. The United States share of conservation storage in the projects is administered by the Texas Department of Water Resources, currently under provisions compliant with the decision of the Thirteenth Court of Civil Appeals in (State of Texas et al., v. Hidalgo Water Control and Improvement District No. 18 et al.,) 443 S.W. 2d 728, as approved by the Supreme Court of Texas in 1969. This milestone case is commonly referred to as the "Lower Rio Grande Valley Water Case."

According to the judgement rendered in the court case, water was allocated for 742,808.61 acres of irrigation use below Falcon Dam. Of this amount, 641,221 acres was awarded Class A irrigation and 101,587.48 acres was awarded Class B irrigation. Stipulated allocations of water for municipal, industrial, and domestic use were 135,980 acre-feet annually, with an additional 7,209.743 acre-feet annually under Section III of the Trial Court Judgement. Further, municipal use under a Class A basis was 11,813.525 acre-feet annually, and a reserve of 60,000 acre-feet annually was provided for municipal and industrial demands.

A watermaster employed by the Texas Department of Water Resources is responsible for allocating the amount of water which can be diverted by each A and B class irrigator, and for supervising each use of water.

Under current rules and regulations of the Texas Water Development Board, allocations of water in the Lower Rio Grande Valley from the two reservoirs, operated as a unit, are based upon the "Lower Rio Grande Valley Water Case" and, in the middle Rio Grande (between Amistad and Falcon Reservoir), upon water rights recognized in the Texas Water Commission's Final Determination of water rights and claims. A reserve of 100.0 thousand acre-feet of storage must be held for domestic and municipal uses. In the Lower Valley, the allotment for municipal, industrial, and domestic use must be in the amount necessary to provide 25.0 thousand acre-feet at the beginning of each "accounting period" (each month);

in no event may this allotment exceed 25.0 thousand acre-feet at any one time.

Additionally, a reserve not to exceed 375.0 thousand acre-feet of water must be maintained in storage to provide for: losses by seepage, evaporation, and conveyance; emergency requirements; and adjustments of amounts in storage as may be necessary by finalization of "provisional computations" by the International Boundary and Water Commission. As of April 13, 1977, adjudicated water rights in the Lower Rio Grande Valley (Starr, Hidalgo, Willacy, and Cameron Counties) were as follows: Municipal—148,198 acre-feet, Industrial—10,393 acre-feet, Irrigation—1,852,193 acre-feet, Irrigated Acreage—740,355 acres. There are additional permits and claims (principally claims) which have not been adjudicated.

There are currently more than 33 active irrigation districts in the four-county Lower Rio Grande Valley region in addition to individual and corporate irrigation systems. In 1980, over seven thousand operating units used over 1.3 million acre-feet of water (principally Rio Grande supplies released from International Falcon Reservoir) for irrigation of about 800 thousand acres. In addition to individual industrial plants which have independent water systems, there are about 74 purveyors of municipal, domestic, and "light" industrial water supplies within the four-county Valley region. Several irrigation districts also supply water to a number of cities and communities frequently on a temporary basis. About 30 communities were not served by public water systems in 1980. The Military Highway Water Supply Corporation project has been completed or partially completed in Cameron and Hidalgo Counties and has resulted in service of treated water to about 14,000 people in communities and rural areas in these two counties. However, adequate water-supply service remains a critical problem in the Lower Rio Grande Valley. Expansion of treated water distribution systems is progressing, particularly from the systems owned and operated by the Cities of Brownsville, McAllen, and Harlingen. In 1980, municipal and manufacturing freshwater use in the four-county Valley region totaled approximately 103.0 thousand acre-feet, of which over 95 percent was surface water diverted from the Rio Grande.

There are three major reservoirs in Zone 3, Red Bluff Reservoir, Imperial Reservoir, and Lake Balmorhea. Red Bluff Reservoir is located on the Pecos River in Loving and Reeves Counties, and backs water into New Mexico. Completed in 1936, the reservoir has a total controlled storage capacity of 310.0 thousand acre-feet. The reservoir is owned and operated by the Red Bluff Water Power Control District to provide water supplies for irrigation and hydroelectric power generation. Apportionment of the waters of the Pecos River is governed by provisions of the Pecos River Compact between Texas and New Mexico, which was consumated in 1948. Basically, the Compact provides that New Mexico shall not deplete, by man's activities, the flow of the Pecos River at the New Mexico-Texas state line below an amount which gives to Texas a quantity of water equivalent to water available to Texas under the 1947 condition in the Pecos River Basin. Texas and New Mexico are currently in the seventh year of litigation before the U.S. Supreme Court concerning the failure of New Mexico to deliver annually Texas' share of the Pecos River flow to the state line. The Special Master is presently trying to redefine the 1947 condition, upon which New Mexico's annual deliveries to the State line would then be evaluated.

The Compact provides that beneficial consumptive use of unappropriated floodwaters is apportioned 50 percent to Texas and 50 percent to New Mexico. However, there have been no unappropriated floodwaters since the signing of the Compact.

Further, the Compact provides that the beneficial consumptive use of water which might be salvaged by a joint project in New Mexico is apportioned 43 percent to Texas and 57 percent to New Mexico. Provisions of the Compact addressing the "salvage" of water relate principally to the recovery, for beneficial uses, of water consumed (evapotranspired) by extensive growth of phreatophytes, principally saltcedar, within the basin. Extensive studies of the phreatophyte problem by the Bureau of Reclamation led to the implementation of eradication and control projects in New Mexico, and in Texas from Red Bluff Reservoir to the vicinity of Girvin, Texas. The potential full beneficial effects of the program have been lessened, however, due to extensive and prolonged litigation initiated by interests concerned with the environmental effects of the saltcedar control program. Saltcedar has developed dense growths in areas where the root systems can reach underflow of streams in alluvial deposits along streams and/or ground-water levels. The species are not indigenous to North America, having been introduced in the late 1800's. Studies have indicated that a mature saltcedar consumes from three to five acre-feet of water per year, and that about 290.0 thousand acre-feet of water was being consumed annually in the basin prior to initiation of eradication and control measures. These study results are now being questioned, as clearing of large areas of saltcedar infestation in New Mexico have failed to provide identifiable salvage water.

Red Bluff Reservoir, which was designed to supply water to more than 42.8 thousand acres of land in irrigation areas of the Red Bluff Water Power Control District, contains highly saline water as a result of saline water entering from New Mexico. The supply is also insufficient to meet the full needs of these irrigation areas. In 1980, less than five thousand acres was irrigated with surface water from Red Bluff Reservoir in Zone 3 of the basin.

Imperial Reservoir, located on the Pecos River in Pecos County, is owned by the Pecos County Water Improvement District No. 2. The reservoir, constructed in 1910, is operated for irrigation purposes and has a storage capacity of about six thousand acre-feet.

Lake Balmorhea, located on Sandia Creek in Reeves County, was constructed in 1917. The reservoir, which has a storage capacity of 6.4 thousand acre-feet, is owned and operated by the Reeves County Water Improvement District No. 1 for irrigation purposes. Lake Balmorhea, although it controls some drainage area, is highly dependent upon spring flow.

Water Rights

The quantity of surface water authorized or claimed for diversion and use in the Rio Grande Basin was 5,951,673 acre-feet as of December 31, 1983 (Table III-23-1). Irrigation and hydroelectric power authorizations and claims amounted to a combined total of 5,662,943 acre-feet, or 95 percent of the basin total (Table III-23-2). Hydroelectric power is generated by run-of-the-river water or water released from reservoir storage for other downstream uses. Hydroelectric use is nonconsumptive and the figure attributed to hydroelectric use is obtained by accumulating the use of water through each successive hydroelectric plant.

Water Quality

The waters of the Rio Grande Basin vary greatly in quality because of the basin's size and the wide range of geologic and climatic conditions which exist in the basin. Most of the flow of the Rio Grande in the area of El Paso is diverted for irrigation uses. Intermittent flows below Fort Quitman are the result of locally heavy rains and are generally of poor quality. In Presidio County, inflow from the Rio Concho of Mexico has been identified as a source of pesticides.

Flow of the Pecos River is highly saline as it enters Texas from New Mexico, but during years of very high runoff, the water impounded in Red Bluff Reservoir can be used for irrigation. In the lower reaches of the Pecos River, spring flows improve the quality of the river and thus the Rio Grande. The quality of the Devils River is excellent. From Presidio through Big Bend, the Rio Grande periodically contains detectable mercury concentrations, of natural origin, which originate within the Terlingua Creek drainage area. Relatively high sulfate concentrations occur in the area from Amistad Reservoir to Falcon Reservoir, due partly to geologic conditions. Releases from International Falcon Dam are degraded by return flows and saline ground-water effluent above Brownsville. Point sources of pollution are not a major problem in the basin, with the exception of the reach downstream from El Paso where the river has depressed dissolved oxygen levels, elevated nutrients, and elevated fecal coliform levels as a result of municipal effluents.

Table III-23-1. Authorized or Claimed Amount of Water, by Type of Right, Rio Grande Basin[1]

Type of Authorization	Number of Rights	Acre-Feet Authorized and Claimed
Permits	57	2,524,474
Claims	55	82,901
Certified Filings	32	1,085,203
Certificates of Adjudication	1,177	2,259,095
Total	1,321	5,951,673

[1]The Texas Water Rights Adjudication Act of 1967 authorizes the Texas Department of Water Resources to investigate and determine, with the Court's approval, the nature and measure of water rights for all authorized diversions from surface-water streams or portions thereof except domestic and livestock uses and to monitor and administer each adjudicated water right. These totals incorporate the results of water-rights adjudication in the basin as of December 31, 1983. Certified Filings are declarations of appropriation which were filed with the State Board of Water Engineers under the provisions of Section 14, Chapter 171, General Laws, Acts of the 33rd Legislature, 1913, as amended. Permits are statutory appropriative rights which have been issued by the Texas Water Commission or its predecessor agencies. Claims are sworn statements of historical uses to be adjudicated in accordance with the Texas Water Rights Adjudication Act. A certificate of adjudication is the final result after recognition of a valid right in the adjudication process and is based on a permit, certified filing or claim or any combination of the three.

Table III-23-2. Authorized or Claimed Amount of Water, by Type of Use and Zone, in Acre-Feet, Rio Grande Basin

Type of Use	Number of Rights	Zone 1	Zone 2	Zone 3	Total
Municipal	129	11,000	194,762	1,890	207,652
Industrial	18	178	51,440	0	51,618
Irrigation	1,218	247,456	2,076,234	1,339,253	3,662,943
Mining	5	0	412	7,500	7,912
Hydroelectric	3	0	2,000,000	0	2,000,000
Recreation	6	52	21,496	0	21,548
Total	1,321[1]	258,686	4,344,344	1,348,643	5,951,673

[1]Does not sum due to multipurpose "rights", which may be applied to more than one type of use.

Flooding and Drainage

Reliable estimates of flood-damage losses were not made by the U.S. Army Corps of Engineers until the 1950's. The great Devils River Flood of June 1954 caused total flood damages estimated at $5.6 million. The greatest concentration of flood damages occurred along Johnson Creek in Ozona where 16 people lost their lives, and the City of Ozona suffered an estimated $3.5 million in urban damages.

Localized flooding with resultant flood damages has been a common occurrence in the greater El Paso area. Floods in 1950, 1955, 1958, 1962, 1963, 1966, 1967, and 1968 produced damages estimated at $7.3 million within the city.

The City of Presidio has also experienced periods of damaging flooding. Periodic overbank flooding of Cibolo Creek and infrequent Rio Grande flooding have produced excessive damages. Floods in 1958, 1968, and 1974 produced $5.01 million in damages to flood-control works, agriculture, roads, and residences.

The great Sanderson Canyon flood of June 10-11, 1965, caused $2.66 million in nonagricultural damages. The flood produced substantial residential and commercial property damage in the town of Sanderson and severe damage to highways and railroads. Agricultural losses were estimated at $4 thousand. The flood produced a heavy toll of human misery when it took 21 lives and destroyed possessions of many families.

During the period 1978-1981, minor flooding resulted in 20 flood insurance claims filed for $53 thousand in flood damages.

Within the Rio Grande Basin, 32 incorporated cities have been designated flood prone by the Federal Emergency Management Agency. Maps of the 100-year flood plain have been prepared for most of the cities and work is currently in progress on mapping flood plains in the unincorporated areas of the counties. Federally subsidized flood insurance is available in 18 participating cities and the unincorporated areas of 10 participating counties. Detailed flood insurance rates studies, used to convert communities to the Regular Phase of the National Flood Insurance Program have been completed in Eagle Pass and Del Rio. Additional studies are underway in El Paso and Laredo and in Webb County.

In the Rio Grande Basin, drainage improvements are needed in areas located along the flood plains of the Rio Grande and the Pecos River, and in the ground water irrigated districts around Pecos, Balmorhea, and Fort Stockton.

The upper part of the basin, in the vicinity of El Paso, has very good drainage systems, but the lower basin is in need of on-farm drainage improvements.

Maverick County has adequate on-farm drainage facilities, but due to large amounts of silt blockage, much of the system is now unsatisfactory for effective drainage.

The lower part of the basin is extremely narrow and has little or no drainage problem. This is due in part to the well-planned levee system which borders the Rio Grande.

Recreation Resources

There are six reservoirs in the Rio Grande Basin with capacities of 5.0 thousand acre-feet or more. These six reservoirs provide over 173.0 thousand surface acres for recreational purposes. This represents 12 percent of the total surface area of all lakes in the State. Four reservoirs located in Zone 2 have 92 percent of the basin surface area with the remaining two lakes in Zone 3. International Falcon Reservoir, with over 87.0 thousand surface acres (fourth largest in the State), and Amistad Reservoir, with 64.9 thousand surface acres, are both located in Zone 2. Red Bluff Reservoir (11.7 thousand surface acres) on the Texas-New Mexico boundary in Loving and Reeves Counties and Lake Balmorhea (600 surface acres) in Reeves County are the two lakes in Zone 3. In addition to streams and ponds in the basin, other freshwater recreation resources include the Rio Grande, Pecos, and Devils Rivers.

PROJECTED WATER REQUIREMENTS

Population Growth

The population of the Rio Grande Basin is projected to almost triple by 2030 (Table III-23-3). The projected population growth rates for the basin exceed those for the State as a whole over the 1980-2000 and 2000-2030 periods.

El Paso County is the most populous county in the basin, containing 61.5 percent of the basin population in 1980. A projected growth rate of 187.5 percent will yield a county population of nearly 1.4 million by 2030. By then, El Paso County will contain 59.8 percent of the basin population.

Table III-23-3. Population, Current Water Use, With Projected Population and Water Requirements, 1990-2030[a/]
Rio Grande Basin

River Basin Zone & Category of Use	1980 Ground Water	1980 Surface Water	1980 Total	1990 Ground Water	1990 Surface Water	1990 Total	2000 Ground Water	2000 Surface Water	2000 Total	2010 Ground Water	2010 Surface Water	2010 Total	2020 Ground Water	2020 Surface Water	2020 Total	2030 Ground Water	2030 Surface Water	2030 Total
Zone 1																		
Population			482.6			635.6			795.2			970.3			1,179.1			1,386.4
Municipal	84.3	18.9	103.2	130.3	11.4	141.7	164.8	13.3	178.1	200.8	15.2	216.0	188.1	73.1	261.2	36.8	269.3	306.1
Manufacturing	9.2	0.4	9.6	11.3	0.8	12.1	13.6	0.7	14.3	15.4	0.8	16.2	17.8	0.9	18.7	20.6	1.1	21.7
Steam Electric	3.9	0.0	3.9	3.9	0.0	3.9	3.9	0.0	3.9	4.9	0.0	4.9	5.8	0.0	5.8	6.8	0.0	6.8
Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Irrigation	143.0	227.7	370.7	26.2	241.9	268.1	29.5	328.7	358.2	29.5	328.7	358.2	29.4	328.8	358.2	26.0	332.2	358.2
Livestock	1.1	0.1	1.2	1.4	0.0	1.4	1.5	0.1	1.6	1.5	0.1	1.6	1.5	0.1	1.6	1.4	0.2	1.6
Zone Total Water	241.5	247.1	488.6	173.1	254.1	427.2	213.3	342.8	556.1	252.1	344.8	596.9	242.6	402.9	645.5	91.6	602.8	694.4
Zone 2																		
Population			234.7			331.8			434.4			541.0			664.2			784.5
Municipal	11.2	44.9	56.1	30.0	59.5	89.5	37.4	81.4	118.8	39.8	107.3	147.1	52.4	127.3	179.7	55.6	156.0	211.6
Manufacturing	0.1	0.3	0.4	0.1	0.5	0.6	0.2	0.5	0.7	0.2	0.7	0.9	0.3	0.8	1.1	0.3	1.1	1.4
Steam Electric	2.1	1.7	3.8	2.1	1.7	3.8	2.1	1.7	3.8	2.1	4.1	6.2	2.1	6.5	8.6	2.1	8.9	11.0
Mining	15.6	0.4	16.0	18.0	0.5	18.5	20.5	0.4	20.9	22.9	0.5	23.4	25.4	0.5	25.9	27.8	0.6	28.4
Irrigation	111.5	200.3	311.8	93.6	183.0	276.6	117.9	266.3	384.2	118.2	266.9	385.1	118.1	266.7	384.8	22.3	362.5	384.8
Livestock	7.1	3.9	11.0	9.2	3.6	12.8	10.1	4.6	14.7	10.1	4.6	14.7	10.1	4.6	14.7	9.0	5.7	14.7
Zone Total Water	147.6	251.5	399.1	153.0	248.8	401.8	188.2	354.9	543.1	193.3	384.1	577.4	208.4	406.4	614.8	117.1	534.8	651.9
Zone 3																		
Population			63.6			68.0			74.1			82.5			95.3			110.4
Municipal	16.3	0.3	16.6	20.4	0.0	20.4	22.6	0.0	22.6	25.1	0.0	25.1	29.1	0.0	29.1	33.6	0.0	33.6
Manufacturing	0.2	0.0	0.2	0.3	0.0	0.3	0.4	0.0	0.4	0.5	0.0	0.5	0.6	0.0	0.6	0.6	0.1	0.7
Steam Electric	7.0	0.0	7.0	7.0	0.0	7.0	28.3	0.0	28.3	28.9	0.0	28.9	29.4	0.0	29.4	0.0	30.0	30.0
Mining	35.3	0.0	35.3	18.5	26.1	44.6	22.4	31.5	53.9	22.8	36.7	59.5	23.2	41.9	65.1	23.5	47.2	70.7
Irrigation	216.1	23.1	239.2	168.2	25.7	193.9	202.9	553.5	756.4	200.3	556.2	756.5	197.6	558.9	756.5	109.7	646.8	756.5
Livestock	3.9	0.1	4.0	4.7	0.0	4.7	5.5	0.0	5.5	5.5	0.0	5.5	5.5	0.0	5.5	5.0	0.5	5.5
Zone Total Water	278.8	23.5	302.3	219.1	51.8	270.9	282.1	585.0	867.1	283.1	592.9	876.0	285.4	600.8	886.2	172.4	724.6	897.0
BASIN TOTALS																		
Population			780.9			1,035.4			1,303.7			1,593.8			1,938.6			2,281.3
Municipal	111.8	64.1	175.9	180.7	70.9	251.6	224.8	94.7	319.5	265.7	122.5	388.2	269.6	200.4	470.0	126.0	425.3	551.3
Manufacturing	9.5	0.7	10.2	11.7	1.3	13.0	14.2	1.2	15.4	16.1	1.5	17.6	18.7	1.7	20.4	21.5	2.3	23.8
Steam Electric	13.0	1.7	14.7	13.0	1.7	14.7	34.3	1.7	36.0	35.9	4.1	40.0	37.3	6.5	43.8	8.9	38.9	47.8
Mining	50.9	0.4	51.3	36.5	26.6	63.1	42.9	31.9	74.8	45.7	37.2	82.9	48.6	42.4	91.0	51.3	47.8	99.1
Irrigation	470.6	451.1	921.7	288.0	450.6	738.6	350.3	1,148.5	1,498.9	348.0	1,151.8	1,499.8	345.1	1,154.4	1,499.5	158.0	1,341.5	1,499.5
Livestock	12.1	4.1	16.2	15.3	3.6	18.9	17.1	4.7	21.8	17.1	4.7	21.8	17.1	4.7	21.8	15.4	6.4	21.8
Basin Total Water	667.9	522.1	1,190.0	545.2	554.7	1,099.9	683.6	1,282.7	1,966.3	728.5	1,321.8	2,050.3	736.4	1,410.1	2,146.5	381.1	1,862.2	2,243.3

a/ Population in thousands of persons, water requirements in thousands of acre-feet per year.

Water Requirements

Municipal

Municipal water requirements are projected for two cases of future growth based on both population and per capita water use. Water requirements in the Rio Grande Basin are projected to increase from the 1980 level of 175.9 thousand acre-feet by a projected maximum of 82 percent by the year 2000 (high case). In the year 2030, water requirements are projected to range from 411.1 to 551.3 thousand acre-feet. Zone 1 is projected to account for 55 to 56 percent of total basin municipal requirements in 2000 and 2030.

A range of 81.6 to 118.8 thousand acre-feet of municipal water requirements is projected in Zone 2 by 2000. Total municipal water requirements in Zone 3 are projected to range from 17.6 to 22.6 thousand acre-feet in the year 2000. By 2030, Zone 3 is projected to account for 5.7 to 6.1 percent of the total basin municipal water requirements.

Industrial

Manufacturing water requirements in 1980 were 10.2 thousand acre-feet in the Rio Grande Basin. Projections of future water requirements for manufacturing purposes were made by decade and for a low and high case for each industrial group. In 1980, over 90 percent of total manufacturing water use was concentrated in five industrial groups: chemicals, petroleum refining, primary metals, paper products, and food products. Because of this concentration, careful attention was given to the future growth outlook for these industries in making the projections.

Manufacturing water requirements in the Rio Grande Basin are projected to increase more than two times by the year 2030, to a potential high of 23.8 thousand acre-feet.

The rate of increase in the Rio Grande Basin from 1980 to 2030 is lower than for the State as a whole (104 to 134 percent compared to the State average of 178 to 230 percent).

El Paso County accounted for about three-fourths of basin manufacturing water use in 1980, and that trend is expected to continue to 2030.

Steam-Electric Power Generation

Water requirements for steam-electric power production are projected to increase steadily as installed generating capacity increases (Table III-23-3).

Projections indicate that water consumption will range from 7.7 to 36.0 thousand acre-feet per year, low and high case, respectively, by the year 2000. These water totals are expected to increase to 30.3 thousand and 47.8 thousand acre-feet, low and high case, respectively, in 2030.

Agriculture

Irrigation

Irrigation water requirements were projected for two cases of change based on improvements in on-farm application efficiencies, reduction in ditch losses, changes in future resource costs and crop prices, and corresponding changes in cropping patterns to reflect more profitable crops. A low case projects demand for water based on the effects of changes in the above variables but with irrigated acreage held constant at 1980 levels in each zone for each future time period; a high case projects demand for water for irrigation constrained only by the requirement that irrigated farming produce a net positive return in excess of that possible from dryland farming and the requirement not to exceed the amount of irrigable soil in each zone. Thus, the projections of demand, low and high cases, based on the irrigation efficiency and market conditions mentioned above, give an estimate of the quantity of water needed for irrigation in each zone, at each decadal point for which projections were made. These projections of demand are compared to the projected supply of water locally available. When projected demand exceeds projected supply, the difference is a measure of shortage at that point in time.

Irrigation water requirements in the Rio Grande Basin are projected to increase from the 1980 level of 0.9 million acre-feet by a projected maximum 63 percent by the year 2000 in the high case, declining 22 percent in the low case. In the year 2030, water requirements in the basin are projected to range from 0.7 to 1.5 million acre-feet annually, low and high case, respectively, to irrigate from 0.3 million acres to 0.7 million acres.

Zone 3 is projected to account for about 50 percent of total basin irrigation requirements in 2000 and 2030. Zone 1 is projected to account for about 24 percent of the total and Zone 2 is projected to account for about 26 percent of the total in the high case. A range of 192.2 to 756.5 thousand acre-feet of irrigation requirements is projected in Zone 3 by 2030.

Livestock

A projected increase in the number of cattle is expected to expand livestock water needs from 16.2 thousand acre-feet used in 1980 to 21.8 thousand acre-feet in 2030. The anticipated use will be 1.6 thousand acre-feet in Zone 1, 14.7 thousand acre-feet in Zone 2, and 5.5 thousand acre-feet in Zone 3.

Mining

Mining water requirements in the Rio Grande Basin are projected to expand from 51.3 thousand acre-feet in 1980 to 99.1 thousand acre-feet annually in 2030. As a proportion of State requirements, the basin's share is expected to account for 25 percent of total State mining water use in 2030, as compared to 21 percent in 1980.

Estimates of nonmetal mining water use in 1980 (47.2 thousand acre-feet) are projected to increase to 97.7 thousand acre-feet in 2030. Over 75 percent of the basin's nonmetal water use in 2030 will be employed in sulfur production and sand and gravel operations in Zones 2 and 3.

Navigation

Currently, there are no plans for navigation in the Rio Grande Basin.

Hydroelectric Power

Presently, there is 43.4 megawatts of installed generating capacity in the Rio Grande Basin. A new 32 megawatt unit is under construction at Amistad Reservoir; expansion of hydroelectric power generating capability beyond this level is not anticipated.

WATER SUPPLY PROJECTS AND MEASURES TO MEET FUTURE BASIN NEEDS

Ground-Water Availability and Proposed Development

Based on ground-water storage depletion analyses, the following annual amounts of fresh ground water in thousands of acre-feet are expected to be available from 1990 through 2030 by decade from the Hueco and Mesilla Bolsons in El Paso County within Zone 1 of the Rio Grande Basin:

Year	Hueco Bolson	Mesilla Bolson	Total
1990	107.0	36.7	143.7
2000	133.4	48.0	181.4
2010	196.6	22.5	219.1
2020	186.0	22.5	208.5
2030	37.5	22.5	60.0

The analyses use the assumption that only one-half or about 5.38 million acre-feet of the 10.76 million acre-feet of fresh water in storage can be removed without serious ground-water quality degradation. Under these conditions, the availability of fresh water from the two bolson aquifers primarily for municipal and manufacturing uses is reduced after the year 2000; primarily in about the year 2003 from the Mesilla Bolson and in about the year 2020 from the Hueco Bolson, as indicated in the above table. Any additional ground water removed from the bolson aquifers will have to be desalted because of its high salinity. Other sources of fresh water to meet the additional water requirements within El Paso County will have to come from other fresh ground-water supplies outside of El Paso County or possibly from the Rio Grande, if such supplies can be made available.

The approximate annual ground-water yield to the year 2030 within the remaining portion of the Rio Grande Basin is 1,013.7 thousand acre-feet with the following amounts annually available by aquifer: 404.9 thousand acre-feet from the remaining Alluvium and Bolson Deposits Aquifer in the upper (western) part of the basin, 513.9 thousand acre-feet from the Edwards-Trinity (Plateau) Aquifer, 19.4 thousand acre-feet from the Capitan Limestone Aquifer, 18.3 thousand acre-feet from the Marathon Limestone Aquifer, 17.0 thousand acre-feet from the Bone Spring and Victorio Peak Limestones Aquifer, 14.1 thousand acre-feet from the Carrizo-Wilcox Aquifer, 11.4 thousand acre-feet from the Gulf Coast Aquifer, 10.7 thousand acre-feet from the Igneous Rocks Aquifer, and 4.0 thousand acre-feet from the Rustler Aquifer. The quality of the ground water from the Rustler Aquifer is such that it can only be used for irrigation purposes. In the year 2030, the yields of the Alluvium and Bolson Deposits Aquifer, the Capitan Limestone Aquifer and the Carrizo-Wilcox Aquifer within the basin were reduced to the average annual effective recharge of the aquifers which is 121.0 thousand acre-feet per year. These reductions decrease the total ground-water availability within the basin in 2030 to 696.3 thousand acre-feet (bolson aquifers in El Paso County not included). Consequently, since less ground water will be available in 2030, the total ground-water use projected for the basin in 2030 also may be reduced.

The projected annual ground-water use within the Rio Grande Basin by decade from 1990 through 2030 is expected to be from 381.1 to 736.4 thousand acre-feet per year (Table III-23-3). The approximate average annual projected ground-water use within the basin is expected to be about 614.9 thousand acre-feet per year. Of the 614.9 thousand acre-feet of average annual projected use, about 65 percent is expected to be from the Alluvium and Bolson Deposits Aquifer, and about 26 percent is expected to be from the Edwards-Trinity (Plateau) Aquifer.

Surface-Water Availability and Proposed Development

The surface-water supplies available in the Rio Grande Basin are insufficient to meet projected water requirements in the basin (Table III-23-4, Figure III-23-2). Water shortages for irrigation, municipal, or industrial purposes are projected to occur in each of the three zones in the basin from before the year 1990 and through 2030. Supplemental surface-water supplies for the Rio Grande Basin will be essential if this region of Texas—which is of vital economic importance to both the State and the nation—is to maintain its economic and social well being.

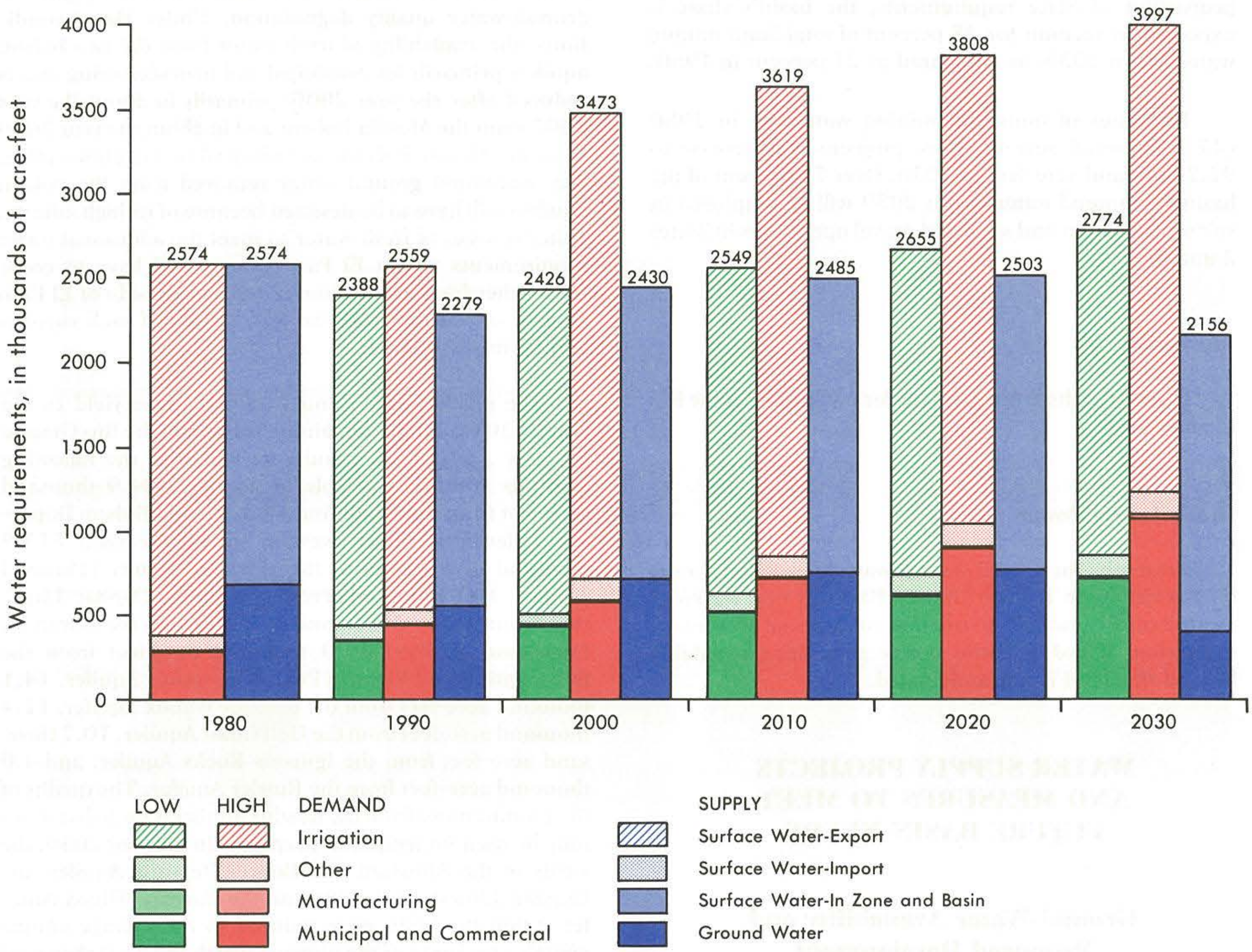

Figure III-23-2. Reported Use and Supply Source, With Projected Water Supplies and Demands, Rio Grande Basin and Nueces-Rio Grande Coastal Basin, Zone 2, 1980-2030

Table III-23-4. Water Resources of the Rio Grande Basin, and the Nueces-Rio Grande Coastal Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	566.8	—	—	—	566.8	566.8	—	—	566.8	.0	.0	.0
Surface Water	1682.7	—	29.4	.0	1712.1	1992.2	—	.0	1992.2	(8.1)	(272.0)	(280.1)
Total	2249.5	—	29.4	.0	2278.9	2559.0	—	.0	2559.0	(8.1)	(272.0)	(280.1)
2000												
Ground Water	708.9	—	—	—	708.9	708.9	—	—	708.9	.0	.0	.0
Surface Water	1682.7	—	38.3	.0	1721.0	2764.1	—	.0	2764.1	(71.1)	(972.0)	(1043.1)
Total	2391.6	—	38.3	.0	2429.9	3473.0	—	.0	3473.0	(71.1)	(972.0)	(1043.1)
2010												
Ground Water	754.8	—	—	—	754.8	754.8	—	—	754.8	.0	.0	.0
Surface Water	1682.7	—	47.3	.0	1730.0	2864.0	—	.0	2864.0	(150.2)	(983.8)	(1134.0)
Total	2437.5	—	47.3	.0	2484.8	3618.8	—	.0	3618.8	(150.2)	(983.8)	(1134.0)
2020												
Ground Water	763.0	—	—	—	763.0	763.0	—	—	763.0	.0	.0	.0
Surface Water	1682.7	—	57.7	.0	1740.4	3045.2	—	.0	3045.2	(306.2)	(998.6)	(1304.8)
Total	2445.7	—	57.7	.0	2503.4	3808.2	—	.0	3808.2	(306.2)	(998.6)	(1304.8)
2030												
Ground Water	405.9	—	—	—	405.9	405.9	—	—	405.9	.0	.0	.0
Surface Water	1682.7	—	67.5	.0	1750.2	3591.1	—	.0	3591.1	(648.6)	(1192.3)	(1840.9)
Total	2088.6	—	67.5	.0	2156.1	3997.0	—	.0	3997.0	(648.6)	(1192.3)	(1840.9)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
Import: A transfer of water from another river basin.
Return Flows: Wastewater returned to a natural stream channel that can be recaptured at a downstream point.
Export: A transfer of water to another river basin.

Zone 1

In the year 2000, the projected water requirements of Zone 1 of the Rio Grande Basin exceed available supplies by 175.5 thousand acre-feet (Table III-23-5, Figure III-23-3). This entire shortage is for irrigated agriculture and arises from limited ground-water availability due to the expected depletion of available ground-water supplies in the Bone Spring-Victorio Peak Limestones Aquifer which is located in northeastern Hudspeth County.

It is projected that in the year 2000 a total of 128.7 thousand acre-feet of surface water will be available for use in this zone. Deliveries to Texas through the Rio Grande Project and return flows below El Paso are the only sources of surface water available to this area. No additional surface-water developments are planned. The surface-water deliveries via the Rio Grande Project have varied widely from year to year. Historically, in years when deliveries have been short of requirements, ground water has been used to make up the deficit. This practice is certain to continue; however, for the purpose of the discussion above, it was assumed that the average of the deliveries to Texas via the Rio Grande Project during the period 1951-1980 (approximately 128.7 thousand acre-feet) will continue to be available.

Between the years 2000 and 2030, the total water requirement in this area is expected to increase to approximately 655.7 thousand acre-feet annually. Unless supplemental surface-water supplies are imported from other areas, the Rio Grande Project under the provisions of the Rio Grande Compact will continue to be the only source of surface water available to this area. Shortages in municipal and manufacturing needs, principally in the El Paso area, are projected to begin between 2010 and 2020 and increase dramatically by 2030. The annual shortage is estimated at 56.1 thousand acre-feet in 2020 and 255.4

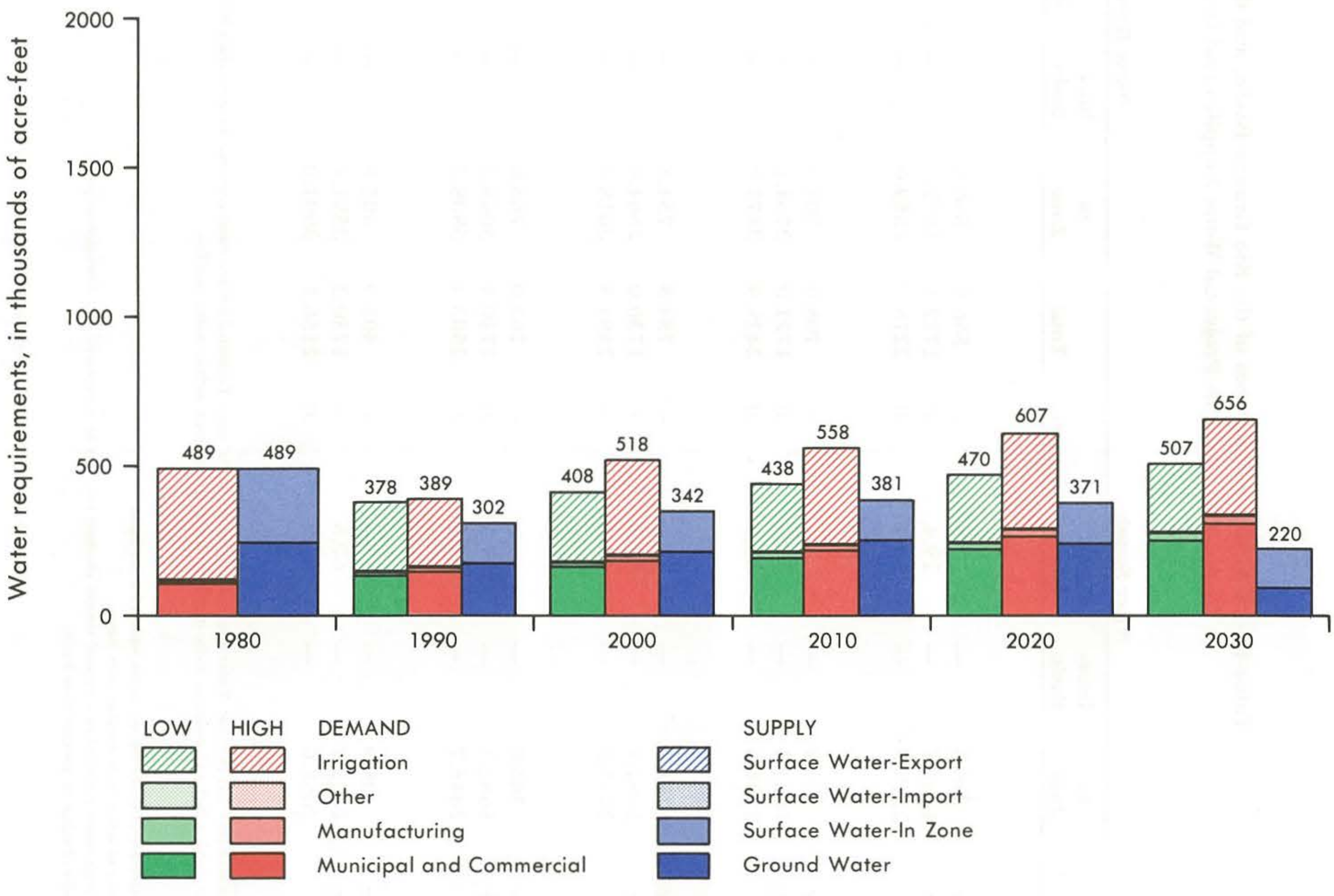

Figure III-23-3. Reported Use and Supply Source, With Projected Water Supplies and Demands, Rio Grande Basin, Zone 1, 1980-2030

Table III-23-5. Water Resources of the Rio Grande Basin, Zone 1, With Projected Water Supplies and Demands, 1990-2030[1]

	Water Supply					Water Demand				Surplus or Shortage		
Decade	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	173.1	—	—	—	173.1	173.1	—	—	173.1	.0	.0	.0
Surface Water	128.7	.0	.0	.0	128.7	215.6	.0	.0	215.6	.0	(86.9)	(86.9)
Total	301.8	.0	.0	.0	301.8	388.7	.0	.0	388.7	.0	(86.9)	(86.9)
2000												
Ground Water	213.3	—	—	—	213.3	213.3	—	—	213.3	.0	.0	.0
Surface Water	128.7	.0	.0	.0	128.7	304.2	.0	.0	304.2	.0	(175.5)	(175.5)
Total	342.0	.0	.0	.0	342.0	517.5	.0	.0	517.5	.0	(175.5)	(175.5)
2010												
Ground Water	252.1	—	—	—	252.1	252.1	—	—	252.1	.0	.0	.0
Surface Water	128.7	.0	.0	.0	128.7	306.2	.0	.0	306.2	.0	(177.5)	(177.5)
Total	380.8	.0	.0	.0	380.8	558.3	.0	.0	558.3	.0	(177.5)	(177.5)
2020												
Ground Water	242.6	—	—	—	242.6	242.6	—	—	242.6	.0	.0	.0
Surface Water	128.7	.0	.0	.0	128.7	364.3	.0	.0	364.3	(56.1)	(179.5)	(235.6)
Total	371.3	.0	.0	.0	371.3	606.9	.0	.0	606.9	(56.1)	(179.5)	(235.6)
2030												
Ground Water	91.6	—	—	—	91.6	91.6	—	—	91.6	.0	.0	.0
Surface Water	128.7	.0	.0	.0	128.7	564.1	.0	.0	564.1	(255.4)	(180.0)	(435.4)
Total	220.3	.0	.0	.0	220.3	655.7	.0	.0	655.7	(255.4)	(180.0)	(435.4)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

Definitions
Intra-Basin: A transfer of water among zones within a river basin.
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thousand acre-feet in 2030. Alternatives for meeting the water needs of El Paso are limited. Current plans to recharge existing water-bearing formations could provide additional resources from the existing ground-water source. Ground-water development in areas of New Mexico is also planned, but must await the outcome of current litigation in the federal courts. Future surface-water projects are not deemed viable toward meeting El Paso's water needs since the Rio Grande is fully developed from El Paso to its headwaters in the State of Colorado.

Zone 2

Water requirements placed upon the water resources in Zone 2 of the Rio Grande Basin include surface-water needs in Zone 2 of the Nueces-Rio Grande Coastal Basin which are currently supplied from existing reservoirs, Amistad and Falcon, in Zone 2 of the Rio Grande Basin. A water balance was computed for the combined zones in order to allow for existing water rights. Water shortages are projected to occur in each decade for these zones with an initial shortage in 1990 of 211.0 thousand acre-feet per year (Table III-23-6, Figure III-23-4). By the year 2030, a total surface-water shortage of 774.5 thousand acre-feet is projected for the combined zones of the two basins. The complex nature of the water rights in the Rio Grande Valley area of Zone 2 of the Nueces-Rio Grande Coastal Basin precludes a precise allocation of the total surface-water shortage among differing purposes. However, shortages were projected based upon existing water rights.

Surface water available for use in the area is projected to be slightly less than 1.6 million acre-feet in the year 2030, with approximately 67.5 thousand acre-feet of this amount from municipal and industrial return flows. The Middle and Lower Rio Grande Valleys will continue to be served from the Amistad-Falcon Reservoir system. However, these supplies from Amistad and Falcon Reservoirs are insufficient to meet projected surface-water needs. Studies to determine the potential increase in surface-water supplies through construction of additional major reservoirs on the Rio Grande have indicated that very little additional dependable surface-water supply can be developed from another major reservoir project. However, studies conducted by the International Boundary and Water Commission, U.S. Section, for the Texas Department of Water Resources have indicated that additional surface waters can be added to the yield of the system without significant cost through the development of up to three channel storage dams below Falcon Reservoir. Channel dams at Retamal and Brownsville are proposed for construction by 1990 to provide additional water resources to the Rio Grande and the Nueces-Rio Grande Coastal Basins.

Zone 3

Water requirements projected for Zone 3 of the basin are estimated to exceed available surface-water resources beginning in 2000 (Table III-23-7, Figure III-23-5). Annual surface-water shortages amounting to some 631.0 thousand acre-feet are projected to occur in year 2030, with 623.8 thousand acre-feet of that shortage in irrigated agricultural demand. Shortages of surface water for municipal and industrial purposes are projected to occur between 2020 and 2030 and amount to 7.2 thousand acre-feet annually by year 2030.

Surface water is limited in this zone and accounts for only 23.0 thousand acre-feet of the total water supply in year 2030. The in-basin surface-water supply in Zone 3 is obtained from Lake Balmorhea, which is dependent upon spring flow, and from Red Bluff Reservoir. Inflows to Red Bluff Reservoir for use in Texas are subject to provisions of the Pecos River Compact with the State of New Mexico, as previously discussed. The future quantity, and to a large extent the quality, of water supplies available in Red Bluff Reservoir may depend in large measure upon the results of current litigation between Texas and New Mexico relative to the Pecos River Compact.

The shortage in irrigated agriculture occurs as a result of limited ground water available for projected area-wide increases in agriculture. The primary ground-water source, the Cenozoic Alluvium in Pecos and Reeves Counties, is estimated to supply significantly lower levels of pumpage than historically provided because of depletion of water in storage in the aquifer, excessive pumping lifts, and encroachment of poor-quality water as the water levels are progressively lowered.

Water Quality Protection

Construction costs associated with municipal wastewater treatment facilities needs have been estimated to be approximately $257.9 million for the planning period of 1980 to the year 2000. These costs are estimated for the entire Rio Grande Basin with approximately $154.3 million required for Zone 1, $83.8 million for Zone 2, and $17.8 million for Zone 3. All costs are in January 1980 dollars and are subject to revision as new data become available. The list of projects, with project costs for 1982-1989, at 1980 prices, is shown in Appendix B.

Additional water quality management costs, such as for control of agricultural, oil and gas, and industrial pollutants, cannot be estimated at this time, but are believed to be increasing.

Table III-23-6. Water Resources of the Rio Grande Basin, Zone 2 and the Nueces-Rio Grande Coastal Basin, Zone 2, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	174.6	—	—	—	174.6	174.6	—	—	174.6	.0	.0	.0
Surface Water	1531.0	.0	29.4	.0	1560.4	1771.4	.0	.0	1771.4	(31.0)	(180.0)	(211.0)
Total	1705.6	.0	29.4	.0	1735.0	1946.0	.0	.0	1946.0	(31.0)	(180.0)	(211.0)
2000												
Ground Water	213.5	—	—	—	213.5	213.5	—	—	213.5	.0	.0	.0
Surface Water	1531.0	.0	38.3	.0	1569.3	1929.4	.0	.0	1929.4	(94.2)	(265.9)	(360.1)
Total	1744.5	.0	38.3	.0	1782.8	2142.9	.0	.0	2142.9	(94.2)	(265.9)	(360.1)
2010												
Ground Water	219.6	—	—	—	219.6	219.6	—	—	219.6	.0	.0	.0
Surface Water	1531.0	.0	47.3	.0	1578.3	2024.6	.0	.0	2024.6	(173.1)	(273.2)	(446.3)
Total	1750.6	.0	47.3	.0	1797.9	2244.2	.0	.0	2244.2	(173.1)	(273.2)	(446.3)
2020												
Ground Water	235.0	—	—	—	235.0	235.0	—	—	235.0	.0	.0	.0
Surface Water	1531.0	.0	57.7	.0	1588.7	2145.1	.0	.0	2145.1	(273.1)	(283.3)	(556.4)
Total	1766.0	.0	57.7	.0	1823.7	2380.1	.0	.0	2380.1	(273.1)	(283.3)	(556.4)
2030												
Ground Water	141.9	—	—	—	141.9	141.9	—	—	141.9	.0	.0	.0
Surface Water	1531.0	.0	67.5	.0	1598.5	2373.0	.0	.0	2373.0	(386.0)	(388.5)	(774.5)
Total	1672.9	.0	67.5	.0	1740.4	2514.9	.0	.0	2514.9	(386.0)	(388.5)	(774.5)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

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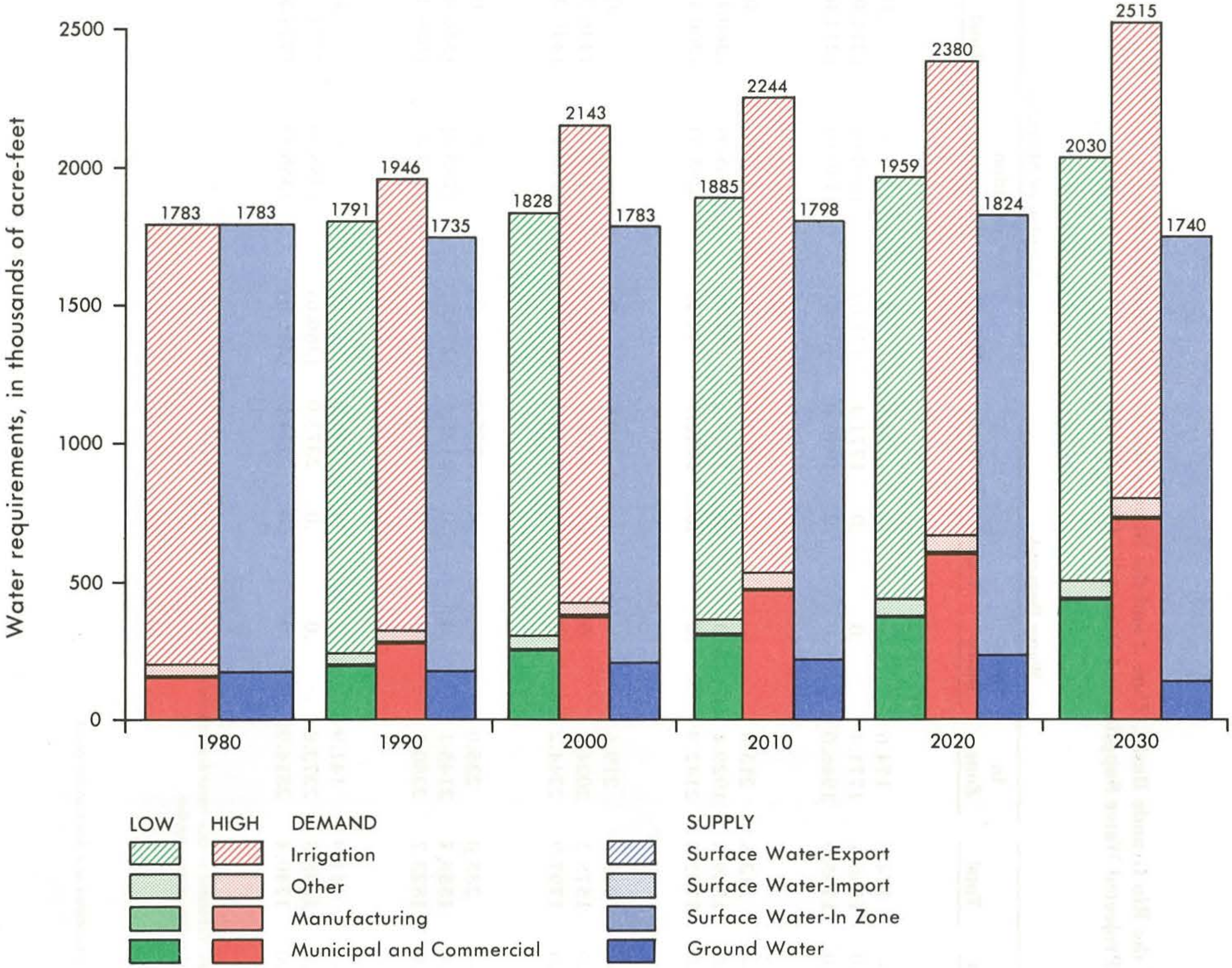

Figure III-23-4. Reported Use and Supply Source, With Projected Water Supplies and Demands, Rio Grande Basin, Zone 2 and Nueces-Rio Grande Coastal Basin, Zone 2, 1980-2030

A water quality management plan for the Rio Grande Basin has been developed pursuant to the requirements of federal and State Clean Water legislation. An areawide water quality management plan has also been developed for the Lower Rio Grande Valley area. The plans serve as a basic element in the State's overall water quality strategy and provide guidance in establishing priorities for construction grants for waste-treatment facilities, permitting of wastewater facilities, revision of stream standards, and other program activities.

Flood Control Measures

Extensive federal, State, and local efforts have been expended within the Rio Grande Basin since as early as 1916, to control overbank flooding of the river. Operations of Elephant Butte Dam, constructed in 1916, and Caballo Reservoir, built in 1938, have greatly modified flood flows of the Rio Grande above El Paso. The Rio Grande Canalization Project, completed in 1943, consists of a normal flow channel and a leveed floodway 105.6

Table III-23-7. Water Resources of the Rio Grande Basin, Zone 3, With Projected Water Supplies and Demands, 1990-2030[1]

Decade	Water Supply					Water Demand				Surplus or Shortage		
	In Zone	Intra-Basin	Return Flow	Import	Total	In Zone	Intra-Basin	Export	Total	M & I	Irrigation (Shortage)	Total
1990												
Ground Water	219.1	—	—	—	219.1	219.1	—	—	219.1	.0	.0	.0
Surface Water	23.0	.0	.0	.0	23.0	5.2	.0	.0	5.2	22.9	(5.1)	17.8
Total	242.1	.0	.0	.0	242.1	224.3	.0	.0	224.3	22.9	(5.1)	17.8
2000												
Ground Water	282.1	—	—	—	282.1	282.1	—	—	282.1	.0	.0	.0
Surface Water	23.0	.0	.0	.0	23.0	530.5	.0	.0	530.5	23.1	(530.6)	(507.5)
Total	301.1	.0	.0	.0	305.1	812.6	.0	.0	812.6	23.1	(530.6)	(507.5)
2010												
Ground Water	283.1	—	—	—	283.1	283.1	—	—	283.1	.0	.0	.0
Surface Water	23.0	.0	.0	.0	23.0	533.2	.0	.0	533.2	22.9	(533.1)	(510.2)
Total	306.1	.0	.0	.0	306.1	816.3	.0	.0	816.3	22.9	(533.1)	(510.2)
2020												
Ground Water	285.4	—	—	—	285.4	285.4	—	—	285.4	.0	.0	.0
Surface Water	23.0	.0	.0	.0	23.0	535.8	.0	.0	535.8	23.0	(535.8)	(512.8)
Total	308.4	.0	.0	.0	308.4	821.2	.0	.0	821.2	23.0	(535.8)	(512.8)
2030												
Ground Water	172.4	—	—	—	172.4	172.4	—	—	172.4	.0	.0	.0
Surface Water	23.0	.0	.0	.0	23.0	654.0	.0	.0	654.0	(7.2)	(623.8)	(631.0)
Total	195.4	.0	.0	.0	195.4	826.4	.0	.0	826.4	(7.2)	(623.8)	(631.0)

[1]Units in thousands of acre-feet per year. Water demands are for the "high" case. Tabulated surface water demands do not include livestock needs, some quantities of irrigation needs and other needs which will continue to be met from local, unregulated surface-water supplies.

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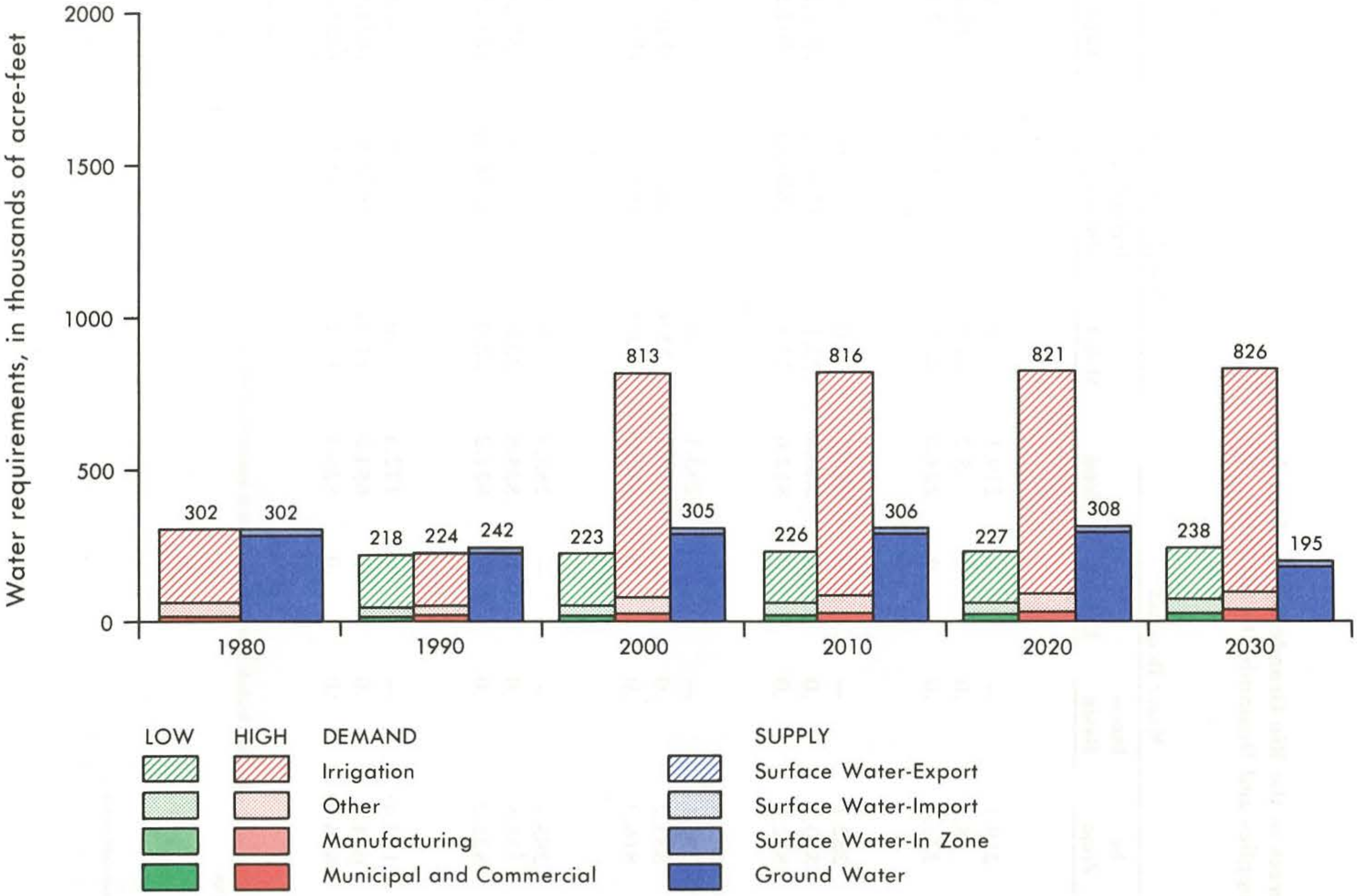

Figure III-23-5. Reported Use and Supply Source, With Projected Water Supplies and Demands, Rio Grande Basin, Zone 3, 1980-2030

miles along the river from two miles below Caballo Dam in New Mexico to the American Dam at El Paso. The project provides protection against flows greater than the present condition 100-year frequency Rio Grande flood for lands in New Mexico and in El Paso County, Texas upstream from the City of El Paso.

The Rio Grande Rectification Project completed in 1983 provides flood protection to the El Paso Valley between the Chamizal Channel and Fort Quitman, a project length of 83.0 miles. The Chamizal Channel Project is a 7.7-mile unit of concrete-lined and earth-leveed channels which provide protection for the Cities of El Paso and Juarez against 100-year flood flows. To control severe flooding within the City of El Paso from tributary arroyos, the Corps of Engineers has been authorized to proceed with an improvement plan which consists of a single-purpose flood-control system of detention dams, diversion dikes, and channels to collect, regulate, and discharge arroyo runoff into the Rio Grande. Construction of elements of the project has been underway since 1970.

The Presidio-Ojinaga Valley Flood Control Project, following approval of the 1970 Boundary Treaty, provides for 2.3 miles of new channel along the confluence of the Rio Grande and the Rio Conchos. Levees extend along 13.3 miles of river channel along the United States side with side levees extending along Cibolo Creek to tie into existing levees developed by local interests. The Corps of Engineers has made extensive studies of flood problems in Presidio, Texas to determine feasible alternatives to control local flooding. Completion of this project will depend upon favorable benefit-cost ratios and the ability of the local interests to provide for the nonfederal share of the project cost.

Localized flooding within the City of Pecos has also been studied by the Corps of Engineers. The authorized project would consist of an integrated system of diversions, floodways, and levees to provide protection from overflow of local tributaries. Construction will again depend upon the ability of the local interests to meet reimbursable costs of the total project cost.

International Falcon Reservoir, located below Laredo, Texas, began operation in 1953 and International Amistad Reservoir, located near Del Rio, Texas, began operation in 1968. Combined total flood-storage capacity at maximum water-surface elevation of the two reservoirs amounts to 3,391.0 thousand acre-feet. Alpine Reservoir, an authorized Corps of Engineers project, if constructed would have 4.5 thousand acre-feet of available flood-control storage.

Below International Falcon Dam, in the Lower Rio Grande Valley, local efforts to control overbank flooding began in the early 1900's. Cameron and Hidalgo Counties took over efforts in the early 1920's and began a system of protective works along the river and the natural overflow channels. By 1930, more than $5 million had been expended, with the project only partially completed. To properly control river flows in the area, international cooperation was needed. Through the treaty with the United States and Mexico, the International Boundary and Water Commission was authorized to develop a coordinated international plan of flood control. Construction of the project proceeded, and from 1935 to 1967 the Lower Rio Grande Flood Control Project provided complete protection to United States lands. However, in September 1967, Hurricane Beulah struck the Valley with 35 inches of rainfall. The project prevented tremendous damages but major flooding occurred in Harlingen and the McAllen area. Efforts were begun in 1970 to provide for additional flood protection. The project, as now completed, includes 102.9 miles of river levees along the United States side, 122.5 miles of off-river improved floodways and natural drains, and two diversion dams. The Lower Rio Grande Flood Control Project levees now provide protection against Rio Grande flows greater than the 100-year frequency flood.

One serious problem common to all areas of the Lower Valley is the inability to remove excess surface water during periods of heavy rainfall. Lack of natural drainage, flat topography, and soils with low permeability all contribute to ponding floodwater. To find solutions to these problems, in 1969 the Soil Conservation Service developed a three-phase plan for flood control and major drainage in Willacy, Hidalgo, and Cameron Counties. Phase I would consist of a system of floodwater channels with a combined length of 164 miles to remove floodwater from Hidalgo and Willacy Counties. Phase II would consist of 1,394 miles of multipurpose channels, 35 water-control structures, and other works of improvement in Hidalgo and Willacy Counties. Phase III would consist of an accelerated land-treatment program in Cameron, Willacy, and Hidalgo Counties. The Water Resources Development Act of 1974 authorized the Corps of Engineers to undertake advance engineering and design for Phase I of the project. The Corps has completed the feasibility report on Phase I and has recommended that Congress authorize construction.

Local interests in Hidalgo and Willacy Counties are proposing a local project of 138 miles of channel and 17 pumping stations. The floodwater channel is similar in alignment to the Corps of Engineers plans. Voters in Hidalgo County Drainage District No. 1 approved a $26 million bond issue in November 1975, and in October 1976 Willacy County Drainage District No. 1 approved a $3.5 million bond issue to fund the project.

Future efforts in the Valley will be to provide all possible support available to local interests and to secure funding for completion of the federal projects.

There are about 646 square miles of drainage area above 42 existing U.S. Soil Conservation Service floodwater-retarding structures within the Rio Grande Basin. As of October 1980, an additional 14 structures with a drainage area of 550 square miles were planned for construction. Zone 1 contains 5 existing structures with none planned, Zone 2 has 37 existing and 12 planned, while Zone 3 has no existing structures, but two planned for construction.

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PART IV

MANAGEMENT AND TECHNICAL METHODS FOR REDUCING WATER DEMAND, INCREASING WATER USE EFFICIENCY, AND INCREASING LOCAL AREA WATER SUPPLIES

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PART IV

MANAGEMENT AND TECHNICAL METHODS FOR REDUCING WATER DEMAND, INCREASING WATER USE EFFICIENCY, AND INCREASING LOCAL AREA WATER SUPPLIES

In previous portions of this volume, water problems have been identified and current water supplies and water use data have been described and presented for each river and coastal basin, by zone, in Texas. Planning methods and projections of future quantities of water supplies and water quality protection needs also have been identified, as have potential projects to meet future needs. For these potential projects, an estimate has been made of the time project implementation should begin in each case so that the projects will be completed and ready to operate as needs develop. Additionally, water management and water supply methods have been identified and described briefly.

Water planning for the future requires long-range projections of future water supplies and future water needs. Projections of demand are based on the best data available about each factor involved, including state-of-the-art analyses of each major water-using function within the State, legal and institutional conditions which affect water use, and habits, custom, and preferences which affect water management and water use. Technical processes, management, prices, and behavioral relationships and data affect the results of the projections. The actual quantities of water that will be used will be determined by the facts about these demand relationships and the quantities of supply available at the time. In making long-range water demand projections, the potential effects of water conservation have been taken into account. However, it will be necessary to publicize conservation methods, as well as provide technical, and in some cases, financial assistance and incentives to effectuate conservation potentials and thereby reduce demands for water.

On the water supply side, desalting, weather modification to increase precipitation, and transportation of water from other areas are techniques that may be used to increase the quantities of water available for use. In this part of the planning report water conservation, reuse, desalting, weather modification, water importation, and drought contingency planning are presented.

WATER CONSERVATION AND REUSE

The term "water conservation" used herein means to reduce the demand for water, improve the efficiency in use and reuse of water, reduce leakage losses and waste of water, and improve land management practices to use less water per acre. The need to conserve or reduce water consumption in Texas is due both to the lack of additional supplies in some areas and the rapidly increasing costs and difficulties associated with new water resources development. Therefore, water conservation and reuse are included in plans to meet future water needs within the State.

Municipal and Commercial Water Conservation and Reuse

Water use in the municipal and commercial sector includes water used in residential, commercial, and institutional areas for drinking, bathing, cooking, toilet flushing, fire protection, lawn watering, swimming pools, laundry, dish washing, car washing, and sanitation, and thus includes the day-to-day activities of all citizens of the State. Per capita water use projections for drought conditions are about 33 percent greater than for average conditions (Table IV-1). Since the early 1960's, per capita water use has been increasing about four gallons per person per decade. Two major purposes of water conservation are to reduce the rate of increase in per capita water use for municipal and commercial purposes and ultimately to reduce water use per capita. These objectives can be accomplished through changes in water-using equipment in homes and public buildings, careful management of water-using equipment, changes in life styles, modification of water-using behavior, changes in plumbing codes and subdivision platting, and public regulation of water use. All methods mentioned here except public regulation are included in long-range water planning.

Table IV-1. Per Capita Water Use Projections for Texas[1] [2] [3]

	1980	1990	2000	2010	2020	2030
Average Conditions	176[4]	157	160	160	160	160
Drought Conditions	176[4]	210	213	213	213	213

[1]Source of data: Texas Department of Water Resources.
[2]Figures in gallons per person per day.
[3]Per capita use held constant from the year 2000 and beyond.
[4]Reported use for 1980.

Interior Residential Conservation Potential

Water use inside the home of a family of four (two adults and two children) is about 250 gpd (gallons per day). About 75 percent of the in-home water use occurs in the bathroom, 14 percent in the utility and laundry room, and about 11 percent in the kitchen (Figure IV-1). About 57 percent of the in-home hot water use is for bathing, 19 percent for laundry, 19 percent for dishwashing, and 5 percent for hand washing in the lavatory sink (Figure IV-2).

Toilet flushing accounts for about 40 percent of the in-house water use or about 100 gallons per day for the family of four. Average water use for toilets is five gallons per flush. Normally, toilets are flushed four to six times daily per person; therefore, a city of 10,000 people uses about 250,000 gpd to flush toilets. Most toilets on the market today require only about 3.5 gallons per full flush. In addition, dual flush toilets with one cycle for solids and one cycle for liquids are now on the market as well as redesigned toilets which require only 2.5 gallons per flush in one model and only 1.0 gallon per flush for another model.

Bathing water in the average home accounts for about 35 percent of the total use. About 60 percent of bathing in homes having a shower and a tub is done in the shower. An average shower lasts about five minutes and normally uses water at the rate of about five gallons per minute. However, many individuals shower from 10 to 15 minutes with shower heads that use up to 10 gallons per minute.

The utility and laundry room account for about 14 percent of the daily water use in homes. The majority of this water use occurs through automatic clothes washers which require an average of about 48 gallons per regular cycle load and about 64 gallons for a durable-press cycle load, for top loading machines. Front loading washing machines use about half as much water.

Water use in the kitchen accounts for about 11 percent of in-house use and includes water for drinking, cooking, dishwashing, garbage grinding, and household cleaning. In the average home, about 12 gpd is used for cooking and drinking and about 15 gpd for dishwashing, garbage grinding, and cleaning.

Exterior Residential Conservation Potential

In Texas, exterior use has been estimated at 35 percent of the total residential usage (Figure IV-3). This category includes lawn watering and car washing, and in the summer the total exterior use may equal or exceed the interior use. The water use pattern is determined by the size of the lawn, and the type and amount of shrubbery and ornamental plants. Use of native grass, shrubs, and ornamentals should reduce exterior water requirements because they are adapted to the climate. The type of lawn sprinkler used, climatic conditions (e.g., wind), soil type, and slope greatly influence the quantity of water needed to maintain lawns, shrubs, and ornamental plants.

Commercial and Institutional Conservation Potential

Commercial water users include restaurants, hospitals, motels, hotels, laundromats, barbershops, beauty salons, schools, offices, banks, retail shops, department stores, service stations, and car washes. Institutional water users include government buildings, facilities, parks, swimming pools, and firefighting. In addition to filling and maintaining swimming pools and firefighting, commercial and institutional water uses include drinking water, toilet flushing, dishwashing, laundry, bathing, washing, and in some cases lawn maintenance. Opportunities for conserving water in the commercial and institutional sector include those pertaining to toilet flushing, bathing, landscaping, and water-using equipment in commercial establishments.

Figure IV-1. Average Interior Residential Water Use

Figure IV-2. Average Residential Hot Water Use

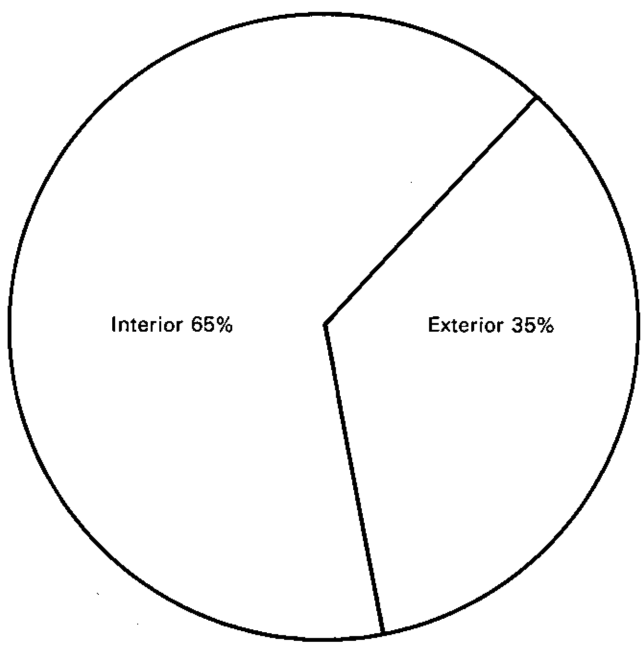

Figure IV-3. Average Household Water Use in Texas

Water Conservation and Reuse Methods and Devices

For each water use category, water conservation methods and devices are identified (Table IV-2). At the present time, if one-half of the homes in Texas were equipped with toilet devices and shower flow restrictors only, the municipal water savings would be about 100,000 acre-feet per year or 3.5 percent of the present level of municipal water use. Installation of low-flush toilets (3.5 gallons per flush) and water-saving shower heads (3.0 gallons per minute flow) in new construction and installing flow restrictors or water-saving shower heads in 65 percent of existing Texas homes would save about 200,000 acre-feet of water per year 20 years after the program is begun, increasing to about 500,000 acre-feet per year 50 years after the program is begun. It has been estimated that if recirculation of gray water for toilet flushing is instituted in 20 percent of new construction, municipal water use could be reduced by about 35,000 acre-feet per year in 20 years and 120,000 acre-feet per year in 50 years. Data pertaining to estimated water savings and costs of water conservation devices for municipal and commercial retrofitting and for new construction are presented (Tables IV-3 and IV-4 respectively). The cost of the retrofit devices assumes owner installation, except for pressure regulators, while the cost for new home items assumes installation at the time of construction.

Water-saving shower heads, dishwashers, and clothes washers, and insulation of hot water pipes are also effective energy savers (Table IV-5). Also, if interior residential and commercial water use is reduced, the volume of sanitary wastes to be treated at sewage treatment plants is reduced, resulting in lower treatment plant costs for the utility.

Water consumption will usually decrease when the price increases, especially as the total outlay for water and wastewater treatment charges begins to be a significant part of a family's household expenditures. Statistical analyses done with data from areas climatically similar to much of Texas indicate that in response to a one percent increase in price, consumption of water will decline about 0.3 of one percent; however, a one percent increase in family income will increase consumption by about one-half of one percent. That is to say that a 10 percent increase in municipal water price would result in a three percent reduction in municipal water use, whereas a 10 percent increase in income would result in a five percent increase in municipal water use. These are approximate values that will vary from place to place depending upon relative price and income, lot size, household characteristics, cooling system type, and local cultural characteristics, i.e., value and emphasis placed on maintenance of lawns, shrubbery, and public areas.

Many public water systems in the State contain undetected leaks in the distribution lines. According to available data, unaccounted losses range from five percent to more than 20 percent. Until about 1980, the technology existed only to detect leaks but not locate them. A device now exists that will detect and locate leaks in pressure pipes. Although there are not data available on the amount of potential water savings that could be affected through a leak detection survey and repair program, it is believed that savings would be significant on a statewide basis.

Dual water systems have been suggested for some time by water-supply planners to take advantage of the cost difference between raw water and treated water. Two parallel water systems are required. One is needed for a safe, but low quality water which could be used by industrial and residential sectors for toilet flushing and lawn watering. The second parallel system would be a higher quality water, completely and highly purified. Uses for the second system would include drinking, cooking, bathing, and other high order uses. Although dual water systems are generally impractical for existing towns and subdivisions, promise has been shown for the use of these systems in new developments.

Municipal and Commercial Water Conservation and Reuse Planning

In the projections of future water requirements, the potential effects of water conservation have been factored into per capita water use coefficients. In order to realize the potentials for reducing municipal and commercial water requirements through conservation and reuse, it will be necessary to conduct public information and public awareness programs in order to inform the water-using public, the housing and commercial construction industries, the landscaping, horticultural, plumbing, and water appliance manufacturing sectors of the economy, members of city councils, and other public officials of the need for conservation and the techniques and methods of conservation. In order to accomplish these objectives, the Department of Water Resources will cooperate with local governments and other State and federal agencies in the dissemination of water conservation information to the public, encourage water conservation through the public media, and support water conservation research and development of water conservation methods. The level of effort will be determined by the level of funding available to both the Department and to cooperating public education, research, and extension agencies. Water conservation efforts will be phased into long-range water development programs so as to assist in meeting the needs for water supplies in future years without disrupting the rate bases of present water

Table IV-2. Potential Water Conservation Methods and Devices

General Application	Industrial Use
Public education	Recirculate cooling water
Metering	Reuse cooling and process water
Pricing:	Reuse treated wastewater
Uniform block rates	Air cooling
Increasing block rates	Efficient landscape irrigation
Penalty charges	Low water-using fixtures
Demand charges	Process modification and redesign
Leak detection and repair	
System rehabilitation	
State and/or local building codes	

Municipal and Commercial Use	Agricultural Irrigation
Retrofit devices:	Off-farm conveyance systems:
Displacement bottles	Canal lining
Toilet dams	Canal realignment
Dual flush valves	Canal consolidation
Shower flow restrictors	Phreatophyte control
Low-flow shower heads	
Faucet aerators	On-farm systems:
Pipe insulation	Canal lining or piping
Pressure regulators	Water control structures
Water efficient appliances	Land leveling or contouring
	Furrow dikes
Devices for new construction:	Improved sprinklers
Low-flush toilets	Drip irrigation
Dual flush toilets	Tailwater recovery
Low-flow shower heads	Irrigation scheduling
Faucet aerators	Improved tillage practices
Pipe insulation	Periodic deep plowing
Pressure regulators	Surface mulches
Water-efficient appliances	Moisture sensing controllers
Dual-water systems	System efficiency evaluation
Urban landscape irrigation:	
Reduced watering	
Low water-use plants	
Sprinkler systems	
Scheduled irrigation	
Moisture sensing controllers	
Greywater systems	

Table IV-3. Water Conserving Retrofit Devices

Application	Device	Function	Water Savings	Estimated Unit Water Savings gpcd	Estimated Cost $	Service Life Years
Toilet	Two displacement bottles	Reduces flush volume	0.5 gal/flush	2.3	0-0.20	5
Toilet	Water closet dam	Reduces flush volume	1 gal/flush	4.5	4-6	5
Toilet	Dual-flush	Variable-flush volume	3.5 gal/flush	15.7	15	15
Shower	Flow restrictor	Limits flow to 3 gpm	1.5 gpm	6.7	0.50	5
Shower	Reduce-flow shower head	Limits flow to 3 gpm	1.5 gpm	6.7	5-20	15
Shower	Reduce-flow shower head with cut-off valve	Limits flow to 2.5 gpm	2 gpm	8.0	5-20	15
Shower	Cut-off valve	Facilitates "navy shower"	—	—	5	15
Faucets	Aerator	Reduces splashing, enhances flow aesthetics, creates appearance of greater flow	—	0.5	2	15
Hot water pipes	Insulation	Reduces warm-up time	—	0.5	0.50/ft	25
Water hook-up	Pressure-reducing valve	Reduces available water pressure at fixtures, hence, flow rate	—	3	85	25

gpcd = gallons per capita per day; gpm = gallons per minute.

Table IV-4. Water Conserving Devices for New Construction

Application	Device	Function	Water Savings	Estimated Unit Water Savings gpcd	Estimated Additional Cost $	Service Life Years
Toilet	Low-flush, 3.5 gal/flush	Reduced flush volume	1.5 gal/flush	7.5	0	25
Toilet	Low-flush, 2.5 gal/flush	Reduced flush volume	2.5 gal/flush	12.5	0	25
Toilet	Low-flush, 1 gal/flush	Reduced flush volume	4 gal/flush	20	*	25
Shower	Reduced-flow shower head	Reduces shower flow rate to 3 gpm	1.5 gpm	6.7	0	15
Shower	Reduced-flow shower head with cutoff valve	Reduces shower flow rate to 2.5 gpm	2 gpm	8.0	0	15
Shower	Cut-off valve	Facilitates "navy shower"	—	—	5	15
Faucet	Aerator	Reduces splashing, enhances flow aesthetics, creates appearance of greater flow	—	0.5	2	15
Water hook-up	Pressure-reducing valve	Reduces available water pressure at fixtures, hence, flow rate	—	3	45	25
Appliances	Water-efficient dish-washing appliances	Reduced water requirement	6-gal/cycle	2	0	15
Appliances	Water-efficient clothes-washing machine	Reduced water requirement	14-gal/cycle	3.5-7.0	70	15

*Somewhat expensive, but on average will pay for itself in water savings in about 5 years in home with private water wells and septic system and in about 10 years in home with municipal water and sewer service.

Table IV-5. Estimated Energy Savings Associated with Residential Water Conservation

Device	Hot Water Saved[1] (Gal/day/D.U.)[2]	Amount of Energy Saved: Gas Water Heaters[3] (Therms/year/D.U.)[4]	Amount of Energy Saved: Electric Water[5] (Kw-hr/year/D.U.)	Value of Energy Saved: Gas[6] (Dollars/year/D.U.)	Value of Energy Saved: Electric[7] (Dollars/year/D.U.)
Showerhead, 3 gpm	8	22.9	541	12.6	32.4
Water saving dishwashers	4.7	13.6	320	7.5	19.2
Water saving clothes-washing machines	2.4	6.8	160	3.7	9.6
Subtotal	15.1	43.3	1,021	23.8	61.2
Insulation of hot water pipes	4.7	13.6	320	7.5	19.2
Total	19.8	56.9	1,341	31.3	80.4

[1]140°F water saved as follows: shower 3.4 gallons per capita per day (gpcd); dishwasher 2 gpcd; washing machines 1 gpcd; thermal pipe insulation 2 gpcd.
[2]D.U. dwelling units; 2.37 persons per dwelling unit.
[3]79 percent efficiency. Source: The California Appliance Efficiency Program - Revised Staff Rept. California Energy Resources Conservation & Devel. Comm. Conservation Div. (Nov. 1977).
[4]One Therm 100,000 BTU.
[5]98 percent efficiency. Source: ibid.
[6]$0.55/therm.
[7]$0.06/kw-hr.

utilities. Abrupt conservation results could result in the necessity to increase water rates in the short run in order to meet debt service and operating costs of existing facilities.

Industrial and Mining Water Conservation and Reuse

In response to rising energy costs and high costs to treat wastewater, industry has reduced water use per unit product produced. Potential exists for increased efficiency of water use in industry, in steam-electric power generation, and in mining in future years.

Cooling Water Conservation Potentials

The reduction of freshwater use for cooling purposes, which accounts for over 55 percent of manufacturing freshwater use and for over 90 percent of freshwater use in the steam-electric generating industry in Texas, offers one of the greatest potentials. Conservation of fresh water is possible through a number of means, including the substitution of saline water for fresh water in coastal areas for cooling at chemical plants, oil refineries, and power plants, and the increased use of treated municipal effluent for cooling water as is done now at four power plants and several industries. Air cooling, which does not consume water as other forms of industrial cooling do, is beginning to be used in several of the State's major industries. About 90 percent of the State's petroleum refineries currently employ air cooling for a portion of their cooling needs, and about 50 percent of the chemical plants in Texas use air cooling. The applicability of air cooling depends on a number of economic factors, but many industries have found air cooling practical, especially as industrial water prices increase.

Increased energy conservation is also a potential cooling water conservation measure. Cooling is used to eliminate "waste" heat. Any energy conservation measure that reduces the quantity of waste heat will thus conserve cooling water. Process substitution, the use of heat pumps for recovery of waste heat in distillation operations, better process control, and improved maintenance to reduce leakage are examples of ways in which cooling water requirements can be reduced.

Process Water Conservation Potentials

Process water and process washdown currently account for over 25 percent of water used in manufacturing industries in Texas. Several industries such as the paper industry have made significant advances in reducing process water use. Unbleached kraft pulp and paper mills (unbleached kraft paper is used for shopping bags, boxes, and many other purposes) have historically used from 15,000 gallons to over 30,000 gallons of water for each ton of paper produced. New production techniques use less than 5,000 gallons per ton of paper produced.

Boiler feedwater accounts for nearly 15 percent of manufacturing freshwater use in Texas. Energy conservation can play a major role in reducing the quantity of boiler feedwater required for a given process. Likewise, process modification or substitution and use of heat sources other than steam or heated water, such as the use of direct process heating furnaces in the chemical and petroleum refining industries, are examples of ways boiler feedwater use is being reduced.

At the present time, power plants, chemical plants, and oil refineries are using nearly 20,000 acre-feet of treated municipal effluent each year to meet a part of their water requirements. Although this is a substantial volume of water, the potential for Texas is much greater. Texas municipalities discharged over 1.4 million acre-feet of treated effluent in 1980, and are projected to discharge nearly 2.0 million acre-feet in the year 2000, and 3.3 million acre-feet by the year 2030. Although much of this effluent is needed for downstream water rights and for instream flow needs, additional industrial, steam-electric power cooling, and mining uses might be met from this source, especially in the arid and semiarid areas of the State.

Mining Water Conservation Potentials

Mining water use, including water used in secondary recovery of crude oil, is not as amenable to reductions in water required per unit of output as is the case in goods-producing industries. There is, however, potential for shifting away from the use of fresh water into the use of saline, brackish, and recycled secondary recovery water and treated municipal effluent for mining purposes. Availability of nonfreshwater supplies and their relative costs will determine the quantity of substitution of these supplies for freshwater in mining operations.

Industrial, Steam-Electric Power, and Mining Water Conservation Planning

Projections of future water requirements for industrial, steam-electric power generation, and mining purposes have been based on the known potentials for water conservation in these sectors. The effects of increased conservation and improved water use efficiency have been factored into the projections. In order to realize these potentials, it will be necessary for these sectors of the economy to invest in water conservation equipment and techniques and to manage the production processes to achieve conservation objectives. The private sector has demonstrated both the capability and the willingness to practice water conservation. Since much of the conservation potential is proprietary, the Department of Water Resources' water conservation planning efforts will be focused upon the encouragement of industry to practice water conservation, the modification of water quality and water rights administration to permit recycling and reuse of treated effluent insofar as possible, but consistent with the protection of water quality and downstream water rights; and assistance to locate suitable sources of lower quality water that would serve the needs of industries, power plants, and mining operations. The Department will cooperate with industry and other public agencies to conduct research and development of water conservation methods.

Agricultural Water Conservation and Reuse

Both the long-range projected scarcity of water supplies for the State's major irrigation areas and the increasing costs of pumping, transporting, and applying irrigation water to grow crops make it necessary that irrigation water use efficiency be increased to the maximum extent feasible. Water conservation districts, the Texas Agricultural Experiment Station, the Texas Agricultural Extension Service, Texas agricultural universities and colleges, the United States Department of Agriculture research and conservation services, the Texas State Soil and Water Conservation Board, the Texas Department of Water Resources, other agencies, and the private sector have major programs and efforts to increase water use efficiency in agriculture, to reduce the costs of irrigation, and to conserve water and soil. These include the fields of soil science, plant science, engineering, soil fertility, and meteorology, as well as practices such as tillage and mulch management, soil moisture measurement and monitoring, irrigation, scheduling and management, tailwater, recovery and use, plant growth regulators, evaporation and transpiration suppressants, weed control, brush control, water conveyance and application technology, crop selection, finance, and farm management. Important irrigation water conservation techniques are identified and described below, followed by an irrigation water conservation plan.

Irrigation Water Conservation Potentials

Some of the practices which can improve irrigation water use efficiency and conserve irrigation water have been known for quite some time, while others have been developed more recently. Irrigation water application with sprinkler equipment has expanded rapidly as labor has become more expensive and less plentiful, and as sprinkler equipment has been improved. Center-pivot systems are used on sandy soils, and on the medium and moderately coarse textured soils of the High Plains. Sprinkler systems are widely used in the Cross Timbers and the Winter Garden-San Antonio area, where the sandy soils have gently sloping and uneven surfaces. Of the 8.1 million acres irrigated in Texas in 1980, sprinkler systems were used on 2.2 million acres (Figure IV-4). Through the use of sprinklers, the quantity of irrigation water can be controlled and timed better than is possible with siphon tubes and other methods of moving water from canals and ditches into the fields. Thus, less water is required; however, sprinkler irrigation is more costly in terms of capital and energy.

Trickle and drip irrigation essentially spot-irrigates crops by applying water at the base of each plant. The system uses plastic tubes that have emitters located near each plant. It is, however, primarily applicable only to orchard crops. Water is saved with this method because the total soil area is not wetted as with sprinkler or flood irrigation. Trickle irrigation applies smaller amounts of water than conventional methods, and runoff water is nearly eliminated. The use of trickle irrigation methods for row-crop production is being researched.

A surge flow furrow system utilizes a combination of a timer and a "T valve" to alternate the flow of water through two sets of furrow rows. This surge of water flow, to the extent field experimentation has been able to verify, appears to allow the water to run down the furrow faster, resulting in a better application of smaller amounts of water than the conventional furrow method. Indications are that a surge system can save about 15 percent of the water normally used.

About 88 million acres of land in Texas is now covered with brush and trees having little or no economic value. Most of this coverage is mesquite or saltcedar, but there are many other varieties less widespread than these that pose serious and costly local brush control problems. About 54 million acres is estimated to have a dense stand of brush. Brush eradication and management to reduce brush growth on these tens of millions of acres of range and pastureland would increase the value of these lands for livestock production and could perhaps make significant contributions to ground-water recharge, increased streamflow, reduced soil erosion and consequent premature silting of reservoirs, and increased supplies of water available for nonagricultural purposes. It is estimated by the United States Department of Agriculture-Soil Conservation Service that more than 10 million acre-feet of water might be salvaged annually through a program for controlling brush in Texas.

Other practices that can make more efficient use of rainfall and irrigation water operate to store moisture in the soil profile. Minimum tillage leaves crop residues on the surface or near-surface of the soil, thereby improving infiltration and reducing evaporation. Breaking the plow pan found in many cultivated soils will increase infiltration and reduce runoff of valuable rainfall and irrigation water. Conservation terraces and the furrow diking practice of creating small dams across the furrows hold both rainfall and irrigation water on the field until it has the opportunity to infiltrate into the soil profile. Through the combined use of furrow dikes and a low energy, precision system of drip application, the quantity of irrigation water that must be obtained from the source (either wells or surface-water sources) per acre irrigated can perhaps be reduced as much as 40 percent, in comparison to furrow flooding methods of application. This technique has been developed through publicly funded research and is being tested and applied in the High Plains area. Its potential as a water conservation tool appears to be significant; however, it is costly in terms of capital investment and operating inputs in relation to furrow flooding irrigation methods.

The improvement of irrigation conveyance systems can reduce conveyance losses and thereby increase the quantity of water available for use. In 1980, there were 1,335 miles of concrete-lined canals and ditches serving 167,600 acres of irrigation land, and 22,303 miles of underground pipelines serving 4.9 million acres of irrigated land in Texas. Sixty-five percent of 1980 irrigated land was supplied with these kinds of water-conserving facilities, leaving opportunity for the installation of pipelines and lined canals to serve 3.0 million acres. Most of the improvements to conveyance facilities are in the Lower Rio Grande Valley, Winter Garden-San Antonio area, and the High Plains. As of 1984, about 1.1 million acre-feet per year, or about 30 percent of the quantity diverted from surface-water sources, is lost from the conveyance canals and ditches. Thus, improvements to these systems, although costly, could increase the quantity of water available for use.

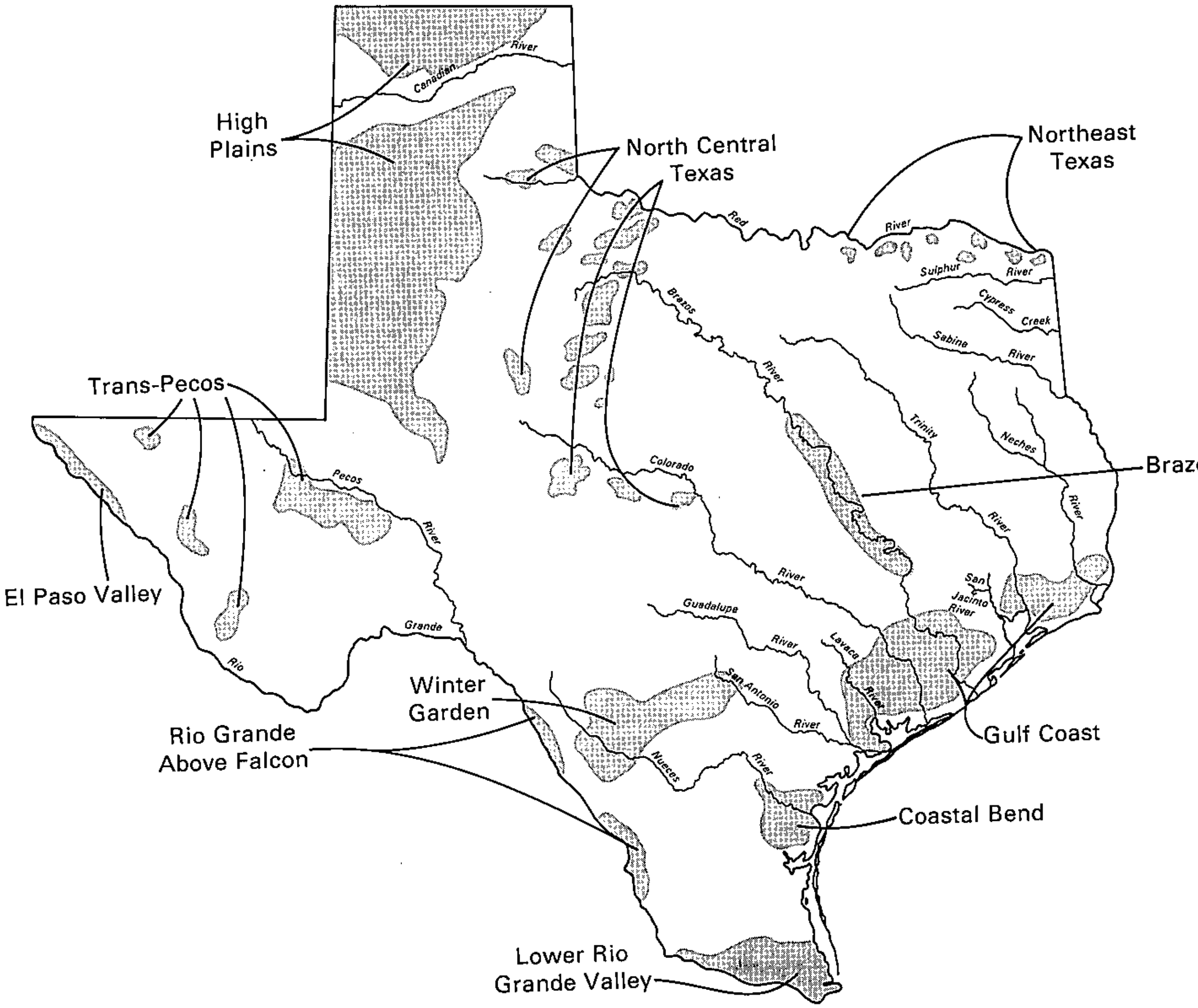

Figure IV-4. Irrigation Areas in Texas

Storage tanks are being built in water-short areas to accumulate and store water being pumped from weak, low-yield wells in order to have sufficient water when needed for irrigation. Playa lakes are being modified in some areas to concentrate the water in deep pools, thus reducing the area exposed to surface evaporation and making larger quantities of water available for irrigation. Some systems are being modified to pump back the runoff (tailwater) from furrow irrigated land and thus conserve water through reuse. In addition, farmers, as well as researchers, are using recharge wells to put playa lake water into the Ogallala Aquifer, although this practice is quite limited due to the relatively small quantities of playa water normally available and the fact that the water contains high concentrations of silt, which in many cases plugs the formation.

On-farm irrigation water use efficiency with in-place equipment and conventional irrigation practices is estimated to be about 60 to 70 percent. Through reconditioning of existing equipment, use of soil moisture monitoring devices to determine irrigation water requirements, and timing of applications for optimum crop yield, this efficiency of water use can be improved to about 75 to 80 percent. Adoption of new irrigation farming practices, e.g., furrow diking (actually an old practice, recently reestablished), or purchase of new, more efficient irrigation equipment, e.g., low-energy, precision-application (LEPA) systems, can dramatically reduce the amount of irrigation water needed to maintain current yield levels. The combined use of furrow dikes, small earthen dams perpendicular to the long axis of the furrows, and a LEPA irrigation system can, for example, reduce the quantity of irrigation water that must be obtained from the source (either wells or surface-water sources) by as much as 45 percent per acre, in contrast with conventional furrow-flooding practices.

Expanded use of effluents and poor quality waters for irrigation could also reduce the demands on the available freshwater supplies in some areas. About 350 confined livestock feeding operations, 80 industrial dischargers, and 360 municipal wastewater discharges are authorized to dispose of wastewater as irrigation applications. Although not all of these permits are utilized, there are several notable examples of wastewater use at Lubbock and Midland, Texas.

Irrigation Water Conservation Planning

Projections show that present supplies of irrigation water are declining and, without major irrigation water conservation, by the year 2030 would support only 60 to 65 percent of the acreage irrigated in 1980. With the full implementation of presently known irrigation water conservation methods, present irrigation water supplies would be adequate to support approximately 90 percent of present irrigated acreage through the year 2000. Inasmuch as at least 40 percent, or about $1.7 billion, of the estimated annual value of crops produced on Texas farms and ranches in recent years is directly attributable to irrigation, that is, yields are increased due to irrigation, water conservation to maintain irrigated acreage is extremely important to consumers of food and fiber.

The potential effects of water conservation upon future agricultural water demands have been factored into the projections presented in Part III. However, in order to realize these potentials it will be necessary for the public sector to expand water conservation research and extension programs, and for the private sector to make significant investments in water conservation equipment. The Texas Department of Water Resources will promote agricultural water conservation and will cooperate with the many public and private agencies, institutions, and establishments to accomplish these objectives.

DESALTING

The program to convert brackish and saline water resources to freshwater differs from other water development programs in that it offers the promise of developing an entirely new source of freshwater to meet future demands in some areas. The need for additional freshwater supplies will lead an increasing number of municipal and industrial users to consider desalting brackish and saline water found in some inland areas, and seawater in coastal areas. Recent research and development activities in desalting processes, especially reverse osmosis and electrodialysis, have reduced the cost of desalting brackish and saline water so that these processes are now being used commercially to provide municipal and industrial supplies of freshwater at about 650 locations in the United States and about 1,600 locations abroad. In Florida, there are about 75 municipal systems that rely on desalting, and in the oil-rich Middle Eastern countries, nearly all water supplies are the result of desalting processes. In Texas seven public systems use desalting to obtain municipal water supplies, and 64 industries use desalting to produce high quality water for specialized purposes. Desalting processes and the potentials for desalting to meet some of Texas' future water needs are presented here.

Desalting Processes

Desalting is the process by which brackish and saline water is converted into freshwater by the removal of dissolved inorganic material. In some cases, desalting also removes suspended material, organic material, bacteria, and viruses. The predominant methods of desalting water in Texas are phase change processes such as distillation, and membrane processes such as electrodialysis and reverse osmosis. Freezing, another phase change process, is still being researched and developed, but is not being used commercially in Texas. Ion exchange, a chemical desalting process, is being used by industry, in addition to conventional water treatment to remove specific inorganic ions that may be detrimental to the water's use if not removed. Ion exchange is also the process used in most home water softeners. All desalting methods generate a product stream (freshwater) and a waste stream (brine) as part of the process. The disposal of brine is costly and may result in environmental problems.

Desalting Projects in Texas

There are 71 desalting plants in Texas, excluding ion exchange systems, producing more than 17.1 million gallons per day of water for public supply, industrial uses, and electrical power generating plant boiler feedwater. Both membrane (electrodialysis and reverse osmosis) and phase change (distillation) processes are used (Table IV-6). Of the 71 plants, 7 produce 824,000 gallons per day (gpd) for municipal use, 43 plants produce 13,279,000 gpd for industrial use, and 21 plants produce 3,041,000 gpd for power plant boiler feedwater. The plants are located throughout the State with the greatest concentrations occurring in the Houston-Texas City, Dallas-Fort Worth, and Lubbock areas.

The sources of water for desalting plants in Texas include seawater, wastewater, inland brackish water, and water from municipal systems.

Potential for Desalting in Texas

Desalting, by either the reverse osmosis or electrodialysis method, may prove to be the most economically feasible means that some municipal water systems have available to provide needed additional water or to bring them into compliance with the standards of the Safe Drinking Water Act Amendments of 1977, or both. Among the possibilities is the desalting of brackish or saline ground water and surface water, and seawater. However, before desalting technology can be considered as a potential source of municipal and industrial water supplies for a specific city or industry, several conditions must be met. There must be a readily available supply of brackish or saline surface or ground water in sufficient quantity to meet the need; the desalting plant must be determined to be economically feasible when compared to available conventional water supplies; a method of brine disposal must be available; and a source and supply of energy must be available. Preliminary information indicates that these conditions prevail in several areas of West Texas, the Panhandle, Western Central Texas, and the Gulf Coast, especially the Lower Rio Grande Valley (Figures IV-5, IV-6, and IV-7).

Cost of Desalting

Several factors influence the cost of desalted water, including the chemical quality of the raw water, energy costs, the size of the plant, and disposal of the waste brine. The costs shown in Table IV-7 include design, engineering, and equipment costs necessary to complete an operable plant, operations and maintenance costs, and amortization of capital for 20 years at 11 percent interest. The costs do not include a well field or intake structure,

Table IV-6. Desalting Plants in Texas as of June 30, 1980 with Individual Capacities of at Least 25,000 Gallons Per Day[1]

Use	Capacity (gal/day)	Number of Plants: Membrane Processes	Number of Plants: Phase Change Processes
Public Supply	824,000	7	0
Industrial	13,279,000	37	6
Power	3,041,000	16	5
Total	17,144,000	60	11

[1]Source of data: El Ramly, N.A. and C.F. Congdon, Desalting Plants, Inventory Report No. 7, The National Water Supply Improvement Association, June 1980.

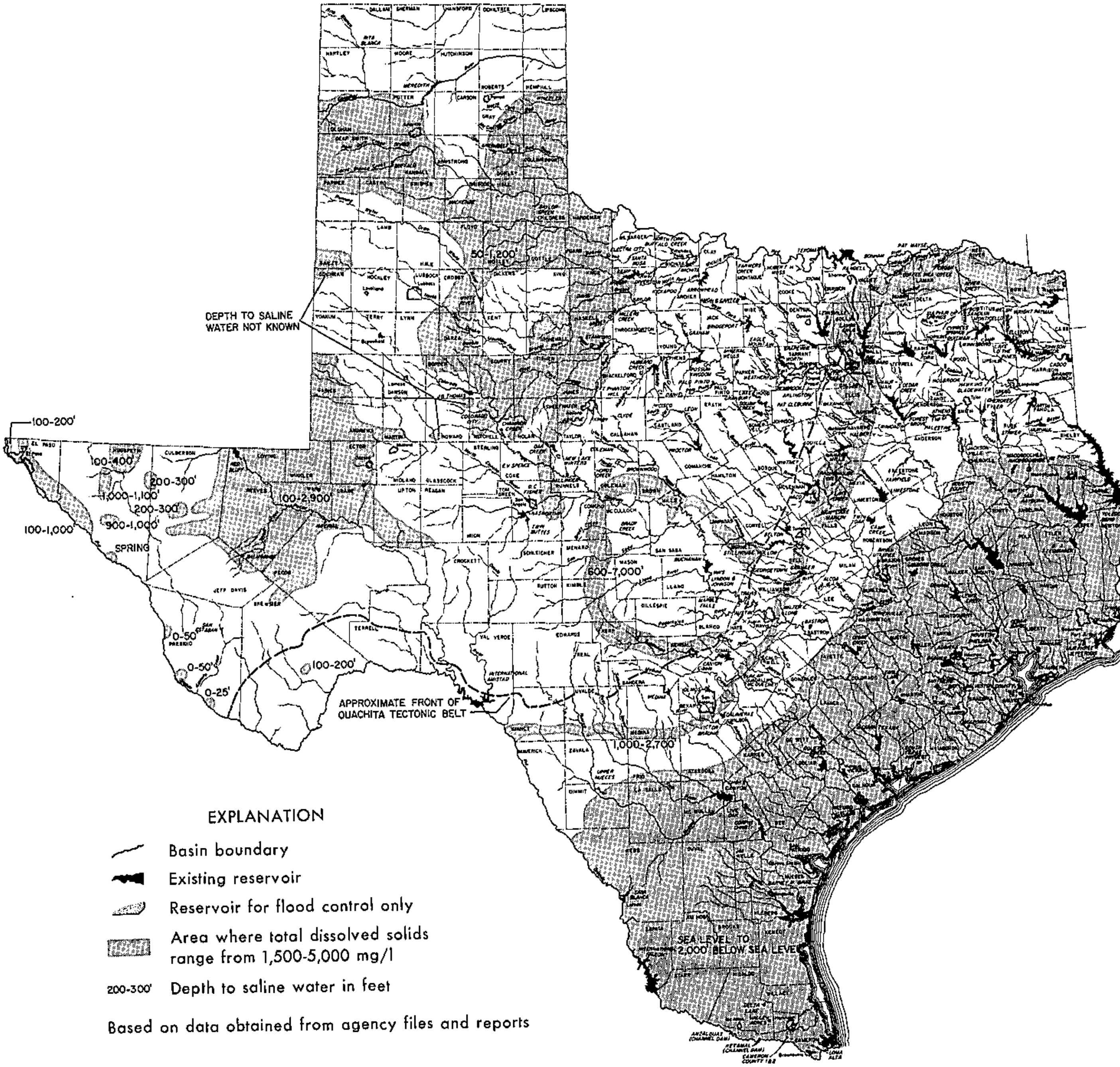

Figure IV-5. Known Areal Extent of Ground Water Containing 1,500-5,000 Milligrams Per Liter Total Dissolved Solids in Texas

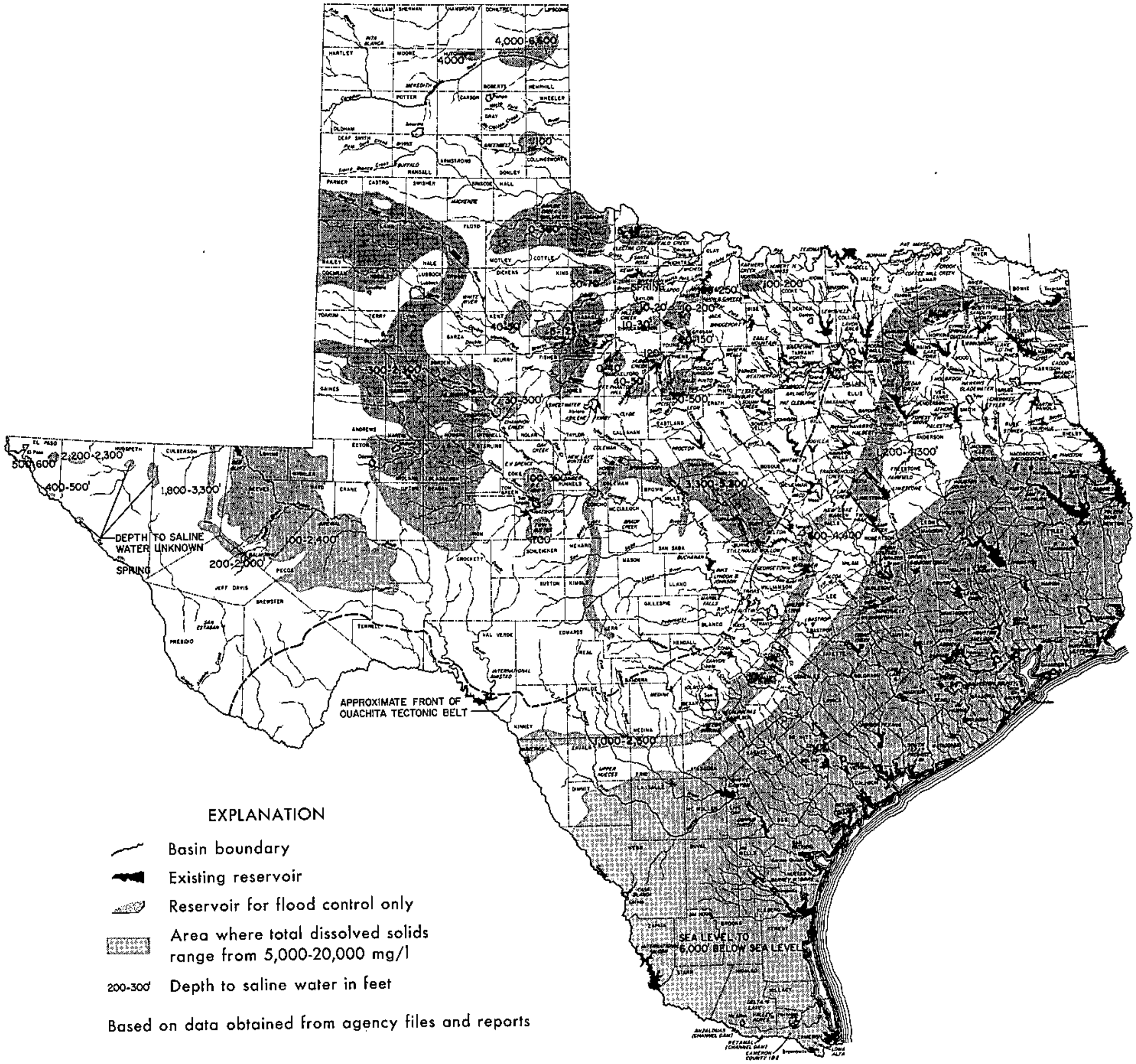

Figure IV-6. Known Areal Extent of Ground Water Containing 5,000-20,000 Milligrams Per Liter Total Dissolved Solids in Texas

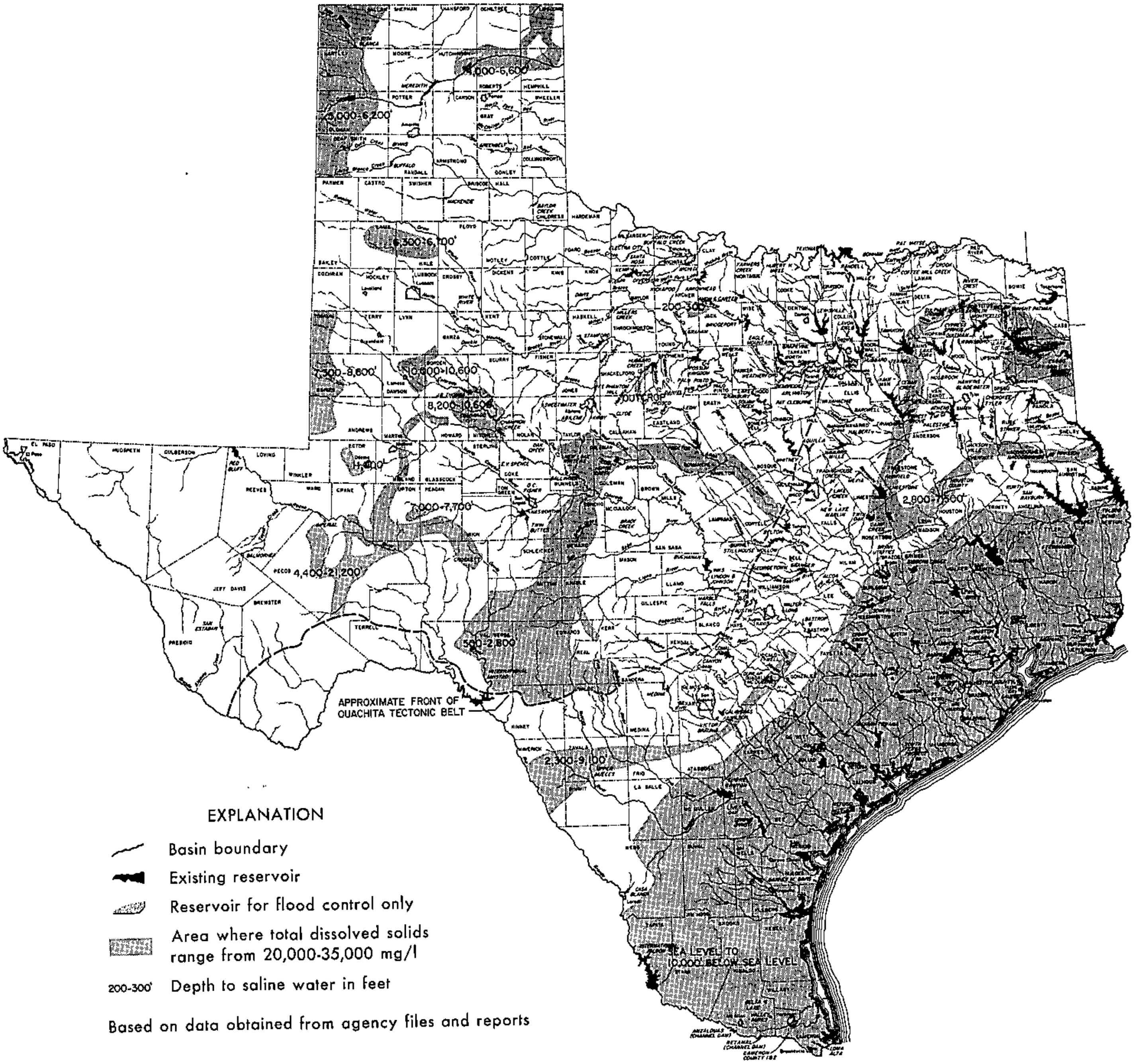

Figure IV-7. Known Areal Extent of Ground Water Containing 20,000-35,000 Milligrams Per Liter Total Dissolved Solids in Texas

Table IV-7. Desalting Cost Estimates for a Plant Producing from 1.0 to 10.0 Million Gallons Per Day in Texas[1]

Desalting Process[2]	Feedwater Quality Range (mg/l TDS)	Possible Feedwater Recovery (%)	Energy Cost[3] ($/1000 gal)	Total Annual Cost[4] ($/1000 gal)
RO	1,500- 5,000	75	0.35-0.50	1.00-2.50
RO	5,000-20,000	50-75	0.50-1.20	2.00-4.00
RO	20,000-35,000	30-50	1.20-1.90[5]	3.00-5.50
RO	35,000-40,000	30	1.25-1.90[5]	3.00-5.50
VTE-VC	35,000-50,000	90	1.30-1.50	4.50-5.50[6]

[1]Data from Water Supply Improvement Association.
[2]RO = Reverse Osmosis, VTE-VC Vertical Tube Evaporation-Vapor Compression
[3]RO using electricity @ $0.05/kw-hr, VTE-VC using natural gas @ $3/million BTU.
[4]Total annual cost includes manufactured equipment, labor, housing, electrical equipment and instrumentation, miscellaneous items needed to complete unit, yard piping, engineering and other costs necessary to furnish a complete system ready to operate, operation and maintenance,and amortization of capital for 20 years at 11% interest. It does not include well field or intake structure, transmission lines to the plant, cost of land, brine disposal and taxes.
[5]Cost range includes plants with and without energy recovery systems.
[6]Dual or multiple purpose plants would have lower costs.

transmission lines to the plant, cost of land, brine disposal, or taxes.

The Texas Department of Water Resources will continue its program of monitoring state-of-the-art desalting technologies and assessing the potential for utilization of these technologies in Texas as an alternative source of freshwater supply where appropriate. The Department also will continue work to identify the areal extent of brackish and saline ground water in Texas and to measure the quantity available at each location.

Assessments will be made of surface-water sources that might be suitable for desalting operations. For surface water, which, unlike most ground water, is in variable motion and its dissolved solids are in transport, measurements of total dissolved solids, weighted by flow volumes, must be made to determine the concentration at various reservoir sites. Preliminary measurements of this type indicate that surface water in the upstream reaches of the Canadian, middle and upper Red and Brazos, upper Colorado, Pecos, and upper Rio Grande Basins is too saline for municipal and some industrial purposes, but suitable for desalting to supplement water supplies in these areas. However, it is noted that chloride control projects are also being planned, which, if implemented, would avoid the necessity to desalt these water supplies.

In some areas of Texas, wastewater that is suitable for desalting may be available. Such water might be used for municipal or industrial purposes. However, additional research is needed to solve potential health problems from use of these supplies for municipal purposes.

DROUGHT CONTINGENCY PLANNING

On a broad scale, Texas relies on developed water supplies for sufficient quantities of water to meet the needs of people, industry, and a part of agriculture during drought conditions. A principal objective of local, state, and federal agency water supply planning is to provide a means whereby sufficient quantities of suitable quality water are available to meet the water needs of each area during both normal and drought conditions. However, even though planning and development of water supplies and delivery systems have been done, some areas do not have sufficient quantities of water nor adequate treatment and distribution facilities to meet the needs during moderate and severe droughts. Even the best equipped systems could experience problems during severe drought periods, as has been demonstrated during the longest drought on record in the 1950's and more recently during the hot, dry summers of 1980 and 1984. During the 1950's, and in more recent years, water supplies could not meet existing needs, resulting in significant economic losses to agriculture, industry, and people. In addition, safety and health were threatened, and large numbers of individuals suffered hardship, inconvenience, and increased costs for the minimum essential quantities of water.

The purpose of water planning and water quality protection is to develop water supplies and facilities that will meet the needs and thereby avoid hardships and economic losses that result from water shortage. However, the unpredictable, but inevitable, occurrence of drought warrants the development of drought contingency plans for those areas that do not have adequate water supply systems.

Drought contingency planning in which there is cooperative local, state, and federal participation is a part of the necessary water planning for Texas. An important part of drought contingency planning is the prediction and the recognition of incipient drought conditions. Unfortunately, no proven means of forecasting weather for more than a few days now exists. Thus, increased weather forecasting research is needed and will be encouraged and supported as funding becomes available.

Drought monitoring will be continued in order to accurately discern the extent and intensity of drought conditions and thereby enable officials to respond more readily and effectively to drought emergencies. Services will include responding to oral and written inquiries from the public and news media, documenting the drought and those mitigative measures taken in response to the drought, and maintaining contact with other agencies and organizations concerned with the drought.

In addition to drought information, drought contingency planning will include public information about water supply conditions, water conservation information, water rationing plans, wastewater reuse potentials, water recycling methods, alternative water supply sources, water supplies for fire protection, water hauling and arrangements for water supplies during emergency conditions, and technical assistance to secure drought relief for farmers and ranchers. Such plans will have to be developed for specific local areas. State water planning will provide technical assistance to local water agencies for drought contingency planning as resources permit.

WEATHER MODIFICATION

The need for additional water supplies in the arid and semiarid parts of Texas is a basis for giving consideration to conduct weather modification research that is directed toward the development of technology to increase precipitation in these water short areas. Experiments in weather modification have indicated that careful "seeding" of convective clouds with suitable materials such as silver iodide, dry ice, urea, or sodium chloride can perhaps result in increased precipitation. In recent years preliminary weather modification research and experimentation have been conducted in several areas of western Texas. During the later 1970's a local water supply district, an agency of the federal government, the Texas Department of Water Resources, researchers from two state supported universities, and private contractors conducted exploratory weather modification research in the Big Spring, Texas area. This project, known as the High Plains Cooperative Program (HIPLEX), identified those cloud systems and atmospheric conditions amenable to precipitation response from the timely application of silver iodide, and gave researchers a better understanding of how rain clouds behave and interact with their surroundings. The principal conclusion of the research was that the potential exists for significant increases in rainfall when convective clouds are seeded in appropriate ways when specific atmospheric conditions exist.

SECONDARY RECOVERY OF GROUND WATER

Large areas of Texas are underlain by water-bearing formations which supply over 60 percent of the water presently used in the State. Formations such as the water table aquifers and some of the artesian aquifers of Texas are composed of three states of matter—solid, liquid, and gas. The solid materials include sand, silt, clay, and gravel. These materials range in size from very small to large and exist in many different shapes. The size, shape, and degree of sorting of the solid particles govern how the solid material is packed together. The solid material does not completely fill a given volume; space exists between the particles. These spaces are called voids, and they may be filled with water or gases. To the degree that the voids are filled or saturated with fresh water, the formations are more or less useful as aquifers from which water supplies may be obtained (setting recharge rates aside for purposes of this discussion). Three general conditions of saturation are identified and described below. These three conditions are: (1) slight wetting of the solid material with a very thin layer of water a few molecules thick surrounding the particles of solid material, (2) wetting of the solid materials with additional water held among the particles of solid material, and (3) complete saturation with all the voids filled with water. The final condition of saturation is the most usual one from which useful water supplies are obtained using state-of-the-art water-well technology. However, saturation condition Number Two listed above exists in some aquifers and is a condition which results as water is withdrawn from fully or partially saturated zones. This is a potential source of water which is the subject of secondary recovery planning and research described below.

For almost all formations, the solid material, such as a sand grain, is slightly wet—saturation condition Number One mentioned above. A very thin layer of water, a few molecules thick, surrounds the sand grain. This water is held to the sand grain by atomic forces, and about the only way to remove this layer of water is to cook the sand grain in a very hot oven. Thus, this layer of water is not a part of the actual or the potential ground-water supply.

When the formation is wetter than described above, additional water is held in voids among the soil particles. This is known as capillary water and is the subject of secondary recovery investigations and planning. Water would drain from even the narrowest voids due to gravity if it were not for the phenomenon of surface tension. Surface tension occurs in any water surface, but is so weak that it becomes important only when the surface area is quite small. Surface tension holds the water among the soil particles. If the voids are completely filled with water, the formation is saturated. In the larger voids, much of the water that is in storage will drain from the void due to gravity. This is the water that flows to a well and can be pumped to the surface. This water, technically referred to as gravity water, is normally referred to as ground water, and is the quantity of ground water presented elsewhere in this report. The top of this saturated portion is called the water table.

Capillary water is that water in the formation that lies in the zone between the water table and the land surface that is held between soil particles by surface tension and other forces. This water is suspended in equilibrium and will not move downward under gravitational force alone. Assuming sufficiently large quantities of capillary water exist in the formation, the question of economic feasibility of recovery cannot be addressed until techniques are identified, tested, and proved feasible for recovering capillary water. Technical feasibility would be accomplished for a particular technique if it were possible to produce a significant increase in the volume of water available for pumping from conventional wells. With technical feasibility demonstrated, economic feasibility would result if the unit cost of making additional water available is less than or equal to the direct benefits from having an additional unit of water available for municipal, industrial, agricultural, and other uses. This method of water supply development would be chosen only if the unit cost is lower than for other available methods of water supply development. However, at the present time dependable secondary recovery methods are not available.

Research sponsored by a local water conservation district and the State in 1982 has identified five secondary recovery techniques having potential for recovering capillary water: air drive, surfactant/foam, thermal, vibration, and electro-osmosis. The air drive technique involves introduction of compressed air into the formation through a series of injection wells in such a fashion that a broad front of air exerts a pressure on water trapped among soil particles and held there by capillary force. The front of air pressure exerts a force on the upper surface of trapped water, upsetting the equilibrium of forces holding capillary water in place and causing the capillary water to move downward. Depending on the pressure level of the injected air and the percentage saturation in the formation, the front of compressed air will move some of the capillary water downward into the saturated portion of the formation where it is recoverable through pumping from conventional wells.

Introduction of a surfactant is an enhancement and extension of the air injection technique. A surfactant is a chemical that reduces the surface tension of water. In effect, it makes the water wetter. An example of a surfactant is household dishwashing liquid. In fact, one of the five surfactants tested was a common brand of dishwashing liquid.

Thermal systems involve introduction of heat into regions of the capillary water zone. As the capillary water temperature increases the water viscosity decreases, surface tension decreases, water expands, and the soil bed expands, thus reducing porosity. The first three effects cause less water to be retained within the soil, i.e., water will be released from suspension. Expansion of the soil bed will "squeeze" some water out of retention; however, the water remaining will be held more tightly than before the temperature change.

The vibration technique is quite complex. Simply stated, the process alters the compaction level of a volume of material thereby reducing its porosity and correspondingly reducing its capacity to hold water. Initially, the soil particles of a body of material containing capillary water are aligned in such a fashion that there are void spaces of various sizes, having a wide range of water-holding capacities and forces. If vibrated vigorously, these soil particles realign—pack down, so to speak—in such a manner that the void spaces are reduced, singularly and collectively. With the voids made smaller the porosity of the material is reduced and correspondingly its ability to hold water in capillary suspension is reduced.

In most general terms, the technique of electro-osmosis involves the process whereby water is caused to move in a capillary system as a result of the application of an electrical potential. When an electric current flows between two electrodes in a saturated soil, the water in the soil migrates from the positive pole toward the negative pole. The technique has found commercial utilization in draining fine-grained soils prior to excavation, hardening of clay, and soil modifications to ease and strengthen the placement of construction pilings.

The identified techniques were studied by means of laboratory experiments and analytic calculations. From these preliminary analyses, it was determined that air drive and surfactant/foam were the most feasible techniques for ground-water application, and that an air drive system can release capillary water from storage. The other four identified techniques were judged to be too expensive to be economically feasible.

A field test of the air drive technique for secondary recovery of capillary water was conducted in the High Plains (Ogallala) Aquifer near Idalou, Texas, during June 1982. This site was selected in part because of a very dense confining layer of clay above the target injection zone. The clay layer hinders air flow, thereby preventing the compressed air from "leaking" out of the ground. Over 10 million cubic feet of air was injected during a 6-day period. Injection rates were as high as 2,300 cubic feet per minute with pressures as high as 160 pounds per square inch. Results showed that an area of over 140 acres was pressurized. In one area, the soil-moisture content decreased, an expected result of increased recovery. Water levels in wells around the injection site rose, and the area around the test site contained an estimated additional 225 acre-feet of water available to wells one month after the test. Nearly eight months after the injection of air was stopped, the affected zone had spread to an area greater than two miles square, as measured by the mound of water under the test site in relationship to adjacent static water levels. The volume of water contained in this mound is estimated at 876 acre-feet.

Although the preliminary secondary recovery tests, using an air injection method, appear to be promising, additional research is needed in order to determine whether or not this method can be developed into a feasible water supply development method. Such tests and additional research will be conducted as resources become available, since many areas of Texas which now depend upon declining ground water could receive a significant short-range benefit from additional quantities of water supplied from present aquifers using established wells and conveyance facilities.

Based on the drilling of test holes and analyses of core samples, it is estimated that the portion of the Ogallala Formation in the Texas High Plains lying above the 1980 water table and below the root zone (approximately 10 feet below land surface) contains about 840 million acre-feet of capillary water. Additionally, the amount of water that may remain when the currently saturated portion of the formation is drained equals about 625 million acre-feet, for a total potential of 1.46 billion acre-feet of capillary water. This is over three times the quantity of "gravity" water that is estimated to be available to conventional wells from the remaining saturated sections of the Ogallala Formation. However, not all of the area would be suitable for secondary recovery techniques due to technical limitations, and not all of the capillary water can be recovered.

Estimates of the quantity of capillary water in aquifers other than the Ogallala have not been made. Neither have tests of secondary recovery techniques been performed. Much research on this topic remains to be done, and it is emphasized that secondary recovery of ground water would be an advanced stage of ground-water mining as opposed to the development of a continuous, long-term, perpetual supply of fresh water. If secondary recovery becomes feasible, it can, however, be considered an interim measure for obtaining additional water supplies of a time duration that will vary with aquifer, technical, and economic conditions.

WATER IMPORTATION

Ground-water supplies in some parts of Texas are, to a large extent, limited to underground deposits of finite and exhaustible quantities. Even with maximum achievable water conservation, it is expected that more than 60 percent of present deposits will be used within the foreseeable 50-year planning period. Other areas of Texas depending upon perpetual surface-water supplies may outgrow the dependable quantities of these supplies in the foreseeable future. Thus, the Texas Department of Water Resources and other appropriate State and federal agencies will continue, expand, and refine interstate and, if warranted, international water development and water transfer planning and feasibility studies, including viable import and other alternatives, in cooperation with and giving adequate emphasis and consideration to the water problems and needs of those states that are located in the basins of origin of potential water supplies for importation. Since 1966, water importation studies of various levels of detail have been conducted including those done by Texas Department of Water Resources staff, private sector consultants, and federal agencies. Future water importation planning studies will take into account and make use of information developed in previous importation studies, including the Six-State High Plains Ogallala Aquifer Regional Study completed in 1980 by the U.S. Department of Commerce, Economic Development Administration, the U.S. Army Corps of Engineers, and the High Plains Study Council whose membership includes Texas and five other states—Colorado, Kansas, Nebraska, New Mexico, and Oklahoma—that depend upon the declining water supplies of the High Plains (Ogallala) Aquifer.

Water importation studies and planning work will be directed toward: (1) estimation of the times that water will be needed and quantities of water that will be needed for each major water-short area of Texas, (2) identification of potential sources of water for import to Texas, and (3) engineering, environmental, economic, and financial analyses of alternative importation projects. Importation studies and planning will be based upon the principle that only quantities of flood water that will be surplus to the future needs of basins of origin of potential import water will be given consideration for importation to Texas. Existing compacts, water rights, contracts, and commitments will be taken into account when estimating potential surpluses. Decisions and agreements regarding quantities of surface water, as well as importation terms and conditions, can only be made after detailed and extensive studies and thorough discussions with representations of potential exporting areas. At the appropriate times, based on the results of importation study results, the necessary federal and state legislation will have to be enacted, if importation projects are to be implemented.

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PART V

ESTIMATES OF COSTS AND FINANCING NEEDED FOR WATER QUALITY PROTECTION AND WATER SUPPLY PURPOSES IN TEXAS 1984-2030

TABLES

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PART V

ESTIMATES OF COSTS AND FINANCING NEEDED FOR WATER QUALITY PROTECTION AND WATER SUPPLY PURPOSES IN TEXAS—1984-2030

Estimates have been made of the costs of projects and the financing required to meet the projected needs of water quality protection and water supply as presented in Part III. The procedures, assumptions, and total cost estimates are presented for water quality protection, water wells and facilities, major raw water treatment facilities, major raw water conveyance facilities, reservoir and chloride control projects, hardship cases, and research and planning. In addition, estimates are presented for the proportions of total funding that are expected to be supplied from federal sources, the proportions that can be supplied by local and regional governments, and the proportion of financial assistance that will be needed from the State. Local governments and the private sector will have to implement and operate the projects and facilities identified herein. Federal and State agencies can provide only technical assistance and a part of the financing.

These cost estimates do not include estimates of costs for privately financed or owned water supply or wastewater treatment companies, or the capital costs incurred by a subdivision developer in providing water or sewer services to new residences. Also not included are cost estimates for some major water treatment and water conveyance systems for which planning is at this time incomplete. Facility capital costs for publicly owned local (as opposed to interregional) water distribution systems, some new wastewater collection lines, smaller water treatment plants, and similar facilities in cities or districts that do not qualify to participate in the Texas Water Development and Water Loan Assistance Funds under the "hardship case" criterion are not included, either.

Federal funding for sewage systems is in the form of annual appropriations allocated to the State, which are then allocated to local governments to pay a part of the costs of constructing sewage systems.

Local governments borrow funds for water quality protection and water supply purposes through the sale of general obligation bonds backed by their respective taxing authorities. Local and regional governments and water authorities also borrow funds for water quality and water supply purposes through the sale of revenue bonds backed by the expected income from the sale of water and sewage treatment services. This type of financing depends upon the credit ratings of the respective governments and authorities, both with respect to the quantity of funds that can be borrowed and the interest rates that must be paid. The better the credit rating, the lower the interest rate.

State financial assistance for water quality protection and water supply projects could be in the form of loans, loan insurance, loan guarantees, storage acquisition by the State of a part of large water supply projects, or a combination of these methods. Storage acquisition of a part of large projects by the State is needed in order to optimize development of scarce project sites and thereby make additional water supply available to meet projected future needs. The source of funding for State financial assistance could be any one of several means, or a combination of two or more means, including a State Bond program, appropriations for direct loans, appropriations into a reserve fund which would be used to guarantee local bonds, constitutionally authorized use of a specified quantity of the State's full faith and credit to guarantee local bonds, or a dedicated tax. In the case of loan guarantees, leveraging could be used in a manner such that a limited quantity of State funds or credit would provide security for local bonds and thereby reduce the interest rates that local sponsors of projects would have to pay for bonded indebtness to finance such projects. However, State financial assistance, in addition to that presently authorized through the water development and water quality enhancement loan funds and the water assistance fund, would require additional legislation. In the following discussion, estimates are presented of the quantity of State financial assistance that will be needed, but the form of such assistance is not specified.

WATER QUALITY PROTECTION

Costs for publicly financed wastewater collection and treatment systems are based on the results of statewide assessments of facility needs through the year 2000, with projections of sewage system costs for the period 2001 through 2030 based on projections of population growth (Table V-1). These assessments and plans developed therefrom have been made in accordance with State and federal legislation and funding for such purposes. Since 1957, federal grants have been made to states for allocation to cities to defray a part of the costs of sewage treatment. During the 1957 through 1972 period, Texas received about $210 million for such purposes. Beginning in 1973, the federal construction grants program was expanded to increase planning assistance to states and cities and to pay 75 percent of the costs of eligible parts of water quality protection systems. During the 1973-1983 period, about $1.34 billion in construction grant funds was allocated to Texas. During this time period, water quality protection needs were estimated and plans have been developed to accomplish the goals set forth in national and State clean water legislation. However, in 1981, federal clean water legislation was amended, and the funding formulas and authorized levels of federal appropriations for sewage system construction grants were changed. Under these amendments, authorization for federal appropriations are less per year than in the past, grants are reduced from 75 percent of eligible project costs to 55 percent (by 1985), and the range of eligible components of projects has been reduced. All of these factors have been taken into account in making projections of future funding needs for water quality protection purposes.

Federal grants are projected to be available through the 1988-1989 biennium, but are expected to cease by 1990. As these federal grants are reduced and phased out, it is estimated that State financial assistance to local governments will need to be increased, if the goals of existing clean water legislation are to be met. It is estimated that for the 1984-1989 period, State financial assistance in an amount of about 30 percent of estimated total wastewater collection and treatment facility costs will be needed, with the share of State financial assistance increasing to 50 percent in 1990 and beyond (Table V-1).

Estimates of capital requirements for municipal wastewater collection and treatment facilities needed to meet wastewater discharge permit requirements are based on 1983 prices and then inflated at an inflation rate of eight percent per year to the planned time of construction (Table V-1). Total capital requirements are projected to increase from $934 million for the 1984-1985 biennium to $1.62 billion for the 1994-1995 biennium, and $3.72 billion for the 2004-2005 biennium, in prices inflated at eight percent per year (Table V-1). "Hardship case" loan funding for political subdivisions that cannot obtain financing through commercial channels at reasonable rates of interest is projected to require an additional $64 million for water quality protection purposes during the 1984-1985 biennium. The "hardship case" loan fund needs are projected to be $856 million for the period 1984-1999 and $704 million for the period from 2000 to 2005. In the case of loans for water quality protection purposes, it is assumed that repayment would begin one year from the date construction is begun, and that the local sponsor would repay the loan in 30 years at eight percent interest. These cost estimates do not include estimates of costs for privately financed or owned wastewater treatment companies, or the costs incurred by a subdivision developer in providing sewer services to new residences.

WATER WELLS FOR WATER SUPPLY

Cost estimates for the future development of municipal well fields were based on drilling and well completion costs for municipal wells in each region of Texas. The projection of the number of wells to be drilled in each aquifer for municipal supply was based on projected ground-water requirements for municipal uses in each respective area of the State and the capabilities of the respective aquifers of meeting local area water demands. (Over the long term, many of the State's aquifers cannot meet the total water demands of the areas in which they are located.) The total cost for well field development for each projected yearly requirement was then inflated at eight percent to the time of development (Table V-2).

It is estimated that State financial assistance in an amount of 25 percent of total well field costs will be needed in future years (Table V-2). Estimated total well field costs during the 1980's is $449 million, of which $113 million of State financial assistance would be needed. It is assumed that repayment of loans for such State assistance would begin one year after the date of the loan, and that repayment would be done over a 30-year period at eight percent interest.

MAJOR WATER CONVEYANCE AND RAW WATER SUPPLY TREATMENT FACILITIES FOR WATER SUPPLY

Several major water conveyance facilities are needed in order to convey water from existing and planned reservoirs to points of use. Water treatment systems need to be built or expanded in conjunction with these conveyance systems. The estimated schedule for adding major water conveyance and treatment systems is based on projections of need for water from existing and new reservoirs and the planned schedules for development of new reservoir projects. The estimates of future conveyance and treatment facility requirements are shown for each State biennium, beginning in the year 1984 (Tables V-3 and V-4). Past 2002, projects for which planning is complete are shown. There will, be additional conveyance and associated treatment facilities needed during the period 2002 through

Table V-1. Estimates of Wastewater Collection and Treatment Facilities Costs for Publicly Owned Facilities,[1] with Estimates of Funding Sources (Costs Inflated at 8 Percent)

	Cost Estimates				Source of Financing					
		At Date of Construction[3]			Percent			Totals		
Time of Construction[2]	Jan. 1983	Hardship Cases	All Other Cases	Total	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)								
1984-1985	801	64	870	934	20	50	30	185	467	282
1986-1987	645	68	810	878	21	50	29	185	439	254
1988-1989	645	79	945	1,024	18	50	32	185	512	327
1990-1991	645	93	1,101	1,194	0	50	50	0	597	597
1992-1993	645	108	1,285	1,393	0	50	50	0	696	697
1994-1995	645	126	1,498	1,624	0	50	50	0	812	812
1996-1997	645	147	1,747	1,894	0	50	50	0	947	947
1998-1999	645	171	2,039	2,210	0	50	50	0	1,105	1,105
2000-2001	665	200	2,456	2,656	0	50	50	0	1,328	1,329
2002-2003	685	233	2,960	3,193	0	50	50	0	1,596	1,597
2004-2005	685	271	3,453	3,724	0	50	50	0	1,862	1,862
2006-2007	685	317	4,027	4,344	0	50	50	0	2,172	2,172
2008-2009	685	370	4,697	5,067	0	50	50	0	2,533	2,534
2010-2011	815	431	6,600	7,031	0	50	50	0	3,515	3,516
2012-2013	815	503	7,698	8,201	0	50	50	0	4,100	4,101
2014-2015	815	586	8,980	9,566	0	50	50	0	4,783	4,783
2016-2017	815	684	10,473	11,157	0	50	50	0	5,578	5,579
2018-2019	815	798	12,216	13,014	0	50	50	0	6,507	6,507
2020-2021	979	931	17,303	18,234	0	50	50	0	9,117	9,117
2022-2023	979	1,086	20,182	21,268	0	50	50	0	10,634	10,634
2024-2025	979	1,267	23,540	24,807	0	50	50	0	12,403	12,404
2026-2027	979	1,478	27,457	28,935	0	50	50	0	14,467	14,468
2028-2029	979	1,724	32,026	33,750	0	50	50	0	16,875	16,875
2030-2031	979	2,011	37,355	39,366	0	50	50	0	19,683	19,683

[1]A public entity in this useage of the term is a political subdivision of the State (an entity created by a unique legislative action or created under existing statute). Included are cities, municipal utility districts (MUD), and other types of special districts, for example, river authorities and water districts and water districts. In order that these latter, special purpose utility districts be included in this table, their charter must expressly permit them to collect, treat, and dispose of wastewater. Estimates of the future capital costs of the wastewater treatment facility needs of private systems that perform wastewater collection, treatment, and disposal functions similar to those of a public system are not included in this tabulation. A privately financed residential, commercial development that owns and operates its own wastewater system, even though it holds a permit from the State allowing it to do so, would be an example of a private system. The cost of facilities required to satisfy the needs of privately owned facilities over the period 1985-2000 is estimated to be about $3.8 billion, is inflated dollars, or abour $237 million per year.

[2]Estimated State biennium in which construction should start in order to meet projected wastewater treatment requirements.

[3]Most recent costs (1983) inflated at 8 percent per year, to date construction is to be started.

Table V-2. Estimates of Well Field Development Costs, with Estimates of Funding Sources (cost inflated at 8 percent)

Time of Construction[1]	Project Cost Estimates: Jan. 1983	Project Cost Estimates: At Date of Const.[2]	Percent: Federal	Percent: Local Sponsor	Percent: State	Totals: Federal	Totals: Local Sponsor	Totals: State
	—(Million Dollars)—					—(Million Dollars)—		
1984-1985	110	128	0	75	25	0	96	32
1986-1987	110	150	0	75	25	0	112	38
1988-1989	108	171	0	75	25	0	128	43
1990-1991	106	196	0	75	25	0	147	49
1992-1993	105	227	0	75	25	0	170	57
1994-1995	103	259	0	75	25	0	194	65
1996-1997	101	297	0	75	25	0	112	38
1998-1999	101	346	0	75	25	0	259	87
2000-2001	101	404	0	75	25	0	303	101
2002-2003	102	475	0	75	25	0	356	119
2004-2005	104	565	0	75	25	0	424	141
2006-2007	106	672	0	75	25	0	504	168
2008-2009	108	799	0	75	25	0	599	200
2010-2011	113	975	0	75	25	0	731	244
2012-2013	113	1,137	0	75	25	0	853	284
2014-2015	116	1,362	0	75	25	0	1,021	341
2016-2017	118	1,615	0	75	25	0	1,211	404
2018-2019	118	1,884	0	75	25	0	1,413	471
2020-2021	123	2,291	0	75	25	0	1,781	573
2022-2023	123	2,672	0	75	25	0	2,004	668
2024-2025	125	3,167	0	75	25	0	2,375	792
2026-2027	129	3,813	0	75	25	0	2,860	953
2028-2029	129	4,447	0	75	25	0	3,335	1,112
2030-2031	129	5,187	0	75	25	0	3,890	1,297

[1]Estimated State biennium in which construction on the project should start in order to meet projected water supply requirements.
[2]Most recent cost estimates at 8.0 per year to date construction is to be started.

2030, but they are not shown since planning is incomplete at this time. Costs of projects needed to satisfy these requirements were estimated in 1983 prices and then inflated at eight percent per year in order to show the cost estimates at the time in which the systems would be constructed. Thus, for a major canal that would be built during the period 2002 to 2003, the costs were inflated at eight percent per year from 1983 to January 1, 2003. The sources of data for making cost estimates include federal agencies, consultants to municipalities and water authorities, and cost data from water development permit applications. The proportion of financing that can be handled by local and regional authorities was estimated by each respective local sponsor. The percentages vary among the projects because of differences in project sizes, and the rates at which demands for water would increase to full capacity of the facilities, thus affecting the abilities of local authorities to issue revenue bonds. In the case of water treatment plants, a high percentage of the financing is estimated to be manageable through local bonding sources, since such projects can be staged to meet growing needs and thus would have revenue sources which more closely coincide with project costs. More State financial assistance would be needed for major water conveyance facilities, since such facilities would have to be sized to meet longer-term future needs, for which near-term revenues would not be readily available.

Estimated capital costs for major water conveyance and water treatment facilities during the 1980's is $2.51 billion, for which an estimated $397 million of State financial assistance is needed (Tables V-3 and V-4). These costs are inflated at an annual rate of eight percent per annum for the period of time between 1983, the base year for cost, and the year construction begins. Estimated total capital requirements for these facilities during the 1990's is $1.46 billion of which State financial assistance of $594 million is estimated to be needed. It is assumed that State financial assistance for conveyance facilities and water treatment plants, in the form of loans, would be repaid in 30 years at eight percent interest, with the first payment due five years following the date of the loan. Local treatment facilities and in-city distribution system costs that are not associated with major regional systems are not included. Also, some

Table V-3. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983	Project Cost Estimates: At Date of Construction[2]	Source of Financing: Percent: Federal	Source of Financing: Percent: Local Sponsor	Source of Financing: Percent: State	Source of Financing: Totals[3]: Federal	Source of Financing: Totals[3]: Local Sponsor	Source of Financing: Totals[3]: State
		(Million Dollars)					(Million Dollars)		
1984-1985									
1. Richland Creek	Tarrant Co. WCID No. 1	31	36	0	100	0	0	36	0
2. Northeast Plant	Houston	82	96	0	100	0	0	96	0
3. East Plant	Houston	113	132	0	100	0	0	132	0
4. Sherman	Greater Texoma MUD				Planning Incomplete				
Total		226	264				0	264	0
1986-1987									
1. Gatesville	Gatesville	10	14	0	50	50	0	7	7
2. Stacy-Midland	Colorado River MWD	26	35	0	50	50	0	18	18
3. Tawakoni-Ray Hubbard	Dallas	31	42	0	100	0	0	42	0
4. Lower Valley	Southmost Reg. Water Auth.	50	68	0	100	0	0	68	0
5. Joe Pool Regional	Trinity River Auth.	11	15	0	50	50	0	8	8
6. Applewhite	San Antonio City Water Bd.	18	24	0	50	50	0	12	12
7. Austin	Austin	187	254	0	100	0	0	254	0
8. Lake Georgetown	BRA/Round Rock	120	163	0	50	50	0	82	82
Total		453	615				0	491	127
1988-1989									
1. Bryan	Bryan College Station/BRA				Planning Incomplete				
2. Southeast Plant	Houston	147	233	0	100	0	0	233	0
3. Brazoria Cities	Brazos River Auth.				Planning Incomplete				
4. Austin	Austin	62	98	0	100	0	0	98	0
Total		209	331				0	331	0

*See footnotes at end of table.

Table V-3. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

		Project Cost Estimates		Source of Financing					
				Percent			Totals[3]		
Time of Construction/ Name of Project[1]	Name of Local Sponsor	January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
1990-1991									
1. Double Mountain	Lubbock	31	57	0	50	50	0	29	29
2. Prairie Creek	Longview				Planning Incomplete				
3. Cooper-Lavon I	North Texas MWD/Irving	30	56	38	62	0	21	34	0
Total		61	113				21	63	29
1992-1993									
1. Wheeler	Wheeler	4	9	0	50	50	0	5	5
2. Paluxy	Stephenville/Neighbors	18	39	0	100	0	0	39	0
3. Palo Duro	Palo Duro River Authority	13	28	0	100	0	0	28	0
4. Lake Fork-Dallas	Dallas	31	67	0	100	0	0	67	0
Total		66	143				0	139	5
1994-1995									
1. Applewhite No. 2	San Antonio City Water Bd.				Planning Incomplete				

*See footnotes at end of table.

Table V-3. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983	Project Cost Estimates: At Date of Construction[2]	Source of Financing, Percent: Federal	Source of Financing, Percent: Local Sponsor	Source of Financing, Percent: State	Source of Financing, Totals[3]: Federal	Source of Financing, Totals[3]: Local Sponsor	Source of Financing, Totals[3]: State
		(Million Dollars)					(Million Dollars)		
1996-1997									
1. Planning Incomplete									
1998-1999									
1. Denton	Denton				Planning Incomplete				
2. East Wichita Falls	Wichita Falls				Planning Incomplete				
Total									
2000-2001									
1. San Marcos	San Marcos	8	32	0	50	50	0	16	16
2. Cooper-Lavon II	North Texas MWD/Irving	57	228	0	40	60	0	91	137
Total		65	260				0	107	153
2002-2003									
Planning Incomplete									
Total									
2004-2005									
Planning Incomplete									

*See footnotes at end of table.

Table V-3. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)

		Project Cost Estimates		Source of Financing					
				Percent			Totals[3]		
Time of Construction/ Name of Project[1]	Name of Local Sponsor	January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
2006-2009									
Planning Incomplete									
2010-2019									
1. Tehuacana-Rolling Hills	Tarrant County WCID No. 1	52	610	0	100	0	0	610	0
2020-2030									
Planning Incomplete									

[1]Estimated State biennium in which construction should start in order to meet projected need for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.
[2]All costs are inflated from 1983 to January 1 of second year of the biennium.
[3]The totals have been rounded to the nearest million dollars.

Table V-4. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources (Costs Inflated At 8 Percent)*

		Project Cost Estimates		Source of Financing: Percent			Source of Financing: Totals[3]		
Time of Construction/ Name of Project[1]	Name of Local Sponsor	January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
1984-1985									
1. Texoma Diversion	North Texas MWD/Greater Texoma MUD	24	28	0	100	0	0	28	0
2. Luce Bayou Diversion	Houston	76	89	0	100	0	0	89	0
3. Richland Creek	Tarrant Co. WCID No. 1	143	167	0	100	0	0	167	0
4. Gatesville	Gatesville	2	2	0	50	50	0	1	1
Total		245	286				0	285	1
1986-1987									
1. Tawakoni-Ray Hubbard	Dallas	51	69	0	100	0	0	69	0
2. Applewhite-San Antonio	San Antonio	82	112	0	50	50	0	56	56
3. Stacy-Midland	Colorado River MWD	151	205	0	50	50	0	103	103
4. Joe Pool Regional	Trinity River Auth.	4	5	0	50	50	0	3	3
5. Houston System	Houston	302	411	0	100	0	0	411	0
6. Canyon-San Antonio	San Antonio	84	114	0	50	50	0	57	57
Total		674	916				0	699	219
1988-1989									
1. Justiceburg-Post	Lubbock	19	30	0	50	50	0	15	15
2. Millican-Bryan	Brazos River Auth.				Planning Incomplete				
3. Post-Double MTN.	Lubbock	15	24	0	50	50	0	12	12
4. Double MTN.-Lubbock	Lubbock	29	46	0	50	50	0	23	23
Total		63	100				0	50	50

*See footnotes at end of table.

Table V-4. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983	Project Cost Estimates: At Date of Construction[2]	Source of Financing — Percent: Federal	Percent: Local Sponsor	Percent: State	Source of Financing — Totals[3]: Federal	Totals[3]: Local Sponsor	Totals[3]: State
		(Million Dollars)					(Million Dollars)		
1990-1991									
1. Paluxy	Stephenville/Neighbors	16	30	0	100	0	0	30	0
2. Whitney-Cleburne	BRA/Cleburne				Planning Incomplete				
3. Lake Fork-Dallas	Dallas				Planning Incomplete				
4. Cooper-Lavon I	North Texas MWD/Irving	61	113	0	38	62	0	43	70
Total		77	143				0	73	70
1992-1993									
1. Palo Duro	Palo Duro River Auth.	38	82	0	100	0	0	82	0
2. Big Sandy-Marshall	Sabine River Auth.				Planning Incomplete				
3. Lindenau-Applewhite	San Antonio	390	842	0	50	50	0	421	421
4. Sweetwater-Wheeler Co.	Red River Auth.	7	14	0	50	50	0	7	7
Total		435	938				0	510	428
1994-1995									
1. Lindenau Diversion	Guadalupe Blanco River Auth.	26	65	0	50	50	0	33	33
2. Stillhouse Hollow-Lake Georgetown	BRA/Georgetown	23	58	0	50	50	0	29	29
3. Southfork-Round Rock	BRA/Round Rock				Planning Incomplete				
Total		49	123				0	62	62
1996-1997									
Planning Incomplete									

*See footnotes at end of table.

Table V-4. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates		Source of Financing					
				Percent			Totals[3]		
		January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
1998-1999									
1. Ringgold-Wichita Falls	Red River Auth.			Planning Incomplete					
2000-2001									
1. Clopton Crossing-San Marcos	GBRA/San Ant. City Water Bd.	12	48	0	50	50	0	24	24
2002-2003									
1. Cooper-Lavon II	North Texas MWD/Irving	102	475	0	50	50	0	238	238
2004-2005									
Planning Incomplete									
2006-2009									
1. Rockland-Livingston	Lower Neches VA/Houston	378	2,589	0	50	50	0	1,294	1,294
2. Parkhouse-Cooper	North Texas MWD	15	103	0	50	50	0	51	51
Total		393	2,692				0	1,345	1,345

*See footnotes at end of table.

Table V-4. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983	Project Cost Estimates At Date of Construction[2]	Source of Financing Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal	Totals Local Sponsor	Totals State
		(Million Dollars)					(Million Dollars)		
2010-2019									
1. Tehuacana-Rolling Hills	Tarrant Co. WCID No. 1	183	2,148	0	100	0	0	2,148	0
2. Cibolo-Applewhite	San Antonio	102	1,197	0	50	50	0	599	599
Total		285	3,345				0	2,747	599
2020-2030									
Planning Incomplete									

[1] Estimated State biennium in which construction should start in order to meet projected need for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.
[2] All costs are inflated from 1983 to January 1 of second year of the biennium.
[3] The totals have been rounded to the nearest million dollars.

of the major water treatment and conveyance systems costs are not included because planning is incomplete at this time.

Reservoirs and Chloride Control Projects

As Texas' population continues to increase, and as the economy grows, new reservoir projects will be needed to meet increasing future water demands and to replace declining ground-water supplies in some areas. In addition, it will be necessary to construct several chloride control projects in the upstream reaches of the Red and Brazos Basins to keep naturally occurring salty surface water from continuing to contaminate the badly needed surface-water supplies of these basins. After considering the following factors, estimates were made of the capital costs of future reservoir and chloride control projects. First, reservoirs were scheduled according to their estimated time of need, by State biennium, to the year 2005. For the period 2006 to 2030, project planning is either incomplete or, where complete, known projects are grouped into 10-year intervals. Then, cost data and cost estimates were obtained from all available sources including the U.S. Army Corps of Engineers, the Bureau of Reclamation, project reports prepared by consultants, and data on file with the Department. The most recent engineering cost estimate (in 1983 dollars) of each project was inflated at an annual rate of eight percent to the time the reservoir is planned to be constructed. Thus, if a reservoir or chloride control project is planned for construction during the period 2002 through 2003, the most recent engineering costs are inflated at eight percent per year to January 1, 2003 (Table V-5). Finally, estimates were made of the proportion of project costs that can be met from federal, local, and State sources. Estimates of federal funding were made using data from the project-authorizing legislation and indications of recent trends in federal water project funding. Estimates of the proportion of project costs that can be met using local bonding were made by local project sponsors, and are based on the local sponsors' respective estimates of capability to finance the respective projects through the sale of revenue and general obligation bonds. The remainder is estimated to be the quantity of State financial assistance needed for storage acquisition, loans, and loan guarantees to accomplish optimum development of each site in time to meet the projected need for water.

It is estimated that, at eight percent inflation, total capital costs of reservoir and chloride control projects in the State of Texas will be $1.19 billion for the period 1984 through 1989, $4.65 billion for the decade of the 1990's, and $7.6 billion for the period from 2000 to 2005 (Table V-5). The estimated State financial assistance needed for these projects is $291 million in the decade of the 80's, $825 million in the decade of the 90's, and $3.32 billion in the first six years of the 21st century.

In the case of State loans for construction of reservoir and chloride control projects, it is assumed that interest would accrue at eight percent per year, beginning with the date of the loan, that the first payment would be due 15 years after the date of the loan, and that repayment would be made in full during the following 40 year period. It is further assumed that the interest rate would be eight percent for the entire life of such loans. In the case of storage acquired by the State, interest on the acquisition cost would be accrued at eight percent per annum during the time such storage was held by the State; the storage would then be sold to eligible purchasers at cost plus interest and financed for periods of time up to 40 years at an eight percent interest rate.

An exception to the above procedure for State financial participation in construction of reservoir and chloride control projects occurs in the Brazos River Basin. This exception applies only to Millican Reservoir and the three chloride control reservoirs (Kiowa Peak, Dove Creek and Croton Creek) in the upper part of the Brazos River Basin. For these four projects, the Brazos River Authority is identified as the source of financing (Table V-5). (Capital costs for the three chloride control projects have been combined and distributed evenly over the four bienniums of 1992-1993, 1996-1997, 2000-2001 and 2004-2005). It is proposed that the Authority issue revenue bonds to pay the capital costs of the projects. However, the Authority would borrow an amount of funds from the State which would be sufficient to cover the debt service on these local obligations for the first 10 years of their respective lives. In the case of Millican, for example, which is scheduled for construction during the 1994-1995 biennium at a cost of $1.236 billion at time of construction (assuming eight percent inflation), the Brazos River Authority would borrow from the State, in annual increments, an amount of money equal to the debt service on the Authority's debt obligation of $1.236 billion. Interest on these funds borrowed from the State would accrue at eight percent per annum, compound, until repaid. The repayment period would begin in the 11th year of the original Brazos River Authority's obligation and extend for 20 years. Applied to the four projects specified, these debt service loans from the State to the Brazos River Authority will add a total of $1.16 billion to the estimated required State financial assistance for a total State financial requirement through 2005 of $18.0 billion. The earliest State funds will be required for any of these four Brazos River Authority projects will be in 1996 when interest payment for Millican Reservoir begins. The estimated additional State financial assistance required for debt service for the Brazos River Authority in the decade of the 90's is $448 million, $710

Table V-5. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983	Project Cost Estimates: At Date of Construction[2]	Source of Financing, Percent: Federal	Source of Financing, Percent: Local Sponsor	Source of Financing, Percent: State	Source of Financing, Totals[4]: Federal	Source of Financing, Totals[4]: Local Sponsor	Source of Financing, Totals[4]: State
		(Million Dollars)					(Million Dollars)		
1984-1985									
1. Cooper	North Texas MWD/Irving	138	161	62	26	12	100	42	19
2. Stacy	Colorado River MWD	74	86	0	50	50	0	43	43
3. Upper Guadalupe	Upper Guadalupe River Auth.	10	12	0	100	0	0	12	0
4. Retamal(Rio Grande Chan. Dam)	Southmost Reg. WA	3	3	0	40	60	0	1	2
5. Wallisville	Houston	65	76	0	100	0	0	76	0
6. Applewhite	San Antonio/City Water Bd.	77	90	0	100	0	0	90	0
Total		367	428				100	264	64
1986-1987									
1. Rio Grande Chan. Dam A	Southmost Reg. Water Auth.	19	26	60	0	40	16	0	10
2. Palo Duro	Palo Duro River Auth.	42	57	0	50	50	0	29	29
3. Eastex	Angelina/Neches Auth.	67	91	0	60	40	0	55	36
4. Justiceburg	Brazos River Auth./Lubbock	36	49	0	100	0	0	49	0
5. Neches Salt Barrier	Lower Neches Valley Auth.	48	65	0	100	0	0	65	0
6. Paluxy	Stephenville/Neighbors	47	64	0	100	0	0	64	0
Total		259	352				16	262	75

*See footnotes at end of table.

Table V-5. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983 (Million Dollars)	Project Cost Estimates: At Date of Construction[2] (Million Dollars)	Source of Financing, Percent: Federal	Source of Financing, Percent: Local Sponsor	Source of Financing, Percent: State	Source of Financing, Totals[4]: Federal (Million Dollars)	Source of Financing, Totals[4]: Local Sponsor (Million Dollars)	Source of Financing, Totals[4]: State (Million Dollars)
1988-1989									
1. Big Pine	Red River Auth./Clarksville	61	97	0	40	60	0	39	58
2. Big Sandy	Sabine River Auth.	115	182	0	60	40	0	109	73
3. Post	White River Auth.	21	33	0	100	0	0	33	0
4. Sweetwater Creek	Red River Auth./Wheeler Co.	27	43	0	50	50	0	21	21
5. Bosque	Brazos River Auth.	33	52	0	100	0	0	52	0
Total		257	407				0	254	152
1990-1991									
1. Red Basin Chloride Control	Red River Auth.	38	70	100	0	0	70	0	0
2. South Fork	Brazos River Auth.	52	96	0	100	0	0	96	0
3. Lindenau	Guadalupe Blanco River Auth.	235	435	0	50	50	0	218	218
4. South Bend	Brazos River Auth.	180	333	0	100	0	0	333	0
5. Caldwell	Brazos River Auth.	87	161	0	100	0	0	161	0
Total		592	1,095				70	808	218
1992-1993									
1. Brazos Basin Chloride Control[3]	Brazos River Auth.	47	101	25	75	0	25	76	0

*See footnotes at end of table.

Table V-5. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates		Source of Financing: Percent			Source of Financing: Totals[4]		
		January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
1994-1995									
1. Ringgold	Wichita Falls/Red River Auth.	76	191	0	40	60	0	77	115
2. Red Basin Chloride Control	Red River Auth.	38	96	100	0	0	96	0	0
3. Prairie Creek	Longview	25	63	0	50	50	0	31	31
4. Clopton Crossing	GBRA/San Ant. City Water Bd.	181	456	0	50	50	0	228	228
5. Millican[3]	Brazos River Auth.	491	1,236	0	100	0	0	1,236	0
Total		811	2,042				96	1,572	374
1996-1997									
1. Colorado Coastal Plains	Lower Colorado River Auth.	216	634	0	100	0	0	634	0
2. Cleveland	San Jacinto River Auth.	70	206	0	67	33	0	138	68
3. Brazos Basin Chloride Control[3]	Brazos River Auth.	47	138	25	75	0	35	104	0
4. Bedias	Trinity River Auth.	59	173	0	50	50	0	87	87
Total		392	1,151				35	963	155
1998-1999									
1. Red Basin Chloride Control	Red River Auth.	38	130	100	0	0	130	0	0
2. Liberty Hill	Red River Auth.	38	130	0	40	60	0	52	78
Total		76	260				130	52	78

*See footnotes at end of table.

Table V-5. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates: January 1983	Project Cost Estimates: At Date of Construction[2]	Source of Financing, Percent: Federal	Percent: Local Sponsor	Percent: State	Totals[4]: Federal	Totals[4]: Local Sponsor	Totals[4]: State
		(Million Dollars)					(Million Dollars)		
2000-2001									
1. Lake Creek	San Jac. River. Auth./Houston	117	468	0	67	33	0	313	154
2. Brazos Basin Chloride Control[3]	Brazos River Auth.	47	188	25	75	0	47	141	0
Total		164	656				47	454	154
2002-2003									
1. Lockhard	Guadalupe Blanco River Auth.	41	191	0	50	50	0	96	96
2. Little Cypress	Marshall and Other	329	1,533	0	50	50	0	767	767
3. Red Basin Chloride Control	Red River Auth.	38	177	100	0	0	177	0	0
Total		408	1,901				177	863	863
2004-2005									
1. Rockland	Lower Neches VA/Houston	702	3,816	0	50	50	0	1,908	1,908
2. George Parkhouse I		120	652	0	40	60	0	261	391
3. Tehuacana	Tarrant Co. WCID No. 1	50	272	0	100	0	0	272	0
4. Brazos Basin Chloride Control[3]	Brazos River Auth.	47	256	25	75	0	64	192	0
Total		919	4,996				64	2,633	2,299

*See footnotes at end of table.

Table V-5. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources—Continued (Costs Inflated At 8 Percent)

		Project Cost Estimates		Source of Financing					
				Percent			Totals[4]		
Time of Construction/ Name of Project[1]	Name of Local Sponsor	January 1983	At Date of Construction[2]	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)					(Million Dollars)		
2006-2009									
Planning Incomplete									
2010-2019									
1. Weches	Upper Neches River MWA	325	3,815	0	40	60	0	1,526	2,289
2. Cuero	GBRA/San Ant. City Water Bd.	296	3,474	0	50	50	0	1,737	1,737
3. Cibolo	SRA/San Ant. City Water Bd.	129	1,514	0	50	50	0	757	757
4. Breckenridge	Brazos River Auth.	73	857	0	100	0	0	857	0
5. Goliad	San Antonio River Auth.	192	2,254	0	50	50	0	1,127	1,127
6. George Parkhouse II		36	422	0	40	60	0	169	253
Total		1,051	12,336				0	6,173	6,163
2020-2030									
1. Bon Weir	Sabine River Auth.	120	3,041	0	100	0	0	3,041	0
2. Carl Estes	Sabine River Auth.	300	7,602	0	50	50	0	3,801	3,801
3. Tennessee Colony	Trinity River Auth./Houston	919	23,287	0	50	50	0	11,643	11,643
4. Marvin Nichols I		295	7,475	0	40	60	0	2,990	4,485
Total		1,634	41,405				0	21,475	19,929

[1] Estimated State biennium in which construction should start in order to meet project need for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.

[2] All costs are inflated from 1983 to January 1 of second year of the biennium.

[3] The Brazos River Authority (BRA) plans to finance BRA projects through the sale of revenue bonds, but would borrow from a State loan fund to pay interest during the first ten years on BRA bonds sold to finance construction of Millican Reservoir and the three chloride control projects in the Brazos River Basin. The BRA would then repay the State with interest. The estimates of State financial assistance include the following amounts (in millions of dollars) required by BRA, assuming 8 percent interest on the BRA bonds: 1994 = $6; 1995 = $6; 1996 = $105; 1997 = $105; 1998 = $113; 1999 = $113; 2000 = $113; 2001 = $113; 2002 = $124; 2003 = $124; 2004 = $118; 2005 = $118; 2006 = $34; 2007 = $34; 2008 = $26; 2009 = $26; 2010 = $26; 2011 = $26; 2012 = $15; 2013 = $15; 2014 = $15; 2015 = $15.

[4] The totals have been rounded to the nearest million dollars.

million between 2000 and 2005 and $232 after 2005. All of these costs assume inflation of 1983 construction costs at eight percent per year to time of construction.

HARDSHIP CASES

The Texas Water Development and Water Loan Assistance Funds were established to provide low cost State assistance to finance water development and wastewater treatment facilities for cities and water authorities that are considered to be "hardship cases." A "hardship" determination is established when a political subdivision, such as a city, cannot obtain financing through commercial channels for a water supply or a sewage treatment project at reasonable rates of interest. The sources of funding for State loans to hardship applicants are constitutionally authorized State of Texas Water Development Bonds and funds made available by a direct legislative appropriation in 1981. The rate of interest charged for State loans that are made from the proceeds of State Bonds is the rate of interest the State has to pay on its bonds, a rate which varies with market conditions at the time of sale of State Bonds, plus one-half percent. The rate charged on loans from the Water Loan Assistance Fund is set by "Rule" by the Water Development Board. The lending rate has been set at the lower of (A) 12 percent or (B) the lowest point of the Bond Buyer Index of 11 Municipal General Obligation Bonds during the six months immediately preceding the month in which the Board extends a loan commitment to an applicant, and thus is directly related to commercial market bond rates.

In the past, the quantity of hardship loans has ranged between $15 million and $20 million per year for wastewater facilities, and between $30 million and $35 million per year for water supply projects. However, due to extremely high interest rates and reduced federal grants for public works projects, present inquiries for loans have increased to $64 million and $63 million per biennium for water quality protection and water supply purposes, respectively. In the absence of better data, estimates of future need for financing for hardship cases have been set to reflect the higher recent inquiry level cited above for the 1984-1985 biennium. Consequently, $50 million per biennium was specified for wastewater projects and $60 million per biennium for water supply projects (in 1983 dollars), with each of these base amounts inflated at an annual rate of eight percent from 1983 to the future biennium in which the funds are needed (Table V-6). The water quality protection requirements were adjusted for expected federal grants through the 1980's. It is assumed that hardship loans will be for an average period of 30 years, that such loans will be repaid with interest at the interest rate specified for such loans, and that the first payment will be due one year from the date of the loan.

RURAL WATER SUPPLY SYSTEMS

Rural water supply corporations are nonprofit organizations but are not government agencies. Consequently, they do not qualify for loans or grants from the Water Development or the Water Loan Assistance Funds. The Farmers Home Administration (FmHA) of the U.S. Department of Agriculture has made grants and loans to these corporations, but this assistance is declining and is expected to be further reduced in the future. The data contained herein were obtained from the Farmers Home Administration and are presented for information. At the present time, there are 56 rural water supply applications for loans and grants in an amount of $57 million, with 131 preapplications for $85 million (Table V-6). The Texas share of federal funding for these purposes has been about $30 million annually during the 1977-1981 period, but is now reduced to about $18 million annually. Leadership of the Texas Association of Rural Water Corporations has requested that the State give serious consideration to the problem of financing for rural water systems. However, legislation that establishes such systems as eligible applicants for State water financing assistance, reorganization of rural water supply corporations into freshwater supply districts, or reorganization of these corporations into some other type of water utility district under existing State statutes would be required in order to allow these entities to benefit from State financial assistance for water supply purposes.

RESEARCH AND PLANNING

In order to solve long-range water quality protection, water conservation, water development, and flood protection problems, additional basic and applied research and planning are needed in order to improve the state-of-the-art in water resources management. Funding needed for water research and planning that should be administered by the Department of Water Resources is estimated at $2.5 million annually, through the remainder of the 1980's. In administering and conducting this research and planning program, the Department would fully utilize the expertise and capabilities of the State's universities for research and local governments for planning. The Department would coordinate the total research effort by establishing and maintaining evaluations of the water research needs and priorities of the State. A research advisory committee to the Department has been established, which will include State, university, and local government representatives, to assist in the prioritization and coordination of activities. It is emphasized, however, that this is not an adequate water research program for the entire State, and that additional water and related research is needed at State and private colleges and universities, and in private sector establishments, in order to solve the State's water problems. The

Table V-6. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities (costs inflated at 8 percent)*

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	1984 - 1985				1986 - 1987				1988 - 1989			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	64	64	—	—	68	68	—	—	79	79
2. Wastewater Treatment (all others)	185	467	218	870	185	439	186	810	185	512	248	945
3. Wells and Facilities (Hardship)	—	—	13	13	—	—	16	16	—	—	19	19
4. Wells and Facilities (all others)	0	96	19	115	0	112	22	134	0	128	24	152
5. Major Raw Water Treatment	0	264	0	264	0	491	127	618	0	331	0	331
6. Major Water Conveyance	0	285	1	286	0	699	219	918	0	50	50	100
7. Water Supply Facilities (Hardship)	—	—	50	50	—	—	66	66	—	—	76	76
8. Reservoir and Chloride Control[2]	100	264	64	428	16	262	75	353	0	254	152	406
Subtotal (Hardship)	—	—	127	127	—	—	150	150	—	—	174	174
Subtotal (all other)	285	1,376	302	1,963	201	2,003	629	2,833	185	1,275	474	1,934
SUBTOTAL	285	1,376	429	2,090	201	2,003	779	2,983	185	1,275	648	2,108
Research and Planning	—	—	5	5	—	—	5	5	—	—	5	5
TOTAL	285	1,376	434	2,095	201	2,003	784	2,988	185	1,275	653	2,113
Rural Water Supply												
Applications	57	0	0	57	—	—	—	—	—	—	—	—
Preapplications	0	0	0	0	85	—	—	85	—	—	—	—

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	1990 - 1991				1992 - 1993				1994 - 1995			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	93	93	0	0	108	108	—	—	126	126
2. Wastewater Treatment (all others)	0	597	504	1,101	0	696	589	1,285	0	812	686	1,498
3. Wells and Facilities (Hardship)	—	—	22	22	—	—	26	26	—	—	30	30
4. Wells and Facilities (all others)	0	147	27	174	0	170	31	201	0	194	35	229
5. Major Raw Water Treatment	21	63	29	113	0	139	5	144	0	0	0	0
6. Major Water Conveyance	0	73	70	143	0	510	428	938	0	62	62	124
7. Water Supply Facilities (Hardship)	—	—	89	89	—	—	104	104	—	—	121	121
8. Reservoir and Chloride Control[2]	70	808	218	1,096	25	76	0	101	96	1,572	374	2,042
Subtotal (Hardship)	—	—	204	204	—	—	238	238	—	—	277	277
Subtotal (all other)	91	1,688	848	2,627	25	1,591	1,053	2,669	96	2,640	1,157	3,893
SUBTOTAL	91	1,688	1,052	2,831	25	1,591	1,291	2,907	96	2,640	1,434	4,170
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	91	1,688	1,052	2,831	25	1,591	1,291	2,907	96	2,640	1,434	4,170
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-6. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities (costs inflated at 8 percent)*—Continued

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	1996 - 1997				1998 - 1999				2000 - 2001			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	147	147	—	—	171	171	—	—	200	200
2. Wastewater Treatment (all others)	0	947	800	1,747	0	1,105	934	2,039	0	1,328	1,129	2,457
3. Wells and Facilities (Hardship)	—	—	35	35	—	—	41	41	—	—	48	48
4. Wells and Facilities (all others)	0	223	39	262	0	259	46	305	0	303	53	356
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	107	153	260
6. Major Water Conveyance	0	0	0	0	0	0	0	0	0	24	24	48
7. Water Supply Facilities (Hardship)	—	—	141	141	—	—	165	165	—	—	192	192
8. Reservoir and Chloride Control[2]	35	963	155	1,153	130	52	78	260	47	454	154	655
Subtotal (Hardship)	—	—	323	323	—	—	377	377	—	—	440	440
Subtotal (all other)	35	2,133	994	3,162	130	1,416	1,058	2,604	47	2,216	1,513	3,776
SUBTOTAL	35	2,133	1,317	3,485	130	1,416	1,435	2,981	47	2,216	1,953	4,216
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	35	2,133	1,317	3,485	130	1,416	1,435	2,981	47	2,216	1,953	4,216
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	2002 - 2003				2004 - 2005				2006 - 2007			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	233	233	—	—	271	271	—	—	317	317
2. Wastewater Treatment (all others)	0	1,596	1,364	2,960	0	1,862	1,591	3,453	0	2,172	1,855	4,027
3. Wells and Facilities (Hardship)	—	—	56	56	—	—	65	65	—	—	76	76
4. Wells and Facilities (all others)	0	356	63	419	0	424	76	500	0	504	92	596
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	238	238	476	0	0	0	0	0	673	673	1,346
7. Water Supply Facilities (Hardship)	—	—	224	224	—	—	260	260	—	—	304	304
8. Reservoir and Chloride Control[2]	177	863	863	1,903	64	2,633	2,299	4,996	0	0	0	0
Subtotal (Hardship)	—	—	513	513	—	—	596	596	—	—	697	697
Subtotal (all other)	177	3,053	2,528	5,758	64	4,919	3,966	8,949	0	3,349	2,620	5,969
SUBTOTAL	177	3,053	3,041	6,271	64	4,919	4,562	9,545	0	3,349	3,317	6,666
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	177	3,053	3,041	6,271	64	4,919	4,562	9,545	0	3,349	3,317	6,666
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-6. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities (costs inflated at 8 percent)*—Continued

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	2008 - 2009				2010 - 2011				2012 - 2013			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	370	370	—	—	431	431	—	—	503	503
2. Wastewater Treatment (all others)	0	2,533	2,164	4,697	0	3,515	3,085	6,600	0	4,100	3,598	7,698
3. Wells and Facilities (Hardship)	—	—	89	89	—	—	104	104	—	—	121	121
4. Wells and Facilities (all others)	0	599	111	710	0	731	140	871	0	853	163	1,016
5. Major Raw Water Treatment	0	0	0	0	0	122	0	122	0	122	0	122
6. Major Water Conveyance	0	673	673	1,346	0	549	120	669	0	549	120	669
7. Water Supply Facilities (Hardship)	—	—	355	355	—	—	414	414	—	—	483	483
8. Reservoir and Chloride Control[2]	0	0	0	0	0	1,235	1,233	2,468	0	1,235	1,233	2,468
Subtotal (Hardship)	—	—	814	814	—	—	949	949	—	—	1,107	1,107
Subtotal (all other)	0	3,805	2,948	6,753	0	6,152	4,578	10,730	0	6,859	5,114	11,973
SUBTOTAL	0	3,805	3,762	7,567	0	6,152	5,527	11,679	0	6,859	6,221	13,080
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	3,805	3,762	7,567	0	6,152	5,527	11,679	0	6,859	6,221	13,080
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

	Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]											
	2014 - 2015				2016 - 2017				2018 - 2019			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	586	586	—	—	684	684	—	—	798	798
2. Wastewater Treatment (all others)	0	4,783	4,197	8,980	0	5,578	4,895	10,473	0	6,507	5,709	12,216
3. Wells and Facilities (Hardship)	—	—	141	141	—	—	164	164	—	—	192	192
4. Wells and Facilities (all others)	0	1,021	200	1,221	0	1,211	240	1,451	0	1,413	279	1,692
5. Major Raw Water Treatment	0	122	0	122	0	122	0	122	0	122	0	122
6. Major Water Conveyance	0	549	120	669	0	549	120	669	0	549	120	669
7. Water Supply Facilities (Hardship)	—	—	563	563	—	—	657	657	—	—	766	766
8. Reservoir and Chloride Control[2]	0	1,235	1,233	2,468	0	1,235	1,233	2,468	0	1,235	1,233	2,468
Subtotal (Hardship)	—	—	1,290	1,290	—	—	1,505	1,505	—	—	1,756	1,756
Subtotal (all other)	0	7,710	5,750	13,460	0	8,695	6,488	15,183	0	9,826	7,341	17,167
SUBTOTAL	0	7,710	7,040	14,750	0	8,695	7,993	16,688	0	9,826	9,097	18,923
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	7,710	7,040	14,750	0	8,695	7,993	16,688	0	9,826	9,097	18,923
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-6. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities (costs inflated at 8 percent)—Continued

Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]

Type of Facility	2020 - 2021				2022 - 2023				2024 - 2025			
	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	931	931	—	—	1,086	1,086	—	—	1,267	1,267
2. Wastewater Treatment (all others)	0	9,117	8,186	17,303	0	10,634	9,548	20,182	0	12,403	11,137	23,540
3. Wells and Facilities (Hardship)	—	—	224	224	—	—	261	261	—	—	304	304
4. Wells and Facilities (all others)	0	1,718	349	2,067	0	2,004	407	2,411	0	2,375	488	2,863
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	0	0	0	0	0	0	0	0	0	0	0
7. Water Supply Facilities (Hardship)	—	—	894	894	—	—	1,042	1,042	—	—	1,216	1,216
8. Reservoir and Chloride Control[2]	0	3,904	3,624	7,528	0	3,904	3,624	7,528	0	3,904	3,624	7,528
Subtotal (Hardship)	—	—	2,049	2,049	—	—	2,389	2,389	—	—	2,787	2,787
Subtotal (all other)	0	14,739	12,159	26,898	0	16,542	13,579	30,121	0	18,682	15,249	33,931
SUBTOTAL	0	14,739	14,208	28,947	0	16,542	15,968	32,510	0	18,682	18,036	36,718
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	14,739	14,208	28,947	0	16,542	15,968	32,510	0	18,682	18,036	36,718
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

Estimated Capital Costs at Time of Construction, in Millions of Dollars[1]

Type of Facility	2026 - 2027				2028 - 2029				2030			
	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	1,478	1,478	—	—	1,724	1,724	—	—	1,006	1,006
2. Wastewater Treatment (all others)	0	14,467	12,990	27,457	0	16,875	15,151	32,026	0	9,842	8,836	18,678
3. Wells and Facilities (Hardship)	—	—	355	355	—	—	414	414	—	—	241	241
4. Wells and Facilities (all others)	0	2,860	598	3,458	0	3,335	698	4,033	0	1,945	408	2,353
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	0	0	0	0	0	0	0	0	0	0	0
7. Water Supply Facilities (Hardship)	—	—	1,418	1,418	—	—	1,654	1,654	—	—	965	965
8. Reservoir and Chloride Control[2]	0	3,904	3,624	7,528	0	3,904	3,624	7,528	0	1,952	1,812	3,764
Subtotal (Hardship)	—	—	3,251	3,251	—	—	3,792	3,792	—	—	2,212	2,212
Subtotal (all other)	0	21,231	17,212	38,443	0	24,114	19,473	43,587	0	13,739	11,056	24,795
SUBTOTAL	0	21,231	20,463	41,694	0	24,114	23,265	47,379	0	13,739	13,268	27,007
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	21,231	20,463	41,694	0	24,114	23,265	47,379	0	13,739	13,268	27,007
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

[1]Project costs are inflated from 1983 to January 1 of the second year of the biennium in which it is estimated construction would be initiated.

[2]The Brazos River Authority (BRA) plans to finance BRA projects through the sale of revenue bonds, but would borrow from a State loan fund to pay interest during the first ten years on BRA bonds sold to finance construction of Millican Reservoir and the three chloride control projects in the Brazos River Basin. The BRA would then repay the State with interest. The estimates of State financial assistance include the following amounts (in millions of dollars) required by BRA, assuming 8 percent interest on the BRA bonds: 1994 = $6; 1995 = $6; 1996 = $105; 1997 = $105; 1998 = $113; 1999 = $113; 2000 = $113; 2001 = $113; 2002 = $124; 2003 = $124; 2004 = $118; 2005 = $118; 2006 = $34; 2007 = $34; 2008 = $26; 2009 = $26; 2010 = $26; 2011 = $26; 2012 = $15; 2013 = $15; 2014 = $15; 2015 = $15.

proposed research and planning program mentioned here would be coordinated with these other programs in order to increase overall water research and planning efficiency.

SUMMARY

Using the latest information available, Department staff have revised and updated projections of population and economic growth for the period 1980 through 2030 for each county (and in the case of population, for most cities) of Texas, with specific projections for intervening decades. From these projections of population and economic growth, estimates have been derived of the sewage treatment needs and the quantities of water that will be needed for people, industry, agriculture, fisheries, and other purposes in future years. From these projections of future need, sewage systems, water supply facilities, and major water projects required to meet a part or all of the municipal and industrial needs of most areas of the State have been identified, both in terms of approximate location and time of construction.

As a part of the planning work, Department staff, in cooperation with federal agencies and representatives of cities, river authorities, water districts, and Councils of Governments have made estimates of the costs of projects and financing required to meet the needs of sewage treatment, water treatment, water conveyance, and water supplies in Texas. Estimates are presented for each State biennium for the period 1984 through 2030 (Table V-6).

The estimated total capital requirement for publicly financed projects for which planning is complete for the 1984-85 biennium is $2.1 billion of which it is estimated that State of Texas financial assistance will be needed in the amount of $302 million either in the form of loans or through loan guarantees for water and wastewater projects, $127 million in "hardship case" loans, and $5.0 million for research and planning grants (Table V-6). Wastewater collection and treatment facilities account for $934 million of the total, of which approximately $282 million of State supported financial assistance would be needed, including about $64 million for "hardship case" loans. Estimated capital costs for reservoirs are $428 million of the $2.1 billion total, with State financial assistance needed for these projects estimated at about $64 million during the biennium. State financial assistance requirements for conveyance, raw water treatment facilities, and well fields are estimated at $33 million for the 1984-85 biennium. Loans for "hardship cases" during the 1984-85 biennium for water supply are estimated at $63 million, including $13 million in the form of "hardship case" loans for wells and facilities.

Estimated capital requirements for the period 1984 through 2005 are $43.6 billion in inflated dollars at an inflation rate of eight percent ($16.1 billion in 1983 dollars), of which State financial assistance through loans or loan guarantees, and research and planning grants, would be $18.0 billion in inflated dollars ($5.8 billion in 1983 dollars). Wastewater treatment facilities account for $20.7 billion of the total $43.6 billion (in inflated dollars). This includes $1.6 billion in wastewater "hardship cases" loans over the 22 year period from 1984 through 2005. Reservoir construction accounts for $13.4 billion ($4.3 billion in 1983 dollars) of the $43.6 billion total, with the remaining $9.5 billion going to water conveyance, water treatment, wells, and water supply "hardship cases" including some "hardship case" assistance for wells.

With inflation at eight percent per annum, estimated State financial assistance needs for the 1984 through 2005 time period include $4.4 billion for reservoirs, $9.8 billion for wastewater treatment plants and $3.8 billion of funding for raw water conveyance, treatment facilities, well fields, and hardship cases for other water supply facilities. Debt service loans for Millican Reservoir and the three chloride control projects in the Brazos River Basin will add $1.16 billion through the year 2005 to the total State financial assistance of $18.0 billion, if such a financial arrangement were to occur.

The above estimates of total capital requirements and their disaggregation to the respective facility type groupings all assume an eight percent per year inflation rate. Correspondingly, the eight percent per year rate of inflation is factored into the estimates of required State financial assistance. To provide a contrast with these future capital requirements inflated at eight percent per year from 1983 to time of construction, a parallel set was developed under the assumed condition of no increase in material or construction costs through time (i.e., zero rate of inflation). The tabulation of estimated future capital requirements at zero rate of inflation (Tables V-7 through V-12) reflects the same projects and the same construction schedule incorporated into the estimates of future capital requirements inflated at eight percent per year (Tables V-1 through V-6).

Table V-7. Estimates of Wastewater Collection and Treatment Facilities Costs for Publicly Owned Facilities,[1] with Estimates of Funding Sources

	Cost Estimates				Source of Financing					
		At Date of Construction			Percent			Totals		
Time of Construction[2]	Jan. 1983	Hardship Cases	All Other Cases	Total	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)								
1984-1985	801	64	737	801	23	50	27	185	400	216
1986-1987	645	50	595	645	29	50	21	185	323	137
1988-1989	645	50	595	645	29	50	21	185	323	137
1990-1991	645	50	595	645	0	50	50	0	322	323
1992-1993	645	50	595	645	0	50	50	0	322	323
1994-1995	645	50	595	645	0	50	50	0	322	323
1996-1997	645	50	595	645	0	50	50	0	322	323
1998-1999	645	50	595	645	0	50	50	0	322	323
2000-2001	665	50	615	665	0	50	50	0	332	333
2002-2003	685	50	635	685	0	50	50	0	343	342
2004-2005	685	50	635	685	0	50	50	0	343	342
2006-2007	685	50	635	685	0	50	50	0	343	342
2008-2009	685	50	635	685	0	50	50	0	343	342
2010-2011	815	50	765	815	0	50	50	0	407	408
2012-2013	815	50	765	815	0	50	50	0	407	408
2014-2015	815	50	765	815	0	50	50	0	407	408
2016-2017	815	50	765	815	0	50	50	0	407	408
2018-2019	815	50	765	815	0	50	50	0	407	408
2020-2021	979	50	929	979	0	50	50	0	489	490
2022-2023	979	50	929	979	0	50	50	0	489	490
2024-2025	979	50	929	979	0	50	50	0	489	490
2026-2027	979	50	929	979	0	50	50	0	489	490
2028-2029	979	50	929	979	0	50	50	0	489	490
2030-2031	979	50	929	979	0	50	50	0	489	490

[1]A public entity in this useage of the term is a political subdivision of the State (an entity created by a unique legislative action or created under existing statute). Included are cities, municipal utility districts (MUD), and other types of special districts, for example, river authorities and water districts and water districts. In order that these latter, special purpose utility districts be included in this table, their charter must expressly permit them to collect, treat, and dispose of wastewater. Estimates of the future capital costs of the wastewater treatment facility needs of private systems that perform wastewater collection, treatment, and disposal functions similar to those of a public system are not included in this tabulation. A privately financed residential, commercial development that owns and operates its own wastewater system, even though it holds a permit from the State allowing it to do so, would be an example of a private system. The cost of facilities required to satisfy the needs of privately owned facilities over the period 1985-2000 is estimated to be about $2.0 billion, is inflated dollars, or about $125 million per year.

[2]Estimated State biennium in which construction should start in order to meet projected wastewater treatment requirements.

Table V-8. Estimates of Well Field Development Costs, with Estimates of Funding Sources

Time of Construction[1]	Project Cost Estimates January 1983	Source of Financing: Percent			Source of Financing: Totals		
		Federal	Local Sponsor	State	Federal	Local Sponsor	State
	—(million dollars)—				—(million dollars)—		
1984-1985	110	0	75	25	0	82	28
1986-1987	110	0	75	25	0	82	28
1988-1989	108	0	75	25	0	81	27
1990-1991	106	0	75	25	0	80	26
1992-1993	105	0	75	25	0	79	26
1994-1995	103	0	75	25	0	77	26
1996-1997	101	0	75	25	0	76	25
1998-1999	101	0	75	25	0	76	25
2000-2001	101	0	75	25	0	76	25
2002-2003	102	0	75	25	0	76	26
2004-2005	104	0	75	25	0	78	26
2006-2007	106	0	75	25	0	80	26
2008-2009	108	0	75	25	0	81	27
2010-2011	113	0	75	25	0	85	28
2012-2013	113	0	75	25	0	85	28
2014-2015	116	0	75	25	0	87	29
2016-2017	118	0	75	25	0	88	30
2018-2019	118	0	75	25	0	88	30
2020-2021	123	0	75	25	0	92	31
2022-2023	123	0	75	25	0	92	31
2024-2025	125	0	75	25	0	94	31
2026-2027	129	0	75	25	0	97	32
2028-2029	129	0	75	25	0	97	32
2030-2031	129	0	75	25	0	97	32

[1]Estimated State biennium in which construction on the project should start in order to meet projected water supply requirements.

Table V-9. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] (Million Dollars) Federal	Totals Local Sponsor	Totals State
1984-1985								
1. Richland Creek	Tarrant Co. WCID No. 1	31	0	100	0	0	31	0
2. Northeast Plant	Houston	82	0	100	0	0	82	0
3. East Plant	Houston	113	0	100	0	0	113	0
4. Sherman	Greater Texoma MUD				Planning Incomplete			
Total		226				0	226	0
1986-1987								
1. Gatesville	Gatesville	10	0	50	50	0	5	5
2. Stacy-Midland	Colorado River MWD	26	0	50	50	0	13	13
3. Tawakoni-Ray Hubbard	Dallas	31	0	100	0	0	31	0
4. Lower Valley	Southmost Reg. Water Auth.	50	0	100	0	0	50	0
5. Joe Pool Regional	Trinity River Auth.	11	0	50	50	0	6	6
6. Applewhite	San Antonio City Water Bd.	18	0	50	50	0	9	9
7. Austin	Austin	187	0	100	0	0	187	0
8. Lake Georgetown	BRA/Round Rock	120	0	50	50	0	60	60
Total		453				0	361	93
1988-1989								
1. Bryan	Bryan College Sta./BRA				Planning Incomplete			
2. Southeast Plant	Houston	147	0	100	0	0	147	0
3. Brazoria Cities	Brazos River Auth.				Planning Incomplete			
4. Austin	Austin	62	0	100	0	0	62	0
Total		209				0	209	0

*See footnotes at end of table.

Table V-9. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] Federal (Million Dollars)	Totals[2] Local Sponsor (Million Dollars)	Totals[2] State (Million Dollars)
1990-1991								
1. Double Mountain	Lubbock	31	0	50	50	0	16	16
2. Prairie Creek	Longview			Planning Incomplete				
3. Cooper-Lavon I	North Texas MWD/Irving	30	38	62	0	11	19	0
Total		61				11	35	16
1992-1993								
1. Wheeler	Wheeler	4	0	50	50	0	2	2
2. Paluxy	Stephenville/Neighbors	18	0	100	0	0	18	0
3. Palo Duro	Palo Duro River Authority	13	0	100	0	0	13	0
4. Lake Fork-Dallas	Dallas	31	0	100	0	0	31	0
Total		66				0	64	2
1994-1995								
1. Applewhite No. 2	San Antonio City Water Bd.			Incomplete Planning				
Total								

*See footnotes at end of table.

Table V-9. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] (Million Dollars) Federal	Totals Local Sponsor	Totals State
1996-1997								
Planning Incomplete								
1998-1999								
1. Denton	Denton				Planning Incomplete			
2. East Wichita Falls	Wichita Falls				Planning Incomplete			
Total								
2000-2001								
1. San Marcos	San Marcos	8	0	50	50	0	4	4
2. Cooper-Lavon II	North Texas MWD/Irving	57	0	40	60	0	23	34
Total		65				0	27	38
2002-2003								
Planning Incomplete								
2004-2005								
Planning Incomplete								

*See footnotes at end of table.

Table V-9. Estimated Dates of Construction and Capital Costs of Major Raw Water Treatment Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] Federal (Million Dollars)	Totals[2] Local Sponsor (Million Dollars)	Totals[2] State (Million Dollars)
2006-2009								
Planning Incomplete								
2010-2019								
1. Tehuacana-Rolling Hills	Tarrant County WCID No. 1	52	0	100	0	0	52	0
2020-2030								
Planning Incomplete								

[1]Estimated State biennium in which construction should start in order to meet projected need for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.
[2]The totals have been rounded to the nearest million dollars.

Table V-10. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources*

			Source of Financing					
		Project Cost Estimates	Percent			Totals[2]		
Time of Construction/ Name of Project[1]	Name of Local Sponsor	January 1983	Federal	Local Sponsor	State	Federal	Local Sponsor	State
		(Million Dollars)				(Million Dollars)		
1984-1985								
1. Texoma Diversion	North Texas MWD/Greater Texoma MUD	24	0	100	0	0	24	0
2. Luce Bayou Diversion	Houston	76	0	100	0	0	76	0
3. Richland Creek	Tarrant Co. WCID No. 1	143	0	100	0	0	143	0
4. Gatesville	Gatesville	2	0	50	50	0	1	1
Total		245				0	244	1
1986-1987								
1. Tawakoni-Ray Hubbard	Dallas	51	0	100	0	0	51	0
2. Applewhite-San Antonio	San Antonio	82	0	50	50	0	41	41
3. Stacy-Midland	Colorado River MWD	151	0	50	50	0	76	76
4. Joe Pool Regional	Trinity River Auth.	4	0	50	50	0	2	2
5. Houston System	Houston	302	0	100	0	0	302	0
6. Canyon-San Antonio	San Antonio	84	0	50	50	0	42	42
Total		674				0	514	161
1988-1989								
1. Justiceburg-Post	Lubbock	19	0	50	50	0	10	10
2. Millican-Bryan	Brazos River Auth.				Planning Incomplete			
3. Post-Double MTN.	Lubbock	15	0	50	50	0	8	8
4. Double MTN.-Lubbock	Lubbock	29	0	50	50	0	15	15
Total		63				0	33	33

*See footnotes at end of table.

Table V-10. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] Federal (Million Dollars)	Totals[2] Local Sponsor (Million Dollars)	Totals[2] State (Million Dollars)
1990-1991								
1. Paluxy	Stephenville/Neighbors	16	0	100	0	0	16	0
2. Whitney-Cleburne	BRA/Cleburne				Planning Incomplete			
3. Lake Fork-Dallas	Dallas				Planning Incomplete			
4. Cooper-Lavon I	North Texas MWD/Irving	61	0	38	62	0	23	38
Total		77				0	39	38
1992-1993								
1. Palo Duro	Palo Duro River Auth.	38	0	100	0	0	38	0
2. Big Sandy-Marshall	Sabine River Auth.				Planning Incomplete			
3. Lindenau-Applewhite	San Antonio	390	0	50	50	0	195	195
4. Sweetwater-Wheeler Co.	Red River Auth.	7	0	50	50	0	3	3
Total		435				0	236	198
1994-1995								
1. Lindenau Diversion	Guadalupe Blanco River Auth.	26	0	50	50	0	13	13
2. Stillhouse Hollow-Lake Georgetown	BRA/Georgetown	23	0	50	50	0	12	12
3. Southfork-Round Rock	BRA/Round Rock				Planning Incomplete			
Total		49				0	25	25
1996-1997								
Planning Incomplete								

*See footnotes at end of table.

Table V-10. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] Federal (Million Dollars)	Totals[2] Local Sponsor (Million Dollars)	Totals[2] State (Million Dollars)
1998-1999								
1. Ringgold-Wichita Falls	Red River Auth.			Planning Incomplete				
2000-2001								
1. Clopton Crossing-San Marcos	GBRA/San Ant. City Water Bd.	12	0	50	50	0	6	6
2002-2003								
1. Cooper-Lavon II	North Texas MWD/Irving	102	0	50	50	0	51	51
2004-2005								
Planning Incomplete								
2006-2009								
1. Rockland-Livingston	Lower Neches VA/Houston	378	0	50	50	0	189	189
2. Parkhouse-Cooper	North Texas MWD	15	0	50	50	0	8	8
Total		393				0	197	197

*See footnotes at end of table.

Table V-10. Estimated Dates of Construction and Capital Costs of Major Water Conveyance Facilities, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[2] Federal (Million Dollars)	Totals[2] Local Sponsor (Million Dollars)	Totals[2] State (Million Dollars)
2010-2019								
1. Tehuacana-Rolling Hills	Tarrant Co. WCID No. 1	183	0	100	0	0	183	0
2. Cibolo-Applewhite	San Antonio	102	0	50	50	0	51	51
Total		285				0	234	51
2020-2030								
Planning Incomplete								

[1]Estimated State biennium in which construction should start in order to meet projected for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.
[2]The totals have been rounded to the nearest million dollars.

Table V-11. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources*

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal (Million Dollars)	Totals[3] Local Sponsor (Million Dollars)	Totals[3] State (Million Dollars)
1984-1985								
1. Cooper	North Texas MWD/Irving	138	62	26	12	86	36	17
2. Stacy	Colorado River MWD	74	0	50	50	0	37	37
3. Upper Guadalupe	Upper Guadalupe River Auth.	10	0	100	0	0	90	0
4. Retamal(Rio Grande Chan. Dam)	Southmost Red. Water Auth.	3	0	40	60	0	1	2
5. Wallisville	Houston	65	0	100	0	0	65	0
6. Applewhite	San Antonio/City Water Bd.	77	0	100	0	0	77	0
Total		367				86	226	56
1986-1987								
1. Rio Grande Chan. Dam A	Southmost Reg. Water Auth.	19	60	0	40	11	0	8
2. Palo Duro	Palo Duro River Auth.	42	0	50	50	0	21	21
3. Eastex	Angelina/Neches Auth.	67	0	60	40	0	40	27
4. Justiceburg	Brazos River Auth./Lubbock	36	0	100	0	0	36	0
5. Neches Salt Barrier	Lower Neches Valley Auth.	48	0	100	0	0	48	0
6. Paluxy	Stephenville/Neighbors	47	0	100	0	0	47	0
Total		259				11	192	56

*See footnotes at end of table.

Table V-11. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal (Million Dollars)	Totals[3] Local Sponsor (Million Dollars)	Totals[3] State (Million Dollars)
1988-1989								
1. Big Pine	Red River Auth./Clarksville	61	0	40	60	0	24	37
2. Big Sandy	Sabine River Auth.	115	0	60	40	0	69	46
3. Post	White River Auth.	21	0	100	0	0	21	0
4. Sweetwater Creek	Red River Auth./Wheeler Co.	27	0	50	50	0	14	14
5. Bosque	Brazos River Auth.	33	0	100	0	0	33	0
Total		257				0	161	97
1990-1991								
1. Red Basin Chloride Control	Red River Auth.	38	100	0	0	38	0	0
2. South Fork	Brazos River Auth.	52	0	100	0	0	52	0
3. Lindenau	Guadalupe Blanco River Auth.	235	0	50	50	0	118	118
4. South Bend	Brazos River Auth.	180	0	100	0	0	180	0
5. Caldwell	Brazos River Auth.	87	0	100	0	0	87	0
Total		592				38	437	118
1992-1993								
1. Brazos Basin Chloride Control[2]	Brazos River Auth.	47	25	75	0	12	35	0

*See footnotes at end of table.

Table V-11. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal (Million Dollars)	Totals[3] Local Sponsor (Million Dollars)	Totals[3] State (Million Dollars)
1994-1995								
1. Ringgold	Wichita Falls/Red River Auth.	76	0	40	60	0	30	46
2. Red Basin Chloride Control	Red River Auth.	38	100	0	0	38	0	0
3. Prairie Creek	Longview	25	0	50	50	0	13	13
4. Clopton Crossing	GBRA/San Ant. City Water Bd.	181	0	50	50	0	91	91
5. Millican[2]	Brazos River Auth.	491	0	100	0	0	491	0
Total		811				38	625	150
1996-1997								
1. Colorado Coastal Plains	Lower Colorado River Auth.	216	0	100	0	0	216	0
2. Cleveland	San Jacinto River Auth.	70	0	67	33	0	47	23
3. Brazos Basin Chloride Control[2]	Brazos River Auth.	47	25	75	0	12	35	0
4. Bedias	Trinity River Auth.	59	0	50	0	0	30	30
Total		392				12	328	53
1998-1999								
1. Red Basin Chloride Control	Red River Auth.	38	100	0	0	38	0	0
2. Liberty Hill	Red River Auth.	38	0	40	60	0	15	23
Total		76				38	15	23

*See footnotes at end of table.

Table V-11. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal (Million Dollars)	Totals[3] Local Sponsor (Million Dollars)	Totals[3] State (Million Dollars)
2000-2001								
1. Lake Creek	San Jacinto River Auth./ Houston	117	0	67	33	0	78	39
2. Brazos Basin Chloride Control[2]	Brazos River Auth.	47	25	75	0	12	35	0
Total		164				12	113	39
2002-2003								
1. Lockhart	Guadalupe Blanco River Auth.	41	0	50	50	0	21	21
2. Little Cypress	Marshall and Other	329	0	50	50	0	165	165
3. Red Basin Chloride Control	Red River Auth.	38	100	0	0	38	0	0
Total		408				38	186	186
2004-2005								
1. Rockland	Lower Neches VA/Houston	702	0	50	50	0	351	351
2. George Parkhouse I		120	0	40	60	0	48	72
3. Tehuacana	Tarrant Co. WCID No. 1	50	0	100	0	0	50	0
4. Brazos Basin Chloride Control[2]	Brazos River Auth.	47	25	75	0	12	35	0
Total		919				12	484	423

*See footnotes at end of table.

Table V-11. Estimated Dates of Construction and Capital Costs of Reservoir and Chloride Control Projects, with Estimates of Funding Sources*—Continued

Time of Construction/ Name of Project[1]	Name of Local Sponsor	Project Cost Estimates January 1983 (Million Dollars)	Source of Financing: Percent Federal	Percent Local Sponsor	Percent State	Totals[3] Federal (Million Dollars)	Totals[3] Local Sponsor (Million Dollars)	Totals[3] State (Million Dollars)
2006-2009								
Planning Incomplete								
2010-2019								
1. Weches	Upper Neches River MWA	325	0	40	60	0	130	195
2. Cuero	GBRA/San Ant. City Water Bd.	296	0	50	50	0	148	148
3. Cibolo	SRA/San Ant. City Water Bd.	129	0	50	50	0	65	65
4. Breckenridge	Brazos River Auth.	73	0	100	0	0	73	0
5. Goliad	San Antonio River Auth.	192	0	50	50	0	96	96
6. George Parkhouse II		36	0	40	60	0	14	22
Total		1,051				0	526	526
2020-2030								
1. Bon Weir	Sabine River Auth.	120	0	100	0	0	120	0
2. Carl Estes	Sabine River Auth.	300	0	50	50	0	150	150
3. Tennessee Colony	Trinity River Auth./Houston	919	0	50	50	0	460	460
4. Marvin Nichols I		295	0	40	60	0	118	177
Total		1,634				0	848	787

[1]Estimated State biennium in which construction should start in order to meet projected need for water supply. Although construction may span more than one State biennium, total project costs are shown for the biennium in which it is estimated construction would be initiated.

[2]The Brazos River Authority (BRA) plans to finance BRA projects through the sale of revenue bonds, but would borrow from a State loan fund to pay interest during the first ten years on BRA bonds sold to finance construction of Millican Reservoir and the three chloride control projects in the Brazos River Basin. The BRA would then repay the State with interest. The estimates of State financial assistance include the following amounts (in millions of dollars) required by BRA, assuming 8 percent interest on the BRA bonds: 1994 = $3; 1995 = $3; 1996 = $42; 1997 = $42; 1998 = $45; 1999 = $45; 2000 = $45; 2001 = $45; 2002 = $48; 2003 = $48; 2004 = $45; 2005 = $45; 2006 = $9; 2007 = $9; 2008 = $6; 2009 = $6; 2010 = $6; 2011 = $6; 2012 = $3; 2013 = $3; 2014 = $3; 2015 = $3.

[3]The totals have been rounded to the nearest million dollars.

Table V-12. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities*

Estimated Capital Costs, in Millions of Dollars[1]

Type of Facility	1984 - 1985				1986 - 1987				1988 - 1989			
	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	64	64	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	185	400	152	737	185	323	87	595	185	323	87	595
3. Wells and Facilities (Hardship)	—	—	13	13	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	82	15	97	0	82	16	98	0	81	15	96
5. Major Raw Water Treatment	0	226	0	226	0	361	93	454	0	209	0	209
6. Major Water Conveyance	0	244	1	245	0	514	161	675	0	33	33	66
7. Water Supply Facilities (Hardship)	—	—	50	50	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	86	226	56	368	11	192	56	259	0	161	97	258
Subtotal (Hardship)	—	—	127	127	—	—	110	110	—	—	110	110
Subtotal (all other)	271	1,178	224	1,673	196	1,472	413	2,081	185	807	232	1,224
SUBTOTAL	271	1,178	351	1,800	196	1,472	523	2,191	185	807	342	1,334
Research and Planning	—	—	5	5	—	—	5	5	—	—	5	5
TOTAL	271	1,178	356	1,805	196	1,472	528	2,196	185	807	347	1,339
Rural Water Supply												
Applications	57	—	—	57	—	—	—	—	—	—	—	—
Preapplications	0	—	—	0	85	—	—	85	—	—	—	—

Estimated Capital Costs, in Millions of Dollars[1]

Type of Facility	1990 - 1991				1992 - 1993				1994 - 1995			
	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	322	273	595	0	322	273	595	0	322	273	595
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	80	14	94	0	79	14	93	0	77	14	91
5. Major Raw Water Treatment	11	35	16	62	0	64	2	66	0	0	0	0
6. Major Water Conveyance	0	39	38	77	0	236	198	434	0	25	25	50
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	38	437	118	593	12	35	0	47	38	625	150	813
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all other)	49	913	459	1,421	12	736	487	1,235	38	1,049	462	1,549
SUBTOTAL	49	913	569	1,531	12	736	597	1,345	38	1,049	572	1,659
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	49	913	569	1,531	12	736	597	1,345	38	1,049	572	1,659
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-12. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities*—Continued

Estimated Capital Costs, in Millions of Dollars[1]

Type of Facility	1996 - 1997 Federal	Local	State	Total	1998 - 1999 Federal	Local	State	Total	2000 - 2001 Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	322	273	595	0	322	273	595	0	332	283	615
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	76	13	89	0	76	13	89	0	76	13	89
5. Raw Water Treatment	0	0	0	0	0	0	0	0	0	27	38	65
6. Water Conveyance	0	0	0	0	0	0	0	0	0	6	6	12
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	12	328	53	393	38	15	23	76	12	113	39	164
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all others)	12	726	339	1,077	38	413	309	760	12	554	379	945
SUBTOTAL	12	726	449	1,187	38	413	419	870	12	554	489	1,055
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	12	726	449	1,187	38	413	419	870	12	554	489	1,055
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

Estimated Capital Costs, in Millions of Dollars[1]

Type of Facility	2002 - 2003 Federal	Local	State	Total	2004 - 2005 Federal	Local	State	Total	2006 - 2007 Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	343	292	635	0	343	292	635	0	343	292	635
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	76	14	90	0	78	14	92	0	80	14	94
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	51	51	102	0	0	0	0	0	99	99	198
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	38	186	186	410	12	484	423	919	0	0	0	0
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all other)	38	656	543	1,237	12	905	729	1,646	0	522	405	927
SUBTOTAL	38	656	653	1,347	12	905	839	1,756	0	522	515	1,037
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	38	656	653	1,347	12	905	839	1,756	0	522	515	1,037
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-12. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities*—Continued

	Estimated Capital Costs, in Millions of Dollars[1]											
	2008 - 2009				2010 - 2011				2012 - 2013			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	343	292	635	0	407	358	765	0	407	358	765
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	81	15	96	0	85	16	101	0	85	16	101
5. Major Raw Water Treatment	0	0	0	0	0	10	0	10	0	10	0	10
6. Major Water Conveyance	0	99	99	198	0	47	10	57	0	47	10	57
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	0	0	0	0	0	105	105	210	0	105	105	210
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all other)	0	523	406	929	0	654	489	1,143	0	654	489	1,143
SUBTOTAL	0	523	516	1,039	0	654	599	1,253	0	654	599	1,253
Research and Planning	—	—	—	—	—	—	—	—	—	—		
TOTAL	0	523	516	1,039	0	654	599	1,253	0	654	599	1,253
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

	Estimated Capital Costs, in Millions of Dollars[1]											
	2014 - 2015				2016 - 2017				2018 - 2019			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	407	358	765	0	407	358	765	0	407	358	765
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	87	17	104	0	88	18	106	0	88	18	106
5. Major Raw Water Treatment	0	10	0	10	0	10	0	10	0	10	0	10
6. Major Water Conveyance	0	47	10	57	0	47	10	57	0	47	10	57
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	0	105	105	210	0	105	105	210	0	105	105	210
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all other)	0	656	490	1,146	0	657	491	1,148	0	657	491	1,148
SUBTOTAL	0	656	600	1,256	0	657	601	1,258	0	657	601	1,258
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	656	600	1,256	0	657	601	1,258	0	657	601	1,258
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

*See Footnotes at end of Table.

Table V-12. Summary of Estimated Capital Costs for Future Water Quality Protection and Water Development, with Estimates of Funding Needed by Local, State, and Federal Governments for Wastewater Treatment and Municipal and Industrial Water Supply Facilities—Continued

	Estimated Capital Costs, in Millions of Dollars[1]											
	2020 - 2021				2022 - 2023				2024 - 2025			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	50	50
2. Wastewater Treatment (all others)	0	489	440	929	0	489	440	929	0	489	440	929
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	12	12
4. Wells and Facilities (all others)	0	92	19	111	0	92	19	111	0	94	19	113
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	0	0	0	0	0	0	0	0	0	0	0
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	48	48
8. Reservoir and Chloride Control[2]	0	154	143	297	0	154	143	297	0	154	143	297
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	110	110
Subtotal (all other)	0	735	602	1,337	0	735	602	1,337	0	737	602	1,339
SUBTOTAL	0	735	712	1,447	0	735	712	1,447	0	737	712	1,449
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	735	712	1,447	0	735	712	1,447	0	737	712	1,449
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

	Estimated Capital Costs, in Millions of Dollars[1]											
	2026 - 2027				2028 - 2029				2030			
Type of Facility	Federal	Local	State	Total	Federal	Local	State	Total	Federal	Local	State	Total
1. Wastewater Treatment (Hardship)	—	—	50	50	—	—	50	50	—	—	25	25
2. Wastewater Treatment (all others)	0	489	440	929	0	489	440	929	0	245	220	465
3. Wells and Facilities (Hardship)	—	—	12	12	—	—	12	12	—	—	6	6
4. Wells and Facilities (all others)	0	97	20	117	0	97	20	117	0	49	10	59
5. Major Raw Water Treatment	0	0	0	0	0	0	0	0	0	0	0	0
6. Major Water Conveyance	0	0	0	0	0	0	0	0	0	0	0	0
7. Water Supply Facilities (Hardship)	—	—	48	48	—	—	48	48	—	—	24	24
8. Reservoir and Chloride Control[2]	0	154	143	297	0	154	143	297	0	77	72	149
Subtotal (Hardship)	—	—	110	110	—	—	110	110	—	—	55	55
Subtotal (all other)	0	740	603	1,343	0	740	603	1,343	0	371	302	673
SUBTOTAL	0	740	713	1,453	0	740	713	1,453	0	371	357	728
Research and Planning	—	—	—	—	—	—	—	—	—	—	—	—
TOTAL	0	740	713	1,453	0	740	713	1,453	0	371	357	728
Rural Water Supply												
Applications	—	—	—	—	—	—	—	—	—	—	—	—
Preapplications	—	—	—	—	—	—	—	—	—	—	—	—

[1]Project costs in 1983 dollars are shown for the biennium in which it is estimated construction would be initiated.

[2]The Brazos River Authority (BRA) plans to finance BRA projects through the sale of revenue bonds, but would borrow from a State loan fund to pay interest during the first ten years on BRA bonds sold to finance construction of Millican Reservoir and the three chloride control projects in the Brazos River Basin. The BRA would then repay the State with interest. The estimates of State financial assistance include the following amounts (in millions of dollars) required by BRA, assuming 8 percent interest on the BRA bonds: 1994 = $3; 1995 = $3; 1996 = $42; 1997 = $42; 1998 = $45; 1999 = $45; 2000 = $45; 2001 = $45; 2002 = $48; 2003 = $48; 2004 = $45; 2005 = $45; 2006 = $9; 2007 = $9; 2008 = $6; 2009 = $6; 2010 = $6; 2011 = $6; 2012 = $3; 2013 = $3; 2014 = $3; 2015 = $3.

APPENDIX A

Reported 1980 Population and Municipal Water Use and Projected Population and Water Requirements for Cities and Rural Areas in Texas, Low and High Case, 1990 and 2000

APPENDIX A. REPORTED 1980 POPULATION AND MUNICIPAL WATER USE AND REQUIREMENTS FOR CITIES AND RURAL AREAS IN TEXAS, LOW AND HIGH CASE, 1990 AND 2000

RIVER BASIN: 1 CANADIAN
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BOOKER	1219	292	1440	312	1463	411	1676	372	1759	504
GRUVER	1216	293	1345	333	1345	420	1460	368	1505	477
LIPSCOMB	212	29	219	37	223	52	238	41	250	60
PERRYTON	7991	1268	7800	1407	7789	1911	7767	1436	7769	1941
SPEARMAN	3413	892	3464	923	3463	1148	3419	927	3526	1185
STRATFORD	1917	700	2052	609	2051	742	2440	741	2661	981
OTHER	6769	912	6616	1035	6653	1351	7120	1140	7410	1519
ZONE TOTAL	22737	4386	22936	4656	22987	6035	24120	5025	24880	6667

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 1 CANADIAN
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) AMARILLO	53260	11750	59087	13171	60439	17399	62415	14123	64002	18640
BORGER	15837	2503	16422	2722	16640	3840	17061	2886	17367	4066
CANADIAN	3491	1376	3671	1184	4661	1806	4696	1541	5536	2177
CHANNING	304	82	376	72	394	101	450	87	488	126
DALHART	6854	1492	8425	2265	8600	2871	9145	2499	9514	3218
DUMAS	12194	2429	15444	3131	15866	4248	17457	3618	18002	4900
FRITCH	2299	484	3040	603	3080	811	3457	693	3520	934
MIAMI	813	189	926	188	945	253	940	195	920	250
PAMPA	21396	4031	21366	3757	21243	5116	21333	3823	21269	5194
PHILLIPS	1724	371	1985	285	2011	419	2066	305	2104	448
STINNETT	2222	485	2441	405	2473	571	2586	435	2632	613
SUNRAY	1952	453	2088	472	2145	625	2173	501	2240	662
(P) VEGA	225	70	259	72	264	90	321	91	354	123
(P) WHITE DEER	1149	238	1325	276	1326	362	1483	316	1539	428
OTHER	21084	3032	19212	3272	20049	4361	17265	3170	18417	4284
ZONE TOTAL	144804	28985	156067	31875	160136	42873	162848	34283	167904	46063
BASIN TOTAL	167541	33371	179003	36531	183123	48908	186968	39308	192784	52730

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 2 RED
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) AMARILLO	95970	21283	100111	22315	108905	31351	105333	23834	115326	33588
CANYON	10724	1919	10528	2040	11992	3103	11223	2213	12906	3383
CLARENDON	2220	610	2600	664	2600	833	2718	709	2718	886
CLAUDE	1112	162	1261	218	1270	302	1366	239	1396	335
FRIONA	3809	837	4625	1088	4633	1391	5261	1261	5436	1656
HEREFORD	15853	4012	20320	4848	20917	6350	23555	5726	24620	7584
MCLEAN	1160	370	1164	319	1157	393	1163	322	1160	396
PANHANDLE	2226	461	2606	441	2608	611	2912	502	3024	718
SHAMROCK	2834	645	3030	543	3030	740	2967	542	2967	734
SILVERTON	918	105	966	127	955	187	1019	137	1041	208
TULIA	5033	1132	5439	1292	5381	1627	6536	1589	7149	2202
(P) VEGA	675	210	778	216	792	271	964	272	1064	369
WHEELER	1584	511	1908	393	1908	517	1997	421	1997	550
(P) WHITE DEER	61	12	70	15	70	19	78	17	81	23
OTHER	34579	4719	37716	5538	40091	7532	43166	6501	47364	9105
ZONE TOTAL	178758	36988	193122	40057	206309	55227	210258	44285	228249	61737

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN.

APPENDIX A. CONTINUED

RIVER BASIN: 2 RED
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ARCHER CITY	1862	487	1901	221	1966	357	1917	228	1981	364
BURKBURNETT	10668	1577	12633	1939	12716	2778	15689	2478	17119	3816
CHILDRESS	5817	1393	6268	1081	6302	1497	6366	1127	6318	1529
CHILLICOTHE	1052	200	1106	214	1094	283	1113	222	1101	291
CROWELL	1509	497	1599	389	1578	486	1652	411	1648	517
ELECTRA	3755	704	3740	746	3765	995	4361	884	4758	1274
GUTHRIE	116	13	107	13	102	19	102	12	99	19
HENRIETTA	3149	716	3191	511	3330	750	3284	537	3382	773
HOLLIDAY	1349	299	1547	201	1600	312	1683	221	1740	341
IOWA PARK	6184	1115	8229	1383	8283	1930	10479	1808	11435	2715
MATADOR	1052	266	1092	290	1070	354	1128	308	1133	383
MEMPHIS	3352	600	3607	566	3566	791	3888	627	3976	900
MONTAGUE	234	16	235	26	240	42	257	31	267	50
NOCONA	2992	640	3223	549	3286	773	3505	612	3652	875
PADUCAH	2216	524	2325	471	2290	613	2440	506	2457	669
QUANAH	3890	761	3907	521	3863	766	3888	527	3845	771
(P) SAINT JO	269	43	289	39	295	58	310	43	323	65
VERNON	12695	2494	13809	2985	13856	3896	14567	3247	14737	4242
WELLINGTON	3043	655	3450	607	3451	831	3587	647	3556	872
WICHITA FALLS	94201	17565	96745	17339	97383	23780	112809	20597	123092	30472
OTHER	32937	8170	27938	4775	28416	6198	26500	4746	27243	6204
ZONE TOTAL	192342	38735	196941	34866	198452	47509	219525	39819	233862	57142

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 2 RED
ZONE: 3

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BLOSSOM	1487	112	1627	197	1662	309	1737	214	1791	337
BONHAM	7338	1423	8025	1214	8146	1761	8605	1349	9028	2002
(P) DE KALB	1108	148	1083	142	1120	220	1115	152	1194	241
DENISON	23884	4786	24559	4732	25158	6482	25019	4960	25791	6789
(P) HONEY GROVE	99	11	100	14	102	21	106	15	111	23
HOOKS	2507	391	2704	415	2797	611	2891	457	3095	690
(P) HOWE	1657	211	2386	353	2444	520	2841	426	2929	630
(P) NEW BOSTON	927	150	1099	180	1137	260	1248	207	1336	308
(P) PARIS	12749	1924	14178	2605	14484	3602	15085	2839	15554	3938
RENO	1059	67	1159	401	1184	487	1237	439	1275	536
SHERMAN	30413	7201	33820	6440	34644	8848	36026	7022	37137	9651
(P) TEXARKANA	297	107	309	116	320	141	333	128	357	160
(P) WHITESBORO	3039	471	3453	553	3537	796	3727	614	3842	882
WHITEWRIGHT	1760	246	2099	358	2150	505	2283	402	2354	567
OTHER	46606	5477	50139	6177	51358	9238	54086	6967	56293	10483
ZONE TOTAL	134930	22725	146740	23897	150243	33801	156339	26191	162087	37237
BASIN TOTAL	506030	98448	536803	98820	555004	136537	586122	110295	624198	156116

•(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 3 SULPHUR
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) ATLANTA	190	27	246	36	254	53	283	42	297	64
BOGATA	1508	206	1771	240	1781	357	1909	269	1950	402
CLARKSVILLE	4917	602	5292	735	5322	1085	5670	813	5791	1207
COMMERCE	8136	1768	9777	1468	9947	2139	10529	1628	10974	2409
COOPER	2338	314	2670	374	2679	549	2847	405	2892	599
(P) DE KALB	1109	148	1084	142	1121	220	1117	153	1196	241
(P) HONEY GROVE	1874	216	1906	267	1935	397	2019	292	2118	444
(P) LEONARD	143	19	175	21	178	33	197	25	207	40
MAUD	1059	133	1079	140	1116	218	1122	152	1201	241
MOUNT VERNON	2025	479	2688	584	2790	788	3151	709	3378	980
(P) NAPLES	572	104	656	112	676	159	737	128	785	187
NASH	2022	203	2611	304	2701	490	2982	361	3192	594
(P) NEW BOSTON	3701	598	4391	718	4542	1038	4983	826	5335	1231
(P) PARIS	12749	1924	14178	2605	14484	3602	15085	2839	15554	3938
(P) QUEEN CITY	523	84	668	112	691	161	777	136	816	196
SULPHUR SPRINGS	12804	1408	15054	2445	15542	3534	16576	2785	17287	4028
(P) TEXARKANA	30974	11205	32339	12099	33451	14688	34789	13327	37243	16687
WAKE VILLAGE	3865	405	5357	624	5541	1005	6452	781	6907	1284
WOLFE CITY	1594	170	1688	197	1717	312	1816	220	1893	352
OTHER	61913	8050	62899	7951	65337	11864	66808	8822	70288	13197
ZONE TOTAL	154016	28063	166529	31174	171805	42692	179849	34713	189304	48321
BASIN TOTAL	154016	28063	166529	31174	171805	42692	179849	34713	189304	48321

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 4 CYPRESS
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) ATLANTA	6083	904	7863	1136	8133	1704	9064	1360	9520	2047
DAINGERFIELD	3030	508	3028	397	3122	612	3234	435	3443	686
GILMER	5167	870	5456	929	5965	1403	6030	1054	6576	1576
HUGHES SPRINGS	2196	284	2440	446	2524	625	2676	501	2811	708
JEFFERSON	2643	339	3126	399	3279	632	3375	442	3585	703
LINDEN	2443	304	3069	399	3174	619	3444	467	3617	725
LONE STAR	2036	248	2556	324	2635	505	2987	391	3180	623
(P) MARSHALL	5327	930	5325	948	5979	1453	6055	1112	7087	1762
MOUNT PLEASANT	11003	1546	11588	1428	14130	2659	14343	1832	15493	2985
(P) NAPLES	1336	245	1530	261	1578	371	1722	299	1833	437
ORE CITY	1050	134	1234	149	1349	251	1446	178	1577	297
PITTSBURG	4245	703	4481	592	4585	904	4581	626	4641	936
(P) QUEEN CITY	1225	196	1564	263	1618	377	1819	318	1911	458
WASKOM	1821	264	2056	283	2308	468	2486	359	2910	610
(P) WINNSBORO	885	145	1078	185	1120	265	1199	210	1284	308
OTHER	67702	7959	74970	9245	80904	14454	85409	11012	92455	17106
ZONE TOTAL	118192	15579	131364	17384	142403	27302	149870	20596	161923	31967
BASIN TOTAL	118192	15579	131364	17384	142403	27302	149870	20596	161923	31967

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 5 SABINE
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BIG SANDY	1258	139	1557	181	1702	309	1836	222	2002	372
CADDO MILLS	1060	107	1138	138	1158	215	1225	151	1277	240
CANTON	2845	621	4567	701	4796	1048	5981	945	6625	1477
CARTHAGE	6447	990	7059	925	8387	1644	8510	1144	9163	1827
EDGEWOOD	1413	188	1835	232	1927	369	2229	297	2469	490
EMORY	813	208	930	261	968	335	1071	310	1169	414
GLADEWATER	6548	1057	6066	829	7199	1452	6797	951	7442	1525
GRAND SALINE	2709	496	3099	552	3255	791	3570	656	3954	983
GREENVILLE	22161	5085	24150	4842	24570	6523	25997	5358	27094	7345
HALLSVILLE	1556	208	2036	283	2286	466	2610	377	3055	640
HAWKINS	1302	302	1579	210	1648	327	1796	245	1917	387
(P) HENDERSON	1148	218	1256	194	1422	312	1443	230	1535	344
KILGORE	10968	2661	9881	2036	12002	3253	11273	2387	12280	3398
LIBERTY CITY	1121	330	1136	141	1411	267	1417	181	1555	300
(P) LINDALE	1090	209	1198	233	1509	392	1562	311	1767	467
LONGVIEW	62762	9167	66421	9226	82258	16770	84135	12064	92474	19267
(P) MARSHALL	19594	3423	19588	3489	21993	5346	22273	4092	26070	6483
MINEOLA	4346	791	4827	860	5039	1225	5152	946	5499	1367
(P) OVERTON	2269	452	2420	597	2747	855	2812	712	2996	953
QUINLAN	1002	126	1076	140	1095	213	1159	154	1208	240
QUITMAN	1893	333	2464	447	2572	634	2859	532	3052	766
ROYSE CITY	1566	244	2128	346	2708	616	3019	500	3881	895
TATUM	1339	216	1375	163	1572	288	1575	191	1680	312
(P) TYLER	6	1	6	1	7	2	7	1	8	2
(P) VAN	94	19	128	23	134	32	158	29	175	43
WHITE OAK	4415	518	5777	699	7175	1334	8031	1008	8812	1678
(P) WILLS POINT	1315	137	1406	224	1477	331	1509	250	1671	386
(P) WINNSBORO	2470	409	2998	513	3129	740	3358	586	3585	860
OTHER	131291	16422	141008	17799	158379	28323	166418	21878	181958	33576
ZONE TOTAL	296801	45077	319109	46285	364525	74412	379782	56708	416373	87037

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

RIVER BASIN: 5 SABINE
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BESSMAY-BUNA	2076	315	3639	505	4156	847	4903	703	5398	1125
(P) BRIDGE CITY	4600	692	6052	780	6200	1201	6834	911	7150	1418
CENTER	5827	1775	6717	1129	7661	1785	8033	1395	8559	2042
HEMPHILL	1353	277	1647	301	1825	452	1989	379	2137	546
KIRBYVILLE	1972	429	1965	370	2244	568	2196	428	2418	628
NEWTON	1620	287	1817	332	1849	458	1948	371	2006	512
ORANGE	23628	4267	25907	4063	26542	5887	28348	4573	29657	6710
PINEHURST	3055	470	3725	467	3816	727	4284	552	4482	869
TENAHA	1005	117	1000	131	1141	224	1091	149	1162	234
TIMPSON	1164	253	1273	201	1452	324	1449	239	1544	355
(P) VIDOR	3634	367	6643	759	6806	1220	8371	975	8758	1589
WEST ORANGE	4610	834	5099	640	5224	995	5579	719	5837	1131
OTHER	55937	6586	53644	7165	57698	10977	57374	8027	60698	11939
ZONE TOTAL	110481	16669	119128	16843	126614	25665	132399	19421	139806	29098
BASIN TOTAL	407282	61746	438237	63128	491139	100077	512181	76129	556179	116135

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 6 NECHES
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALTO	1203	226	1468	289	1589	416	1718	354	1851	502
CHANDLER	1308	184	1751	228	1862	363	2042	272	2194	435
FRANKSTON	1255	238	1375	222	1583	358	1621	269	1820	420
GARRISON	1059	275	1249	259	1291	351	1371	293	1431	399
GRAPELAND	1634	192	1875	227	2292	426	2417	303	2589	493
(P) HENDERSON	10325	1960	11297	1746	12792	2808	12981	2065	13808	3093
JACKSONVILLE	12264	3019	13960	3253	15114	4503	16120	3882	17373	5313
(P) LINDALE	1090	209	1198	233	1509	392	1562	311	1767	467
NACOGDOCHES	27149	5490	36688	5589	37917	8240	42172	6661	44015	9811
(P) OVERTON	161	31	167	42	194	61	196	49	212	68
(P) PALESTINE	6807	1070	6922	1070	7971	1750	7813	1243	8775	1966
RUSK	4681	641	4811	674	5209	1068	5133	742	5532	1159
TROUP	1911	268	1724	291	2160	506	2040	356	2304	552
(P) TYLER	70502	15529	69983	12621	88187	21633	86930	16067	98321	24560
(P) VAN	1787	377	2437	431	2559	619	3009	549	3333	825
WHITEHOUSE	2172	290	2658	336	3350	642	3669	481	4150	814
OTHER	114629	13839	120982	15047	138092	24083	143466	18634	157152	28329
ZONE TOTAL	259937	43838	280545	42558	323671	68219	334260	52531	366627	79206

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 6 NECHES
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) BEAUMONT	37274	6693	38728	6290	39264	8928	40822	6768	42065	9706
BEVIL OAKS	1306	98	1382	381	1401	477	1468	414	1513	525
(P) BRIDGE CITY	3067	461	4034	520	4133	801	4557	607	4767	945
(P) CHINA	68	4	71	9	72	13	76	9	78	15
CORRIGAN	1770	367	2191	329	2704	582	2857	442	3285	721
(P) DAISETTA	942	168	2250	307	2395	483	3374	472	3874	794
DIBOLL	5227	652	10087	1299	10481	2031	12933	1724	13494	2675
FULLER SPRINGS	1470	221	1742	211	1810	337	1936	239	2020	380
(P) GROVES	3678	362	3913	451	3967	715	4121	485	4247	775
(P) GROVETON	379	60	439	54	457	85	462	58	477	91
HUDSON	1659	387	1966	240	2043	382	2185	272	2280	432
HUNTINGTON	1672	183	1969	229	2046	371	2204	267	2299	427
JASPER	6959	2065	7732	1646	8830	2453	9102	1988	10021	2840
KOUNTZE	2716	371	2750	422	3144	687	3326	525	3884	866
LUFKIN	28562	4861	34511	5489	35859	8033	38398	6366	40065	9245
LUMBERTON	2480	735	2791	338	3191	593	3449	425	4028	758
(P) NEDERLAND	477	63	600	81	608	122	673	93	694	141
PINELAND	1111	211	1058	162	1173	256	1108	179	1190	269
(P) PORT ARTHUR	2058	299	2109	307	2138	450	2240	334	2308	494
(P) PORT NECHES	7978	847	9928	1134	10065	1804	11360	1336	11706	2137
SAN AUGUSTINE	2930	672	3157	619	3261	851	3374	684	3474	930
SILSBEE	7684	1178	7448	1035	8514	1736	8266	1185	9653	2011
SOUR LAKE	1807	237	1587	185	1814	329	1668	202	1948	362
(P) VIDOR	8483	859	15508	1772	15888	2847	19543	2277	20445	3710
WOODVILLE	2821	667	3497	678	3628	939	3759	749	3867	1022
OTHER	111843	13517	117878	14826	127866	23283	132899	17445	145040	27331
ZONE TOTAL	246421	36238	279326	39014	296752	59588	316160	45545	338722	69602
BASIN TOTAL	506358	80076	559871	81572	620423	127807	650420	98076	705349	148808

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 7 NECHES-TRINITY
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) BEAUMONT	80828	14515	83982	13640	85143	19361	88521	14675	91217	21048
(P) CHINA	1283	90	1357	164	1376	256	1442	178	1486	280
GRIFFING PARK	1802	267	1930	294	1957	425	2051	319	2114	466
(P) GROVES	13412	1323	14268	1646	14465	2609	15029	1768	15486	2827
(P) NEDERLAND	16378	2172	20593	2791	20878	4186	23123	3212	23827	4858
(P) PORT ARTHUR	59193	8618	60657	8833	61496	12950	64441	9600	66404	14207
(P) PORT NECHES	5966	633	7424	848	7527	1349	8496	999	8755	1599
OTHER	14172	1690	13803	1700	13998	2618	13577	1749	14006	2729
ZONE TOTAL	193034	29308	204014	29916	206840	43754	216680	32500	223295	48014

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 7 NECHES-TRINITY
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) ANAHUAC	1748	259	1801	274	2536	551	2536	401	3429	764
WINNIE	2486	598	2770	571	3901	1057	4076	858	5511	1519
OTHER	6459	759	4930	608	6318	1100	5604	722	7221	1305
ZONE TOTAL	10693	1616	9501	1453	12755	2708	12216	1981	16161	3588
BASIN TOTAL	203727	30924	213515	31369	219595	46462	228896	34481	239456	51602

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ADDISON	5553	1634	6279	985	6461	1433	6932	1110	7234	1629
ALEDO	1027	130	1181	143	1174	218	1257	155	1266	238
ALLEN	8314	1213	12316	1835	13317	2849	16715	2565	19277	4211
ALVARADO	2701	300	2788	328	2942	537	2959	351	3352	616
ARGYLE	1111	284	1634	198	1765	328	2103	259	2489	468
ARLINGTON	160123	40239	180623	33990	185748	47023	195994	37322	203285	51918
ATHENS	10197	1375	12721	1795	13527	2788	13403	1982	14404	3066
AZLE	5822	915	6698	1081	6849	1549	7310	1212	7544	1740
BALCH SPRINGS	13746	1563	16933	1992	17424	3181	18696	2241	19509	3606
BEDFORD	20821	4233	23486	3657	24152	5330	25484	4053	26432	5922
BENBROOK	13579	2845	15316	2402	15751	3493	16620	2662	17238	3881
BLUE MOUND	2169	258	2445	293	2514	465	2653	324	2752	515
BOWIE	5610	1031	6384	980	6509	1422	7024	1117	7317	1639
BRIAR	1810	274	2035	256	2097	399	2167	279	2301	446
BRIDGEPORT	3737	822	3901	520	4110	815	4118	577	4651	953
BURLESON	11734	1503	17615	2466	18553	3803	20355	2919	22926	4776
CARROLLTON	40591	8188	43512	8091	45523	11422	50267	9516	54707	13911
CEDAR HILL	6849	1425	9204	1608	9471	2270	10163	1799	10605	2566
CELINA	1520	206	2191	307	2369	486	2973	426	3429	714
COCKRELL HILL	3262	440	3677	515	3784	776	4059	582	4236	883
COLLEYVILLE	6700	984	7557	1126	7771	1663	8199	1258	8504	1858
COPPELL	3826	673	5720	1038	5886	1450	6315	1188	6590	1668
CORINTH	1264	187	1859	225	2008	373	2393	295	2832	533
CORSICANA	21712	5107	22037	4073	25534	6378	25613	4849	26919	6845
CROWLEY	5852	777	6600	791	6787	1254	7162	882	7428	1398
DALLAS	904078	227667	896175	188723	922214	254120	989281	212762	1032468	289128
DALWORTHINGTON GARD.	1100	278	1239	153	1274	240	1345	170	1395	267
DE SOTO	15538	2834	23923	3912	24616	5625	26412	4438	27561	6421
DECATUR	4104	765	4731	763	4984	1128	5542	913	6259	1437
DENTON	48063	9882	51842	10104	55994	14551	51117	10192	60494	15992
DUNCANVILLE	27781	5461	43481	6721	44741	9823	48007	7582	50095	11167
EDGECLIFF	2695	506	3039	524	3125	742	3297	580	3420	824

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ENNIS	12110	1974	14889	1935	15541	3029	17343	2331	19684	3925
EULESS	24002	4383	27074	4337	27842	6269	29377	4837	30470	6997
EVERMAN	5387	680	6075	701	6247	1127	6592	775	6837	1248
FARMERS BRANCH	24863	7380	33077	6410	34035	8807	36519	7200	38108	9989
FARMERSVILLE	2360	413	3630	708	3925	1020	4927	988	5682	1508
FERRIS	2228	299	2706	376	2824	576	3107	442	3527	731
FLOWER MOUND	4402	650	10198	1554	11015	2394	15206	2402	17996	4011
FOREST HILL	11684	1711	13178	1668	13552	2596	14300	1858	14832	2891
FORNEY	2483	375	3064	511	3216	746	3809	644	4286	1003
FORT WORTH	385141	91788	434451	78837	446779	110100	471422	87130	488960	122138
FRISCO	3499	653	4780	701	5168	1094	6157	917	7105	1520
GAINESVILLE	14081	2834	14381	1901	15619	3079	15618	2134	17018	3431
GARLAND	138857	26202	197922	28821	203657	42888	218523	32555	228029	48786
GLENN HEIGHTS	1033	224	1166	282	1200	368	1284	319	1343	421
GRAND PRAIRIE	71462	10998	60412	7985	62158	12254	66577	8950	69429	13843
GRANDVIEW	1205	157	1546	187	1631	303	1857	229	2104	396
GRAPEVINE	11801	2417	13322	1567	13700	2502	14455	1716	14994	2755
GUN BARREL CITY	2118	595	2836	337	3016	554	3306	400	3553	661
HALTOM CITY	29014	4544	32727	4032	33656	6334	35512	4495	36833	7055
HEATH	1459	279	1813	219	2357	438	2332	287	3039	572
HICKORY CREEK	1422	115	2091	253	2259	420	2692	332	3186	600
HIGHLAND PARK	8909	3884	9663	3182	9943	3920	10668	3549	11132	4427
HIGHLAND VILLAGE	3246	599	4776	578	5158	959	6145	757	7272	1368
(P) HOWE	415	53	597	88	612	130	711	107	733	158
HUBBARD	1676	213	1829	232	1870	358	1937	252	1990	388
HURST	31420	6028	35441	5002	36447	7512	38457	5557	39888	8355
HUTCHINS	2837	429	3696	505	3803	767	4080	567	4258	868
IRVING	109943	24781	152081	22657	156488	33480	167910	25767	175215	38272
ITALY	1306	125	1472	170	1536	277	1626	195	1845	341
(P) ITASCA	80	12	93	16	95	22	101	18	104	25
JACKSBORO	4000	726	4426	739	4508	1045	4777	819	4923	1164
KAUFMAN	4658	755	5898	813	6191	1255	7241	1022	8147	1679

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) KEENE	605	79	831	114	877	178	1001	140	1134	232
KELLER	4156	747	4686	871	4819	1209	5086	974	5275	1353
KEMP	1035	166	1188	144	1247	232	1414	174	1591	299
KENNEDALE	2594	477	2924	419	3007	626	3173	462	3291	693
KERENS	1582	250	1543	187	1788	332	1777	219	1868	352
LAKE DALLAS	3177	565	7560	1059	8165	1674	11232	1623	13292	2784
LAKE WORTH VILLAGE	4394	660	4955	577	5096	925	5377	644	5577	1031
LANCASTER	14807	2157	17726	2264	18240	3514	19571	2543	20422	3980
(P) LEONARD	1278	176	1573	192	1597	299	1769	224	1856	356
LEWISVILLE	24273	4369	44507	8226	48072	12008	63107	11876	74684	18906
LUCAS	1371	350	2031	243	2196	406	2756	336	3179	595
MABANK	1443	267	1835	509	1928	661	2272	641	2543	883
MALAKOFF	2082	279	2294	321	2439	500	2674	389	2874	605
MANSFIELD	8092	1377	9133	1176	9393	1821	9912	1310	10284	2027
MCKINNEY	16256	2458	24369	3194	26349	5165	33072	4482	38142	7648
MESQUITE	67053	9915	91541	11792	94193	18253	101068	13246	105465	20674
MIDLOTHIAN	3219	437	4712	718	4918	1069	5977	937	6784	1505
MUENSTER	1408	280	1552	259	1686	391	1734	297	1889	446
MURPHY	1150	234	1704	202	1842	338	2312	280	2666	496
NORTH RICHLAND HILLS	30592	5837	34507	4754	35486	7195	37444	5285	38837	8005
OVILLA	1067	71	1291	156	1347	250	1522	187	1723	324
PALMER	1187	150	1438	174	1501	279	1701	210	1931	363
PANTEGO	2431	607	2740	703	2818	906	2974	773	3085	1002
PARKER	1098	388	1626	193	1758	323	2208	267	2546	473
PILOT POINT	2211	385	2168	279	2342	454	2047	273	2422	480
PLANO	72331	16183	107161	18126	115869	27126	145437	25088	167731	39832
PRINCETON	3408	226	5853	813	6329	1290	8612	1225	9932	2058
RED OAK	1882	234	2281	309	2381	477	2698	375	3062	624
RENO	1174	117	1350	228	1342	314	1437	249	1448	345
RICHARDSON	72496	16773	112956	19232	116757	27464	125748	21973	132556	31775
RICHLAND HILLS	7977	1580	8997	1330	9252	1969	9763	1465	10126	2178
RIVER OAKS	6890	2108	7771	1158	7991	1710	8432	1294	8746	1910

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ROCKWALL	5939	1316	8068	1283	10499	2352	10615	1736	13839	3162
ROWLETT	8696	1207	12246	1756	12967	2702	13775	2021	14828	3139
SACHSE	1640	261	1851	344	1906	478	2042	389	2134	545
SAGINAW	5736	892	6468	978	6652	1438	7019	1077	7280	1590
(P) SAINT JO	802	131	865	115	882	175	925	127	964	195
SANGER	2574	309	3015	375	3257	617	3399	434	4022	775
SANSOM PARK VILLAGE	3921	390	4422	505	4547	815	4798	554	4976	897
SEAGOVILLE	7304	976	8342	1308	8584	1904	9210	1475	9611	2164
SOUTHLAKE	2808	388	3168	454	3259	679	3440	513	3571	764
SPRINGTOWN	1658	261	1861	306	1850	425	1975	334	1990	466
SUNNYVALE	1404	353	1587	192	1633	304	1752	216	1828	344
TERRELL	13225	2543	13008	2594	13654	3609	13862	2842	15596	4210
THE COLONY	11586	1838	17047	2139	18412	3506	21934	2825	25958	5030
TOOL	1591	354	2130	258	2265	421	2484	306	2669	502
TRINIDAD	1130	247	1420	359	1510	480	1497	387	1609	521
UNIVERSITY PARK	22254	6024	24205	5314	24906	7086	26723	5927	27886	7997
VAN ALSTYNE	1860	184	2077	242	2128	386	2184	262	2251	416
WATAUGA	10284	1214	11599	1403	11928	2218	12586	1551	13054	2457
WAXAHACHIE	14624	2747	16414	2445	17132	3665	18367	2819	20847	4554
(P) WEATHERFORD	11445	2366	13136	2148	13059	2984	13986	2334	14090	3267
WESTWORTH VILLAGE	3651	613	4117	609	4234	901	4467	670	4633	996
WHITE SETTLEMENT	13508	1934	15236	2253	15668	3335	16533	2537	17148	3746
(P) WHITESBORO	158	24	179	29	183	41	193	32	199	46
WILLOW PARK	1113	246	1279	155	1272	237	1363	168	1373	258
(P) WILLS POINT	1316	137	1408	224	1479	331	1510	250	1672	386
WILMER	2367	241	2534	290	2607	467	2796	332	2918	536
WYLIE	3152	576	5183	610	5604	1023	7035	851	8113	1509
OTHER	242976	33002	315162	41705	334121	62399	388582	52933	433147	82850
ZONE TOTAL	3045531	650951	3555282	609214	3694245	868893	4020862	701474	4286608	1020318

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BUFFALO	1507	326	1730	258	2022	433	2145	332	2217	487
CENTERVILLE	799	194	821	121	960	204	956	147	989	216
CROCKETT	7405	1190	8736	1204	10678	2165	11132	1584	11924	2471
ELKHART	1317	251	1400	168	1612	298	1664	203	1869	350
FAIRFIELD	3505	627	4382	717	5431	1241	5942	998	6393	1490
(P) HUNTSVILLE	20346	3362	28043	4837	29697	7052	34521	6148	37620	9144
MADISONVILLE	3660	833	4443	771	4613	1101	4857	865	5020	1220
(P) MEXIA	2128	362	2593	427	2593	595	2757	469	2757	649
(P) PALESTINE	9141	1437	9295	1437	10704	2350	10492	1669	11784	2640
(P) TEAGUE	1017	161	1142	170	1415	303	1446	224	1555	341
WORTHAM	1187	213	1239	229	1536	384	1519	293	1634	421
OTHER	51270	6429	53912	7381	61218	11712	63657	9024	68759	13499
ZONE TOTAL	103282	15385	117736	17720	132479	27838	141088	21956	152521	32928

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 8 TRINITY
ZONE: 3

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
AMES	1155	100	1557	188	1658	308	2046	252	2350	442
(P) ANAHUAC	92	13	94	14	133	29	133	21	180	40
(P) COLDSPRING	455	123	596	131	682	194	726	164	793	231
(P) DAISETTA	235	41	561	77	597	120	841	118	966	198
DAYTON	4908	709	6754	840	7191	1361	8825	1137	10134	1964
(P) GROVETON	883	139	1023	125	1065	199	1078	136	1111	213
LIBERTY	7945	1335	9663	1559	10288	2328	12171	2004	13976	3209
LIVINGSTON	4928	919	5420	917	6690	1566	6650	1162	7646	1833
(P) MONT BELVIEU	174	40	290	52	408	100	470	86	635	158
OLD RIVER-WINFREE	1058	102	1057	128	1489	277	1490	184	2014	379
SHEPHERD	1674	197	1995	1086	2283	1391	2431	1356	2656	1654
TRINITY	2620	483	3626	638	3773	909	4082	750	4210	1047
OTHER	41078	4935	50565	6232	57515	10203	66098	8515	75847	13964
ZONE TOTAL	67205	9136	83201	11987	93772	18985	107041	15885	122518	25332
BASIN TOTAL	3216018	675472	3756219	638921	3920496	915716	4268991	739315	4561647	1078578

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 9 TRINITY-SAN JACINTO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) BARRETT	33	3	32	4	33	6	31	4	33	6
(P) BAYTOWN	56581	8627	73263	11243	76725	16759	85870	13370	91939	20288
(P) CROSBY	16	3	32	6	34	9	44	9	47	13
(P) HIGHLANDS	643	55	685	111	717	163	795	133	851	197
MCNAIR	2267	379	2733	435	2862	641	3172	522	3396	780
(P) MONT BELVIEU	1556	359	2596	468	3656	897	4203	772	5683	1413
OTHER	19088	2244	24553	3180	27192	4982	31015	4188	34801	6610
ZONE TOTAL	80184	11670	103894	15447	111219	23457	125130	18998	136750	29307
BASIN TOTAL	80184	11670	103894	15447	111219	23457	125130	18998	136750	29307

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 10 SAN JACINTO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) BARRETT	3168	372	3027	363	3170	586	3020	372	3233	608
(P) BAYTOWN	342	52	442	68	463	101	518	81	555	122
BELLAIRE	14950	3799	18240	3596	19102	5007	21171	4245	22667	6018
BUNKER HILL VILLAGE	3750	838	4901	961	5133	1340	5482	1087	5869	1545
CLEVELAND	5977	908	6533	929	6956	1441	7378	1091	8472	1803
(P) COLDSPRING	114	30	149	33	170	48	182	41	199	58
CONROE	18034	4497	28169	5553	30697	8046	37326	7610	42515	11429
(P) CROSBY	1504	298	3115	621	3262	862	4144	836	4437	1183
(P) DEER PARK	9802	1465	15905	2387	16656	3582	20504	3124	21953	4771
GALENA PARK	9879	1116	11794	1374	12351	2241	13689	1641	14656	2709
HEDWIG VILLAGE	2506	549	4099	1028	4293	1356	4827	1227	5168	1650
(P) HIGHLANDS	5793	496	6176	1003	6468	1471	7169	1197	7675	1780
(P) HOUSTON	1575675	349851	1811644	355128	1901619	496310	2030707	404894	2177404	575606
HUMBLE	6729	1365	10190	1803	10671	2582	13051	2368	13973	3443
HUNTERS CREEK VIL.	4215	924	5228	1142	5475	1552	5861	1300	6275	1799
(P) HUNTSVILLE	3590	592	4948	854	5240	1244	6090	1085	6637	1613
JACINTO CITY	8953	1471	10843	1470	11355	2277	12585	1762	13474	2762
JERSEY VILLAGE	4084	671	5035	603	5273	975	5844	714	6257	1170
KATY	5660	915	8343	1289	8996	1975	10763	1712	11810	2646
(P) MISSOURI CITY	13609	2287	18679	3222	24630	5849	28105	5006	34643	8420
OAK RIDGE NORTH	2504	601	3906	473	4257	792	5176	638	5896	1110
PANORMA VILLAGE	1186	298	1850	224	2016	375	2451	302	2792	525
(P) PASADENA	88921	14916	112348	16108	117655	24513	130028	19080	139215	29473
PATTON VILLAGE	1050	172	1638	198	1785	332	2170	267	2472	465
PINEY POINT VILLAGE	2958	647	3446	741	3609	1011	3827	832	4097	1156
SHELDON	1995	281	4218	619	4417	935	5620	850	6017	1301
SHENANDOAH	1793	252	2797	1426	3048	1751	3707	1939	4222	2483
SOUTH HOUSTON	13293	2208	16429	2429	17205	3662	18603	2813	19917	4306
SOUTHSIDE PLACE	1366	249	1723	461	1804	600	2000	542	2141	719
SPRING VALLEY	3353	483	4040	588	4231	891	4689	693	5020	1068
(P) STAFFORD	1790	299	2022	397	2833	739	2875	583	3670	983
TOMBALL	3996	633	5407	727	5662	1129	6517	898	6977	1415

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 10 SAN JACINTO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
WALLER	1241	273	1234	203	1316	302	1200	203	1359	318
WEST UNIVERSITY PL.	12010	2416	14082	2524	14747	3601	16343	2984	17498	4332
WILLIS	1674	291	3092	485	3370	747	4098	670	4668	1067
OTHER	531772	80291	764935	102460	810625	153192	967819	134743	1053979	205956
ZONE TOTAL	2369236	476806	2920627	513490	3080560	733417	3415539	609430	3687812	887812
BASIN TOTAL	2369236	476806	2920627	513490	3080560	733417	3415539	609430	3687812	887812

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 11 SAN JACINTO-BRAZOS
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALVIN	16515	2209	23727	3322	26340	5399	30690	4366	34364	7121
ANGLETON	13929	1814	15831	2146	17574	3524	18585	2581	20810	4242
BROOKSIDE	1453	140	2337	322	2594	526	2953	417	3306	681
CLUTE	9577	1272	11402	1507	12658	2495	13860	1863	15519	3094
DANBURY	1357	201	1675	229	1859	375	2060	288	2307	473
(P) DEER PARK	12846	1921	20843	3129	21828	4694	26871	4094	28770	6252
DICKINSON	7505	2070	10924	2423	11214	3216	12620	2841	13406	3889
EL LAGO	3129	446	3858	527	4040	815	4478	627	4794	983
(P) FREEPORT	9223	1800	11141	2334	12368	3394	13706	2948	15347	4298
FRIENDSWOOD	10719	2223	18432	2849	18922	4154	24189	3793	25695	5699
GALVESTON	61902	13695	66829	14298	68604	19135	75429	16729	80125	22976
HITCHCOCK	6655	1155	6892	1266	7075	1759	7581	1435	8053	2048
(P) HOUSTON	19482	4307	21218	4160	23511	6136	24263	4838	26921	7117
KEMAH	1304	393	2437	762	2502	944	3163	1006	3360	1287
LA MARQUE	15372	2200	15328	2266	15735	3349	15998	2437	16994	3693
LA PORTE	17053	2435	23681	3608	24799	5389	29381	4608	31457	6977
(P) LAKE JACKSON	18145	2509	21264	2477	23606	4284	25302	3033	28331	5236
LEAGUE CITY	16578	2104	29387	3786	30168	5846	38403	5033	40794	7997
MANVEL	3549	249	4381	530	4864	904	5390	664	6035	1136
(P) MISSOURI CITY	10924	1836	13413	2314	19771	4695	21172	3771	27809	6760
NASSAU BAY	4526	1244	9120	2544	9551	3284	12206	3432	13068	4523
OYSTER CREEK	1473	147	1818	255	2018	414	2237	321	2505	522
(P) PASADENA	23639	3964	29866	4282	31277	6516	34567	5072	37009	7835
PEARLAND	13248	2064	23300	3184	25774	5197	32414	4538	36197	7420
RICHWOOD	2591	235	4011	472	4453	813	5370	650	6013	1118
SANTA FE	5413	699	6056	936	6217	1365	6835	1087	7261	1627
SEABROOK	4670	1017	9834	1983	10298	2745	13085	2697	14010	3798
SHOREACRES	1260	288	2317	285	2426	457	2775	351	2971	569
(P) STAFFORD	2965	497	3184	624	4694	1225	4629	939	6080	1628
(P) SUGAR LAND	8227	1570	9038	1762	13322	3462	13989	2774	18374	4837
TAYLOR LAKE VILLAGE	3669	698	4523	547	4737	881	5250	647	5621	1058
TEXAS CITY	41403	5886	45122	6924	46321	10118	49870	7876	52974	11808

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 11 SAN JACINTO-BRAZOS
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
WEBSTER	2405	788	4693	1220	4915	1597	6085	1615	6515	2153
OTHER	164092	22753	195580	26780	222833	43792	248930	35581	284115	57882
ZONE TOTAL	536798	86829	673462	106053	738868	162899	834336	134952	926910	208737
BASIN TOTAL	536798	86829	673462	106053	738868	162899	834336	134952	926910	208737

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ABERNATHY	2904	485	3145	560	3210	781	3373	616	3570	884
ANTON	1180	252	1326	302	1351	395	1430	327	1471	432
BOVINA	1499	501	1719	520	1722	633	1896	584	1959	731
CROSBYTON	2289	444	2627	394	2636	567	2842	436	2895	632
DIMMITT	5019	1225	6212	1719	6305	2154	7179	2026	7484	2599
EARTH	1512	332	1881	392	1904	520	2122	452	2166	602
FARWELL	1354	351	1455	380	1457	475	1585	419	1637	539
FLOYDADA	4193	750	4659	788	4621	1082	5269	915	5510	1315
HALE CENTER	2297	416	2457	410	2499	579	2761	470	2926	688
HART	1008	186	1072	130	1088	202	1162	143	1211	228
IDALOU	2348	405	3090	460	3188	682	3659	557	3856	838
LEVELLAND	13809	2567	17008	2820	17331	3999	19028	3176	19562	4536
LITTLEFIELD	7409	1486	8534	1654	8637	2235	9254	1835	9445	2486
LOCKNEY	2334	372	2516	409	2495	567	2842	471	2972	686
LORENZO	1394	266	1593	257	1599	362	1743	287	1775	408
LUBBOCK	173979	34679	203176	38690	209617	53535	227450	44331	239724	62298
MORTON	2674	410	3037	575	3041	773	3428	664	3582	927
MULESHOE	4842	1227	5421	1251	5379	1591	6138	1444	6426	1929
OLTON	2235	427	2640	695	2672	877	2923	783	2983	992
PETERSBURG	1633	266	1827	303	1858	429	2101	360	2227	526
PLAINVIEW	22187	5039	25595	5103	26036	6883	29513	5984	31277	8373
POST	3961	1206	4102	478	4111	746	4470	541	4677	870
RALLS	2422	343	2630	386	2639	559	2848	427	2901	624
REESE AFB	1921	707	1862	503	1921	643	1823	496	1921	648
SHALLOWATER	1932	365	2554	478	2635	664	3044	580	3208	819
SLATON	6804	919	6702	901	6914	1379	6840	942	7209	1462
SUDAN	1091	430	1145	139	1159	216	1196	147	1221	230
TAHOKA	3262	614	3599	500	3575	729	4060	578	4241	879
WOLFFORTH	1701	228	2501	314	2580	491	3086	394	3252	627
OTHER	65400	7743	57062	7752	58034	10524	57488	8145	60171	11354
ZONE TOTAL	346593	64641	383147	69263	392214	95272	422553	78530	443459	110162

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ABILENE	98315	22877	111922	19557	114793	27517	120703	21498	124928	30366
ALBANY	2450	591	2906	531	2906	719	3008	563	3008	758
ANSON	2831	587	3304	625	3384	860	3527	683	3597	931
ASPERMONT	1357	280	1515	288	1515	387	1449	282	1449	377
BAIRD	1696	335	1890	409	1993	560	2151	475	2351	672
BENJAMIN	257	39	263	39	258	55	261	40	259	56
BRECKENRIDGE	6921	1632	7222	1335	7916	1977	8041	1522	8512	2164
DICKENS	409	58	484	60	481	91	517	65	509	97
HAMLIN	3248	962	3607	699	3694	956	3733	744	3807	1006
HASKELL	3782	612	3988	491	3911	736	3999	502	3904	743
JAYTON	638	149	655	106	655	148	588	96	588	134
KNOX CITY	1546	295	1591	201	1564	300	1616	215	1602	318
MERKEL	2493	566	2729	404	2799	596	2932	447	3035	660
MUNDAY	1738	327	1811	347	1780	457	1846	360	1830	476
ROBY	814	129	842	187	835	239	867	194	867	251
ROSCOE	1628	183	1904	247	1924	375	2045	270	2080	410
ROTAN	2284	419	2315	407	2295	553	2343	425	2345	578
RULE	1015	148	967	235	948	292	934	229	912	283
SEYMOUR	3657	786	3782	771	3782	1017	3535	740	3535	970
SPUR	1690	322	1736	333	1726	443	1722	338	1697	443
STAMFORD	4542	1175	4911	929	5027	1278	5064	987	5162	1341
SWEETWATER	12242	3623	12645	3555	12777	4422	12974	3720	13193	4640
THROCKMORTON	1174	139	1190	200	1190	277	1230	209	1230	289
TYE	1394	128	1553	188	1593	296	1676	207	1735	326
OTHER	36441	7311	34262	4244	35040	5806	34955	4519	35985	6178
ZONE TOTAL	194562	43673	209994	36388	214786	50357	221716	39330	228120	54467

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 3

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BELLMEAD	7569	996	9914	1155	10761	1953	10603	1259	11703	2150
BEVERLY HILLS	2083	614	2539	702	2756	942	2625	735	2897	999
(P) BRUCEVILLE-EDDY	1092	202	1179	143	1280	238	1205	148	1330	250
CLEBURNE	19218	3855	24266	4240	25605	6138	29157	5226	33027	8065
CLIFTON	3063	677	3472	626	3577	877	3860	718	4062	1019
DUBLIN	2723	391	2823	414	2896	613	2873	434	2985	645
GLEN ROSE	2075	408	2188	294	2471	493	2528	348	2830	574
GRAHAM	9170	2013	10509	1954	10876	2729	11409	2173	11811	3016
GRANBURY	3332	685	2424	451	3524	884	3836	730	4943	1262
HEWITT	5247	844	5670	686	6155	1144	5791	714	6392	1203
HILLSBORO	7397	1012	8025	1303	8204	1866	8428	1407	8658	2008
(P) ITASCA	1520	234	1778	305	1818	430	1933	340	1986	478
JOSHUA	1470	277	1886	228	1990	370	2266	279	2567	483
(P) KEENE	2408	316	3311	456	3494	708	3988	558	4517	926
LACY-LAKEVIEW	2752	639	3170	437	3441	698	3283	467	3624	751
MART	2324	669	2458	526	2668	744	2462	535	2717	767
MCGREGOR	4513	837	4517	678	4903	1054	4613	708	5092	1112
MERIDIAN	1330	115	1544	195	1591	305	1725	226	1815	356
MINERAL WELLS	14468	4242	16104	2597	16634	3764	16458	2710	17429	4002
MOODY	1385	159	1651	194	1792	327	1731	211	1911	357
NORTHCREST	1944	173	2984	348	3239	588	3388	406	3739	691
OLNEY	4060	931	4713	1130	4877	1486	5078	1251	5257	1637
PALO PINTO	442	76	466	55	482	88	530	64	561	104
ROBINSON	6074	649	8609	984	9345	1675	9806	1131	10823	1952
STEPHENVILLE	11881	2630	14350	2925	14721	3958	16144	3382	16776	4604
VALLEY MILLS	1236	173	1398	262	1441	363	1423	279	1497	391
WACO	101261	29618	105489	26232	114504	35913	104970	26691	115859	36987
(P) WEATHERFORD	604	124	693	113	689	157	738	123	743	172
WEST	2485	423	2655	390	2882	610	2659	399	2935	631
WHITNEY	1631	163	2130	293	2178	442	2423	347	2490	519
WOODWAY	7091	1695	11207	1833	12165	2780	13012	2157	14362	3314
OTHER	98638	12946	108990	14089	121553	22034	129055	17290	144153	26984
ZONE TOTAL	332486	68786	373112	66238	404512	96371	410000	73446	451491	108409

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 4

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BARTLETT	1567	188	1774	220	2210	418	2459	317	3158	612
BELTON	10660	1971	18275	2764	18884	4082	23124	3600	26167	5774
CAMERON	5721	1319	6654	1327	6846	1810	7307	1498	7621	2057
CEDAR PARK	3474	647	3986	496	5941	1125	6357	812	9153	1763
CISCO	4517	1113	4590	987	4607	1290	4555	1005	4516	1290
COMANCHE	4075	634	4505	752	4531	1051	4784	815	4876	1147
COPPERAS COVE	19469	2943	42049	6264	43767	9364	54593	8317	60665	13183
DE LEON	2478	347	2699	396	2714	575	2882	433	2938	632
EASTLAND	3747	1383	4005	1270	4020	1536	4085	1313	4050	1565
FORT HOOD	31238	8919	30138	7630	31238	9938	27819	7198	31238	10113
GATESVILLE	6260	1009	8699	1393	9054	2038	9250	1513	10279	2349
GEORGETOWN	9468	3118	10785	2839	16076	5276	16321	4442	23500	7923
GORMAN	1258	190	1381	203	1386	293	1398	213	1386	301
GRANGER	1236	485	1607	466	2396	851	2563	764	3691	1340
HAMILTON	3189	557	3295	635	3387	873	3425	671	3404	888
HARKER HEIGHTS	7345	1263	8473	1670	8756	2295	10453	2108	11829	3154
HICO	1375	243	1377	167	1416	263	1416	174	1407	265
KILLEEN	46296	6258	53418	7838	55199	11686	65900	9965	74573	16122
LAMPASAS	6165	1252	6758	1658	8351	2591	8675	2186	11781	3735
LEANDER	2179	179	2500	426	3726	876	3987	697	5741	1376
LITTLE RIVER-ACADEMY	1155	230	1915	232	1979	368	2363	291	2674	503
MORGANS POINT RESORT	1082	162	1794	229	1854	357	2214	290	2505	491
NOLANVILLE	1308	136	2169	262	2241	417	2676	330	3028	570
RANGER	3142	788	3142	933	3153	1141	3113	952	3086	1144
RISING STAR	1204	164	1323	193	1328	280	1364	206	1352	292
ROCKDALE	5611	1517	6999	949	7201	1444	8020	1114	8364	1705
ROGERS	1242	181	2158	326	2230	482	2739	430	3100	688
ROUND ROCK	11812	2753	17138	2688	25545	5666	30860	4978	44435	10054
TAYLOR	10619	1724	8031	1142	11971	2481	12808	1894	18443	3925
TEMPLE	42483	8411	49018	9115	50652	12709	60472	11515	68431	17477
THORNDALE	1300	148	1631	193	1680	309	1883	232	1966	370
TROY	1353	158	2243	271	2318	431	2768	341	3132	589
OTHER	114727	13651	106500	13291	130180	22325	143006	18590	180173	32015
ZONE TOTAL	368755	64041	421029	69225	476837	106641	535639	89204	642662	145412

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 5

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ANDERSON	370	42	350	42	406	75	401	49	450	85
BREMOND	1025	92	1133	137	1160	216	1196	147	1221	230
BRENHAM	10966	2191	13146	2400	14600	3614	16019	2997	17861	4502
(P) BRUCEVILLE-EDDY	9	1	9	1	9	2	9	1	9	2
BRYAN	44337	8638	53357	10579	60996	16056	60416	12317	65784	17685
CALDWELL	2953	768	4127	652	4343	968	5190	843	5639	1282
CALVERT	1732	330	1945	288	1991	424	2011	320	2053	460
COLLEGE STATION	37272	9752	59361	16025	67859	22728	79084	21969	86110	29515
FRANKLIN	1349	241	1675	263	1715	380	1882	310	1921	441
(P) GIDDINGS	986	213	1221	278	1471	430	1497	350	1802	539
GROESBECK	3373	535	4239	603	4239	878	4620	678	4620	978
HEARNE	5418	1672	6465	1600	6619	2069	7070	1806	7217	2312
LEXINGTON	1065	189	1232	167	1484	298	1467	204	1767	360
MARLIN	7099	1239	7920	1615	7958	2139	8280	1734	8279	2272
(P) MEXIA	4966	844	6054	997	6054	1390	6434	1095	6434	1513
NAVASOTA	5971	606	6778	949	7860	1611	8323	1212	9347	1968
ROSEBUD	2076	265	2442	339	2454	500	2629	380	2629	551
SOMERVILLE	1814	190	2613	334	2749	530	3355	443	3645	719
(P) TEAGUE	2373	376	2665	397	3303	707	3374	522	3630	797
OTHER	65350	7690	69434	8831	75744	13460	77006	10200	83141	15259
ZONE TOTAL	200504	35874	246166	46497	273014	68475	290263	57577	313559	81470

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 12 BRAZOS
ZONE: 6

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BELLVILLE	2860	662	3145	574	3848	953	4034	755	4868	1227
(P) BRAZORIA	909	109	1111	139	1233	235	1383	177	1549	298
BROOKSHIRE	2175	338	2762	452	2953	675	3373	571	3855	902
(P) FREEPORT	1712	334	2067	433	2295	630	2543	547	2848	798
HEMPSTEAD	3456	552	4788	735	5118	1118	6238	999	7128	1605
(P) LAKE JACKSON	957	132	1121	131	1245	226	1334	160	1494	276
(P) NEEDVILLE	567	88	406	68	598	139	632	108	830	196
PRAIRIE VIEW	3993	801	5541	943	5923	1393	6849	1189	7827	1867
RICHMOND	9692	1473	11224	1810	16544	3743	16532	2741	21715	5011
ROSENBERG	17995	2340	15057	1872	22195	4202	17546	2241	23046	4440
SEALY	3875	638	4644	681	5682	1203	6255	953	7548	1640
(P) SUGAR LAND	599	114	657	128	969	252	1018	202	1337	352
(P) WEST COLUMBIA	3083	450	3771	494	4186	821	4640	629	5195	1042
OTHER	34996	5351	40825	6561	53390	12004	59371	9621	74275	16896
ZONE TOTAL	86869	13382	97119	15021	126179	27594	131748	20893	163515	36550
BASIN TOTAL	1529769	290397	1730567	302632	1887542	444710	2011919	358980	2242806	536470

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 13 BRAZOS-COLORADO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BAY CITY	17837	3156	22223	4008	23362	5731	26884	4969	29076	7263
(P) BRAZORIA	2116	253	2585	324	2870	547	3222	411	3608	695
(P) EAGLE LAKE	1962	370	2246	342	2297	499	2475	388	2568	570
EAST BERNARD	1715	238	3036	418	3118	632	3947	561	4171	864
(P) FREEPORT	2511	489	3033	635	3367	924	3731	802	4178	1170
JONES CREEK	2634	404	5153	646	5720	1089	7339	945	8218	1593
(P) NEEDVILLE	850	133	608	101	896	208	948	162	1245	294
SWEENY	3538	472	4281	585	4753	958	5267	749	5898	1222
VAN VLECK	1167	114	2554	298	2685	487	3499	423	3785	704
WALLIS	1138	163	2105	321	2575	560	3090	491	3728	835
(P) WEST COLUMBIA	1026	150	1255	164	1393	273	1543	209	1728	346
(P) WHARTON	8245	1145	11137	1572	11437	2357	13357	1945	14114	2972
OTHER	36983	4347	40168	5208	46270	8924	49412	6768	57026	11450
ZONE TOTAL	81722	11434	100384	14622	110743	23189	124714	18823	139343	29978
BASIN TOTAL	81722	11434	100384	14622	110743	23189	124714	18823	139343	29978

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 14 COLORADO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ANDREWS	11061	2788	12496	2813	12849	3728	13442	3087	13833	4075
BIG SPRING	24804	8655	25959	5786	26379	7594	27462	6214	28362	8260
BROWNFIELD	10387	2212	11389	2028	11479	2790	12192	2199	12464	3058
COAHOMA	1069	228	1156	196	1175	275	1249	218	1290	309
DENVER CITY	4704	980	5499	1103	5658	1502	5978	1219	6140	1651
GARDEN CITY	323	50	342	69	346	92	348	72	347	94
LAMESA	11790	1923	12298	2080	12253	2869	13733	2354	14509	3429
MIDLAND	70525	17374	84129	18093	94318	26412	89220	19488	101764	28840
ODESSA	90027	21568	104596	18863	113899	27941	111736	20526	123457	30700
O'DONNELL	1200	99	1201	138	1194	215	1324	157	1385	254
PLAINS	1457	188	1728	277	1778	400	1921	312	1973	449
SEAGRAVES	2596	483	2991	647	3055	859	3144	690	3181	905
SEMINOLE	6080	1587	6452	1684	6591	2148	6688	1775	6766	2236
STANTON	2314	406	2593	369	2640	547	2921	429	3063	648
SUNDOWN	1511	491	1754	540	1787	667	1946	610	2000	757
OTHER	66344	8732	84539	12001	90456	16813	97094	14136	105762	20127
ZONE TOTAL	306192	67764	359122	66687	385857	94852	390398	73486	426296	105792

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 14 COLORADO
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BALLINGER	4207	759	4340	846	4344	1129	4397	882	4396	1167
BANGS	1716	333	2224	419	2323	588	2800	543	3082	797
BIG LAKE	3404	781	4360	982	4538	1317	5059	1156	5306	1557
BRADY	5969	2154	6439	1868	6469	2297	6796	2025	6898	2503
BRONTE VILLAGE	987	243	1032	125	1044	194	1021	126	1005	189
BROWNWOOD	19396	6224	20754	5975	21681	7650	23657	6943	26039	9334
CLYDE	2562	317	3416	436	3603	694	4205	551	4597	901
COLEMAN	5960	1416	6283	1267	6282	1675	6436	1341	6436	1759
COLORADO CITY	5405	1590	5586	1477	5614	1849	5635	1515	5616	1875
CROSS PLAINS	1240	211	1213	190	1279	284	1262	204	1380	312
EARLY	2313	453	3229	517	3373	759	4273	704	4703	1080
EDEN	1294	257	1356	246	1354	334	1332	248	1299	326
ELDORADO	2061	534	2428	367	2505	542	2649	412	2702	596
GAIL	172	35	165	23	161	33	163	24	163	35
GOLDTHWAITE	1783	519	2222	655	2265	814	2480	750	2552	938
MENARD	1697	363	1670	333	1645	435	1608	328	1554	418
MERTZON	687	53	691	79	724	130	719	83	694	125
PAINT ROCK	256	60	402	99	401	125	448	110	437	136
ROBERT LEE	1202	139	1465	361	1482	461	1531	386	1508	478
SAN ANGELO	73240	20858	70872	13734	81763	21156	80346	15930	86124	22671
SAN SABA	2847	866	2831	634	2827	817	2947	680	3027	895
SANTA ANNA	1535	366	1751	424	1751	537	1859	460	1858	581
SNYDER	12705	2619	14680	2828	15103	3891	17357	3402	18794	4905
STERLING CITY	915	193	1001	183	1018	252	1129	209	1195	299
WINTERS	3061	407	3321	792	3324	1009	3443	837	3442	1060
OTHER	57484	6904	58970	7355	62187	10183	65538	8522	69552	11783
ZONE TOTAL	214098	48654	222701	42215	239060	59155	249090	48371	264359	66720

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 14 COLORADO
ZONE: 3

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
AUSTIN	345496	78564	438197	91297	464459	126944	534497	113157	594815	164570
BASTROP	3789	868	4411	1181	5115	1702	5576	1530	6588	2236
BURNET	3410	736	4306	921	4583	1278	5092	1118	5633	1603
COLUMBUS	3923	853	4328	824	4426	1130	4747	925	4924	1280
(P) EAGLE LAKE	1959	369	2242	342	2293	498	2472	388	2565	569
(P) EL CAMPO	1046	147	1306	170	1341	261	1539	205	1627	323
ELGIN	4535	556	5438	664	6307	1180	6930	869	8188	1559
FREDERICKSBURG	6412	1325	7513	1498	8449	2234	9079	1861	10118	2731
(P) GIDDINGS	2964	642	3672	835	4422	1293	4499	1053	5419	1621
JOHNSON CITY	872	188	1001	195	1340	348	1392	281	1780	475
JUNCTION	2593	807	2701	759	3048	1055	3070	898	3226	1153
LA GRANGE	3768	781	4133	593	4381	913	4469	661	4737	1008
LLANO	3071	785	3892	1055	4124	1386	4507	125?4762	1632	
MANOR	1044	130	1370	164	1452	268	1701	208	1893	354
MARBLE FALLS	3252	808	3656	663	3891	959	4245	789	4696	1178
MASON	2153	549	2522	599	2522	763	2892	700	2892	888
(P) ROCKSPRINGS	1185	227	1299	231	1296	315	1523	280	1633	406
ROLLINGWOOD	1027	220	1348	163	1428	266	1674	206	1862	350
SMITHVILLE	3470	743	3884	518	4504	893	4792	660	5662	1148
(P) WEIMAR	958	189	1100	198	1125	276	1203	220	1248	309
WEST LAKE HILLS	2166	716	3481	1295	3688	1611	4630	1743	5151	2273
(P) WHARTON	788	109	1064	150	1093	225	1276	186	1348	284
OTHER	140528	17574	189575	24585	203413	33789	242312	32794	270293	46670
ZONE TOTAL	540409	107886	692439	128900	738700	179587	854117	161984	951060	234620
BASIN TOTAL	1060699	224304	1274262	237802	1363617	333594	1493605	283841	1641715	407132

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 15 COLORADO-LAVACA
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
(P) EL CAMPO	9416	1324	11761	1528	12077	2354	13861	1848	14647	2904
EL CAMPO SOUTH	932	132	1268	220	1302	311	1423	253	1504	366
PALACIOS	4667	913	5368	848	5643	1258	6152	999	6654	1513
POINT COMFORT	1125	154	1389	170	1441	270	1601	203	1708	327
OTHER	9485	1728	10521	1908	10957	2561	11791	2132	12625	2935
ZONE TOTAL	25625	4251	30307	4674	31420	6754	34828	5435	37138	8045
BASIN TOTAL	25625	4251	30307	4674	31420	6754	34828	5435	37138	8045

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 16 LAVACA
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
EDNA	5650	1244	6538	1282	6631	1731	7203	1444	7431	1973
GANADO	1770	303	2005	314	2033	451	2198	352	2268	511
HALLETTSVILLE	2865	602	3338	703	3419	942	3712	815	3867	1100
MOULTON	1009	145	1116	348	1143	430	1219	389	1270	488
SCHULENBURG	2469	414	2918	552	3093	786	3193	619	3385	876
SHINER	2213	479	2737	457	2803	650	3105	536	3234	768
(P) WEIMAR	1170	230	1343	242	1374	337	1469	268	1524	377
YOAKUM	6148	1044	7207	1050	7361	1550	7969	1197	8250	1775
OTHER	20637	3259	20493	2521	21033	3524	21341	2743	22248	3864
ZONE TOTAL	43931	7720	47695	7469	48890	10401	51409	8363	53477	11732
BASIN TOTAL	43931	7720	47695	7469	48890	10401	51409	8363	53477	11732

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 17 LAVACA-GUADALUPE
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BLOOMINGTON	1881	233	1831	228	1916	363	2064	266	2178	422
PORT LAVACA	10911	1717	13428	1985	13932	2965	15636	2382	16680	3625
SEADRIFT	1277	172	1472	181	1527	287	1697	217	1810	349
(P) VICTORIA	10429	1622	13305	1997	13925	2995	15129	2322	15962	3487
OTHER	13383	1631	14607	1859	15217	2832	16149	2140	17105	3294
ZONE TOTAL	37881	5375	44643	6250	46517	9442	50675	7327	53735	11177
BASIN TOTAL	37881	5375	44643	6250	46517	9442	50675	7327	53735	11177

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 18 GUADALUPE
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
BLANCO	1179	239	1379	250	1847	455	1933	362	2472	623
KERRVILLE	15276	3274	18041	3678	21619	5812	22859	4788	26966	7400
KYLE	2093	399	3086	494	3308	745	4110	681	4928	1137
(P) NEW BRAUNFELS	22375	6243	23114	4634	28048	7446	27527	5643	33181	8957
SAN MARCOS	23420	6209	32558	7768	34898	10594	42162	10296	50549	15628
OTHER	38121	4809	47744	6047	55500	9269	64342	8467	76298	13217
ZONE TOTAL	102464	21173	125922	22871	145220	34321	162933	30237	194394	46962

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 18 GUADALUPE
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
CUERO	7124	1178	7905	1107	8037	1647	8468	1214	8680	1808
FLATONIA	1070	475	1273	499	1349	617	1379	547	1462	675
GONZALES	7152	1957	8136	1768	8203	2316	8810	1954	8929	2560
LOCKHART	7953	1428	8522	1289	8790	1900	9118	1420	9415	2078
LULING	5039	1334	5074	949	5234	1319	5188	1000	5357	1380
(P) NEW BRAUNFELS	27	7	28	6	33	9	36	7	40	11
NIXON	2008	434	2309	564	2328	720	2471	612	2504	783
SEGUIN	17854	3498	17853	3020	20782	4865	19970	3490	22180	5317
(P) VICTORIA	40266	6266	51372	7711	53767	11564	58412	8964	61629	13462
YORKTOWN	2498	450	2791	425	2838	617	3002	474	3077	686
OTHER	49890	6103	52830	6789	56660	10001	58155	7773	61734	11294
ZONE TOTAL	140881	23130	158093	24127	168021	35575	175009	27455	185007	40054
BASIN TOTAL	243345	44303	284015	46998	313241	69896	337942	57692	379401	87016

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 19 SAN ANTONIO
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALAMO HEIGHTS	6252	2742	7675	2442	7980	3057	9007	2885	9691	3734
BALCONES HEIGHTS	2853	706	4831	915	5023	1277	6228	1207	6701	1734
BANDERA	947	190	2252	394	2389	573	3153	572	3441	848
BOERNE	3229	614	3933	833	4434	1227	4657	1007	5139	1445
CASTLE HILLS	4773	1696	7464	2349	7761	2947	9166	2916	9862	3778
CASTROVILLE	1821	804	2215	667	2289	838	2509	781	2660	1001
CONVERSE	4907	892	8746	1381	9093	2027	12035	1941	12950	2930
FORT SAM HOUSTON	15638	4736	15440	4791	16053	6024	15023	4695	16164	6102
HOLLYWOOD PARK	3231	1470	5548	1709	5768	2152	7283	2268	7836	2949
KIRBY	6385	1074	10967	1843	11403	2657	14835	2542	15963	3773
LACKLAND AFB	14426	4156	14243	3877	14809	4993	13858	3819	14911	5078
LEON VALLEY	8951	937	15058	1737	15656	2823	20636	2427	22204	4054
LIVE OAK	8183	901	14811	2090	15399	3174	20339	2939	21884	4584
OLMOS PARK	2069	529	2527	526	2627	718	2966	631	3191	886
RANDOLPH AFB	4442	1825	4386	1248	4560	1594	4267	1228	4591	1620
SAN ANTONIO	785880	183204	942716	183740	980152	254715	1095283	218384	1178512	311544
(P) SCHERTZ	28	3	49	8	58	13	65	11	77	18
SHAVANO PARK	1448	575	1783	216	1854	345	2092	258	2251	424
SOMERSET	1102	135	1357	164	1410	262	1593	196	1714	323
TERRELL HILLS	4644	1059	5748	1133	5976	1566	6745	1345	7257	1918
UNIVERSAL CITY	10720	1998	21359	3469	22207	5050	28933	4797	31131	7183
WINDCREST	5332	1362	9909	2298	10302	3058	13339	3138	14352	4308
OTHER	110853	14540	98013	16214	103284	21797	117229	19831	127270	27445
ZONE TOTAL	1008114	226148	1201030	234044	1250487	322887	1411241	279818	1519752	397679

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 19 SAN ANTONIO
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
FLORESVILLE	4381	729	5446	1647	7130	2620	7565	2330	8709	3249
GOLIAD	1990	459	2320	450	2369	613	2628	524	2747	726
KARNES CITY	3296	499	3951	478	4001	744	4368	548	4461	849
KENEDY	4356	772	4852	880	4913	1211	5201	973	5312	1339
POTH	1461	381	1507	321	1973	548	1962	429	2258	640
RUNGE	1244	200	1493	179	1512	279	1646	207	1681	320
(P) SCHERTZ	7243	1087	12975	2107	15104	3434	18279	3051	20302	4707
STOCKDALE	1265	235	1194	226	1563	397	1499	292	1725	448
OTHER	21035	2470	19132	2467	22386	3880	21749	2911	24011	4296
ZONE TOTAL	46271	6832	52870	8755	60951	13726	64897	11265	71206	16574
BASIN TOTAL	1054385	232980	1253900	242799	1311438	336613	1476138	291083	1590958	414253

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 20 SAN ANTONIO-NUECES
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ARANSAS PASS	7173	918	6962	1076	7279	1598	7205	1154	7744	1743
BEEVILLE	14574	2290	16740	2438	17301	3643	18377	2758	19206	4131
GREGORY	2739	252	3470	404	3618	657	4124	499	4443	826
INGLESIDE	5436	918	7464	945	7783	1491	9263	1204	9979	1945
ODEM	2363	331	2686	391	2801	590	3023	454	3257	700
(P) PORT ARANSAS	98	40	137	60	141	71	164	73	170	86
PORTLAND	12023	1605	20301	2388	21167	3865	26799	3212	28871	5336
REFUGIO	3898	644	3898	559	3898	812	3787	556	3787	802
ROCKPORT	3686	1532	4011	1294	4281	1659	4678	1556	4942	1965
SINTON	6044	764	6236	810	6502	1267	6688	906	7205	1445
TAFT	3686	398	3953	465	4122	753	4345	531	4681	876
TAFT SOUTHWEST	2133	231	2431	283	2535	460	2718	329	2928	544
WOODSBORO	1974	399	2098	355	2098	491	2130	372	2130	511
OTHER	32828	3867	39710	6250	41499	9067	44484	7284	46840	10505
ZONE TOTAL	98655	14189	120097	17718	125025	26424	137785	20888	146183	31415
BASIN TOTAL	98655	14189	120097	17718	125025	26424	137785	20888	146183	31415

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 21 NUECES
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ASHERTON	1574	188	1649	225	1719	347	1742	248	1873	388
CARRIZO SPRINGS	6886	2250	8618	1574	8984	2224	10295	1914	11071	2778
CHARLOTTE	1443	314	1551	335	1635	460	1607	360	1701	492
(P) CORPUS CHRISTI	10887	2773	12436	2396	12823	3304	13552	2672	14038	3680
COTULLA	3912	810	4470	1067	4580	1390	5090	1249	5382	1670
CRYSTAL CITY	8334	1677	8731	1809	8837	2405	9258	1981	9544	2662
DEVINE	3756	698	4862	790	5025	1143	5745	952	6092	1406
DILLEY	2579	709	2523	512	3003	804	2866	600	3411	936
FREER	3213	505	3492	661	3562	906	3806	746	3969	1036
GEORGE WEST	2627	578	3450	441	3579	690	3764	498	3821	753
HONDO	6057	1724	7033	1623	7269	2150	7974	1885	8456	2548
JOURDANTON	2743	763	4008	844	4224	1164	4903	1065	5190	1465
LEAKEY	468	151	522	106	541	145	539	115	559	156
LYTLE	1920	433	3094	634	3249	877	3847	814	4073	1127
MATHIS	5667	571	5456	636	5689	1032	5613	679	6047	1124
NATALIA	1264	122	2517	296	2601	475	3275	404	3473	654
PEARSALL	7383	1788	7736	1776	9208	2713	9252	2176	11012	3306
PLEASANTON	6346	781	9942	1225	10477	1972	12122	1548	12831	2472
POTEET	3086	726	3780	915	3984	1223	4126	1035	4367	1379
(P) ROCKSPRINGS	132	25	144	26	144	35	169	31	181	45
SABINAL	1827	636	1977	463	2084	623	2239	544	2455	756
THREE RIVERS	2133	658	2478	400	2570	582	2558	427	2597	602
TILDEN	300	31	279	31	268	47	292	34	304	55
UVALDE	14178	4768	18342	5445	19331	6994	22775	6939	24973	9231
OTHER	54739	6758	57899	7688	61012	11128	64346	8899	69011	12960
ZONE TOTAL	153454	30437	176989	31918	186398	44833	201755	37815	216431	53681
BASIN TOTAL	153454	30437	176989	31918	186398	44833	201755	37815	216431	53681

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 22 NUECES-RIO GRANDE
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALICE	20961	5060	23124	5077	23739	6754	25360	5710	26648	7731
BENAVIDES	1978	452	2149	506	2192	658	2342	567	2443	750
BISHOP	3706	679	3704	485	3819	749	3788	513	3924	787
(P) CORPUS CHRISTI	221112	56319	252581	48663	260449	67100	275850	54383	285746	74898
KINGSVILLE	28808	6067	30360	4625	30621	6654	32734	5097	34016	7506
NORTH SAN PEDRO	2561	405	4859	653	5010	999	6091	846	6310	1286
ORANGE GROVE	1212	219	1376	208	1413	305	1542	244	1621	361
(P) PORT ARANSAS	1870	775	2622	1151	2704	1363	3145	1395	3258	1657
PREMONT	2984	941	3401	865	3491	1114	3706	963	3894	1265
ROBSTOWN	12100	1908	13787	2008	14216	2994	14923	2240	15459	3325
SAN DIEGO	5225	891	5776	900	5898	1301	6355	1003	6637	1480
SOUTH SAN PEDRO	1707	270	3918	592	4040	873	4801	748	4973	1097
OTHER	28865	3828	28686	3675	29435	5345	30162	4041	31540	5931
ZONE TOTAL	333089	77814	376343	69408	387027	96209	410799	77750	426469	108074

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 22 NUECES-RIO GRANDE
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALAMO	5831	1628	8098	1070	8697	1715	10375	1429	11749	2382
ALTON	2732	1517	3878	465	4165	770	5108	624	5784	1082
(P) BROWNSVILLE	84887	17820	129591	32661	138261	43829	170834	44395	189493	61555
COMBES	1441	111	1967	328	2099	487	2474	421	2744	645
DONNA	9952	1290	13129	1647	14099	2685	16436	2154	18612	3648
EDCOUCH	3092	476	3643	522	3912	815	4183	618	4737	1008
EDINBURG	24075	3813	30528	4685	32785	7161	37763	5964	42763	9532
ELSA	5061	829	7129	1070	7656	1647	8938	1382	10121	2222
FALFURRIAS	6103	863	6797	1013	6968	1491	7305	1121	7583	1656
HARLINGEN	43543	9160	49989	11311	53334	15533	57008	13218	63235	18771
HEBBRONVILLE	4680	934	5511	1130	5635	1521	6184	1316	6441	1789
HIDALGO	2288	355	3687	586	3959	887	5133	839	5813	1328
LA FERIA	3495	508	4310	657	4598	999	5104	806	5662	1262
LA VILLA	1442	100	1789	210	1921	351	2107	260	2386	449
LOS FRESNOS	2173	415	3209	543	3424	802	4200	734	4659	1117
LYFORD	1618	321	1943	313	1982	448	2210	366	2314	534
MCALLEN	66281	13027	104760	19949	112503	28732	144982	28095	164180	42482
MERCEDES	11851	2772	13125	1897	14095	2952	14815	2207	16777	3589
MISSION	22589	5332	31526	5544	33856	8154	41768	7486	47299	11550
PHARR	21381	3004	31260	4692	33571	7220	40833	6312	46240	10152
PORT ISABEL	3769	2106	4430	1389	4726	1789	5059	1655	5612	2200
PRIMERA	1380	162	1884	228	2010	374	2369	292	2628	495
RAYMONDVILLE	9493	4100	11082	1986	11304	2760	12549	2333	13136	3296
RIO HONDO	1673	469	2142	422	2285	599	2611	526	2896	772
SAN BENITO	17988	2956	22319	2625	23812	4348	26006	3146	28846	5364
SAN JUAN	7608	1509	11669	1582	12532	2513	15724	2202	17806	3650
SANTA ROSA	1889	221	2448	299	2612	489	2954	381	3277	635
SARITA	160	23	146	18	146	28	128	16	128	25
WESLACO	19331	3653	24710	4207	26536	6242	30121	5263	34110	8177
OTHER	132488	15654	178427	24234	190699	35974	230709	32666	258584	50584
ZONE TOTAL	520294	95128	715126	127283	764182	183315	915990	168227	1025615	251951
BASIN TOTAL	853383	172942	1091469	196691	1151209	279524	1326789	245977	1452084	360025

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 23 RIO GRANDE
ZONE: 1

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ANTHONY	2640	433	4399	581	4622	911	5698	779	6216	1253
CANUTILLO	3866	202	5802	676	6096	1106	7693	931	8392	1560
CLINT	1314	42	1692	205	1778	331	2039	251	2224	419
EL PASO	425259	88941	563725	119345	592291	125392	684395	147191	746559	160561
FABENS	4219	659	5121	826	5381	1218	5996	994	6541	1509
FORT BLISS	12622	7229	12013	6849	12622	8017	11571	6662	12622	8087
SIERRA BLANCA	573	68	606	74	625	117	704	88	781	149
OTHER	32134	5600	11659	3648	12202	4632	10854	3484	11897	4537
ZONE TOTAL	482627	103174	605017	132204	635617	141724	728950	160380	795232	178075

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 23 RIO GRANDE
ZONE: 2

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
ALPINE	5465	1594	5416	1268	5393	1613	5798	1390	6086	1854
BRACKETTVILLE	1676	677	2061	836	2130	1002	2293	963	2376	1152
(P) BROWNSVILLE	110	23	168	42	179	57	221	57	245	80
DEL RIO	30034	9779	44135	11519	46983	15315	56077	14950	62139	20603
EAGLE PASS	21407	4211	23523	4374	32632	8188	30119	5735	41783	10671
FORT DAVIS	787	114	837	103	837	158	816	101	816	154
LA GRULLA	1442	224	3587	450	3850	733	5438	731	6188	1234
LA JOYA	2018	514	4716	898	5065	1294	7156	1395	8104	2106
LAREDO	91449	22283	119170	24562	126137	34193	146640	31045	161291	44625
LAUGHLIN AFB	2971	1663	2791	994	2971	1251	2558	928	2834	1213
MARFA	2466	975	2712	939	2776	1141	2847	1011	2930	1231
OZONA	3764	1695	4456	1927	4646	2311	5124	2250	5426	2735
RIO GRANDE CITY	8887	1654	12130	2147	13019	3150	15913	2923	18109	4503
ROMA-LOS SAENZ	3384	839	5703	1444	6121	1947	8041	2099	9150	2983
SANDERSON	1247	332	981	215	950	270	958	216	978	284
SONORA	3856	1552	5150	1811	5462	2276	6845	2454	7705	3262
VAN HORN	2772	614	2863	686	2860	871	3304	811	3523	1093
ZAPATA	3806	951	5140	1157	5401	1567	6435	1492	6962	2067
OTHER	47150	6369	56889	8261	64427	12141	74305	11063	87759	16922
ZONE TOTAL	234691	56063	302428	63633	331839	89478	380888	81614	434404	118772

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX A. CONTINUED

RIVER BASIN: 23 RIO GRANDE
ZONE: 3

CITY/YEAR	1980 REPORTED		1990 PROJECTED				2000 PROJECTED			
			LOW		HIGH		LOW		HIGH	
	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT	POPLN.	AC-FT
CRANE	3622	905	3994	832	4091	1118	4257	892	4387	1204
FORT STOCKTON	8688	2728	9866	2829	10001	3518	11133	3242	11727	4177
IRAAN	1358	357	1436	174	1456	271	1583	195	1667	314
KERMIT	8015	2396	8632	2321	8711	2908	8971	2452	9077	3071
MCCAMEY	2436	634	2564	597	2593	773	2854	678	3040	919
MENTONE	25	3	9	1	8	2	9	1	10	2
MONAHANS	8397	3128	9411	2540	9557	3201	9895	2704	10053	3400
PECOS	12855	3627	14002	3435	14108	4377	15258	3811	15774	4965
RANKIN	1216	394	1449	368	1465	468	1715	446	1827	593
WINK	1182	246	1152	205	1163	283	1184	215	1198	295
OTHER	15848	2211	14628	2806	14857	3499	14777	2918	15300	3686
ZONE TOTAL	63642	16629	67143	16108	68010	20418	71636	17554	74060	22626
BASIN TOTAL	780960	175866	974588	211945	1035466	251620	1181474	259548	1303696	319473
STATE TOTAL	14229191	2813182	16808440	2955407	17846141	4202274	19567335	3512065	21239279	5080510

*(P) INDICATES THAT PART OF A CITY WHICH IS LOCATED WITHIN THE ZONE AND BASIN

APPENDIX B

APPENDIX B: Wastewater Facility Needs

General

Appendix B contains information on municipal wastewater handling facilities. Information comes from the State/Environmental Protection Agency (EPA) Needs Survey, the Construction Grant Information and Control System, the Department's Water Quality Enhancement Loan records, the Economic Development Administration, the Farmers Home Administration, the Department of Housing and Urban Development, Municipal Advisory Reports, and the numerous other Departmental records. The information is presented in three sections below.

Section I contains historical information on wastewater facilities funding from 1973 to 1982. The total cost and various sources of funding are detailed. Section II contains the Department's projections of wastewater treatment facilities needed for the year 1985 through 2000. Section III lists specific municipal wastewater treatment projects for the years 1985-1989. All of the projects listed are included in EPA's Municipal Construction Grants Program and have received grants to develop facilities plans. Since many of these plans are not yet complete, it is impossible to determine which projects will be funded in each fiscal year.

Section I. Municipal Wastewater Facility Construction in Texas (1973-1982).

A. Federal — State Assistance
The amount of assistance provided by EPA's Municipal Construction Grants Program and the Texas Water Quality Enhancement Loan program were obtained from Department records. Amounts obtained from the Farmers Home Administration and the Economic Development Administration appear to be firm, but little information is available concerning specific projects. The Department of Housing and Urban Development (HUD) estimates that $1.475 billion in grants have gone to Texas communities since fiscal year 1974 (the year HUD was established). While project specifics are scarce, HUD estimates that between 9 and 12 percent of all grant funds are committed to sewage facilities. The Department has assumed a figure of roughly 10 percent.

B. Federal versus "Local" Share of EPA Construction Grants Projects Since Public Law 92-500 (the Clean Water Act as enacted October 18, 1972).

EPA has awarded grants for up to 75 percent of total eligible sewage project costs for planning, design, and construction. A distinction has been drawn between total eligible project costs and total projects costs, since a number of items such as easements, land, financial administration, and some construction items are ineligible for grant participation. The Department has sampled a number of EPA projects and found that, on average, EPA assistance amounted to 63.75 percent of total costs. The remaining 36.25 percent of total project costs, referred to as the "local" share, frequently includes assistance from one or more of the other listed federal or State sources.

C. Total Expenditure
To derive expenditures not related to EPA's grant program, and thus arrive at a figure for total expenditure, it was necessary to differentiate between treatment system costs and collection system costs. The Department's records include a complete inventory (and construction history) of municipally owned wastewater treatment facilities in Texas. By cross-referencing this inventory with EPA-assisted construction projects, the Department found 350 municipal sewage treatment plant construction projects that were funded without EPA assistance. Since costs associated with these projects were generally not available, a system of estimation was used that has been formulated and updated by EPA contractors since 1976. Allowances were made for type of treatment facility constructed, location, and year of construction.

Reliable, site-specific information concerning collection facility construction is not available. The Department has estimated total municipal wastewater collection facility expenditures at $1.3 billion. This figure is based on the number of persons served by municipal wastewater collection systems in 1982 versus the number served in 1973, the footage of line required to serve the expanded population, and cost assumptions based on these requirements. Of this

$1.3 billion, $468 million was spent in EPA grant related projects.

Section II: Municipal Wastewater Facility Construction Projections (1985-2000).

The "Needs Survey" is the basic Departmental tool used for wastewater facilities projections. The Needs Survey is mandated by Sections 205(a) and 516(b) of the Federal Water Pollution Control Act and amendments and serves three purposes:

1. It provides Congress and other interested parties with an estimate of needed, publicly owned wastewater treatment works to meet the goals of the Act.
2. It is used as a mechanism by Congress to allocate EPA Construction Grant funds among the States.
3. It provides an inventory of existing and proposed wastewater facilities.

The Act requires EPA, in cooperation with the States, to revise the Needs Survey and report to Congress in each odd-numbered year.

In addition to providing an inventory of wastewater facilities, the Needs Survey generates cost estimates, projected to the year 2000, for individual facilities to meet the goals of the Act. Costs for each facility are separated into the following categories:

Category I	— Secondary Treatment and Best Practicable Wastewater Treatment Technology
Category IIA	— Advanced Secondary Treatment (AST)
Category IIB	— Advanced Wastewater Treatment (AWT)
Category IIIA	— Infiltration/Inflow Correction
Category IIIB	— Major Sewer System Rehabilitation
Category IVA	— Collectors and Appurtenances
Category IVB	— New Interceptors and Appurtenances
Category V	— Correction of Combined Sewer Overflows

Cost estimates for the Needs Survey generally come from two sources:

a. From engineering reports and planning documents prepared for individual facilities under the Construction Grants Program.
b. From EPA developed cost estimation procedures. These procedures are used when engineering estimates and/or site-specific planning reports are not available.

EPA's procedures were developed under contract and represent the compilation of data from hundreds of Construction Grant projects across the Nation.

Section III: Planning Portion of the Fiscal Year 1984 Priority List (1985-1989).

The planning portion of the priority list consists of potential EPA Construction Grant projects which will be needed at some time between 1985 and 1989. All of the entities listed have received EPA assistance to develop a facilities plan. Each plan encompasses:

1. A defined service area.
2. An infiltration and inflow analysis.
3. An environmental assessment.
4. A review of waste treatment alternatives and processes.
5. An analysis to determine the most economical method for meeting applicable health and stream standards.

A few of the projects listed have completed facilities plans and have received EPA assistance for the preparation of detailed plans and specifications.

When the local project sponsors (cities and other local governments) entered the Construction Grant Program, they anticipated EPA assistance for up to 75 percent of the grant eligible project costs. However, amendments to the Clean Water Act enacted in December 1981 reduced total program funding authorization from $5 billion to $2.4 billion for each of fiscal years 1982, 1983, 1984, and 1985. Hence, federal funds potentially available to the State of Texas have diminished. In addition, the amendments reduced or eliminated many previously grant-eligible items. Beginning October 1, 1984:

1. Federal grant assistance will drop from 75 percent to 55 percent of grant-eligible project costs.
2. All reserve capacity (growth) will be ineligible.
3. Collection lines and sewer line rehabilitation will no longer be eligible.

Entities which have anticipated 75 percent federal participation are now faced with many difficult financial decisions.

Projects from this list which are funded prior to October 1, 1984 will be funded at 75 percent with capacity for 20 years of growth. Projects funded after this date can be funded at only 55 percent and only for the population living in the service area on the date the grant is made.

Projects are listed in alphabetical order by population category. The categories are:

A = 0 - 3,500
B = 3,501 - 10,000
C = 10,001 - 25,000
D = 25,001 - 100,000
E = 100,001 - 500,000
F = 500,000 - up

Section I

Municipal Wastewater Facility Construction in Texas (1973-1982)

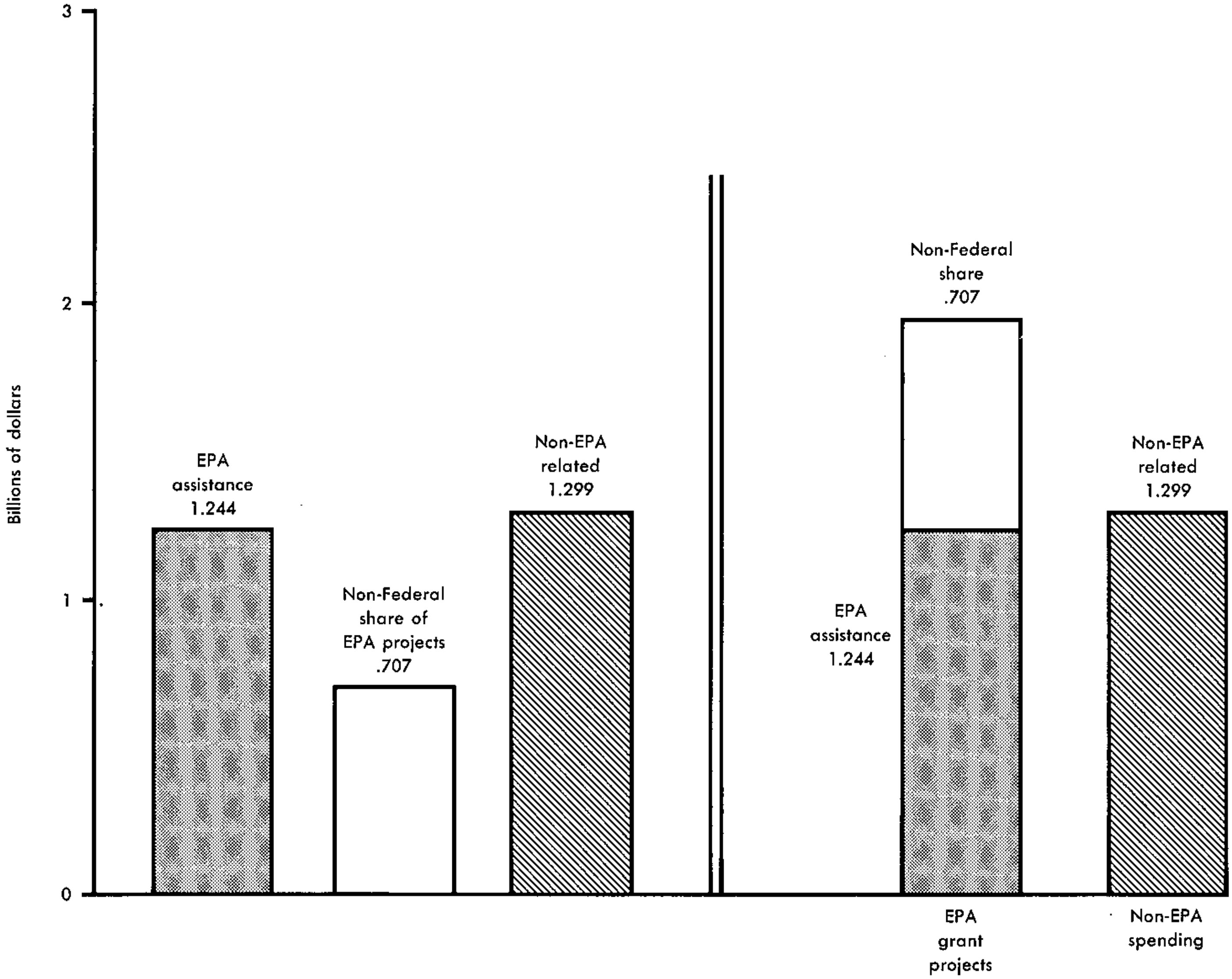
(EPA versus Non-EPA Spending)

EPA Assistance for Construction Grant Projects	$1,244,000,000
Non-Federal Share of EPA Grant Projects	707,000,000
Total EPA Construction Grant Related Spending	$1,951,000,000
Total Spending Not Related to EPA Grant Program	$1,299,000,000
Total Expenditure	$3,250,000,000

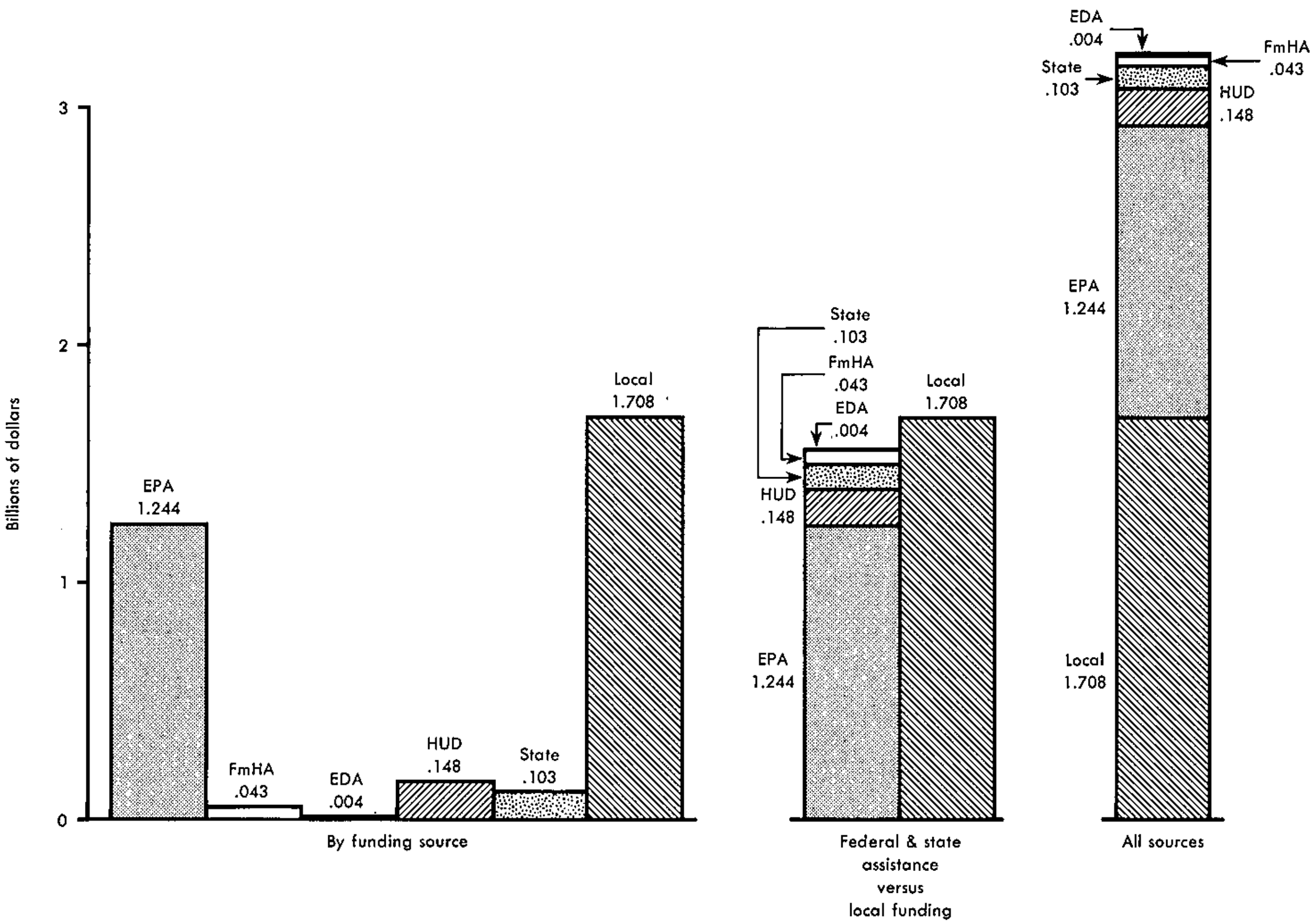
(Source of Funding)

EPA Assistance	$1,244,000,000
FmHA Assistance[1]	43,000,000
EDA Assistance	4,000,000
HUD Assistance[2]	148,000,000
State Assistance[3]	103,000,000
Total Federal and State Assistance	$1,542,000,000
Local Funding[4]	$1,708,000,000
Total Expenditure	$3,250,000,000

[1]Loans 89%, grants 11%
[2]Estimated at roughly 10% of all HUD grants
[3]Water Quality Enhancement Fund loans
[4]Municipal plus "private" contributions to municipal systems



Municipal Wastewater Facility Construction in Texas 1973-1982
EPA Versus Non-EPA Spending



Municipal Wastewater Facility Construction in Texas 1973-1982
By Source of Funding

Section II

Projected Wastewater Facility Needs in Texas from 1985 to 2000*

A.	1982 Needs Survey (Years 1982-2000)	$4.016	(1)
B.	Less 1983 and 1984 construction of facilities identified by the 1982 Needs Survey	-.554	(2)
		3.462	
C.	Estimated publicly owned collection lines and interceptors not included in the 1982 Needs Survey	1.700	(3)
	Total estimated publicly owned facilities needs (years 1985-2000)	5.162	
D.	Estimated private facility needs (year 1985-2000)	2.005	(4)
	Total estimated publicly and privately owned facility needs (year 1985-2000)	7.167	
E.	Estimated Federal Grant Assistance (years 1985-1989)	.465	(5)
	Total estimated needs remaining after estimated Federal Grant Assistance	$6.702	

NOTES:

1. The 1982 Needs Survey includes grant-eligible publicly owned treatment facilities. Ineligible items (collection lines and interceptors) and privately owned facilities are not included in this survey information. The Department has estimated these needs through the year 2000.
2. In 1983 and 1984, $554 million of publicly owned treatment facilities was funded.
3. These dollar estimates are the estimated publicly owned treatment facilities needs which were not included in the 1982 Needs Survey since they are not eligible for grant assistance (collection lines and interceptors).
4. These dollar estimates are the estimated needs of private treatment facilities which are not part of the estimated needs, such as private subdivision systems, commercial buildings, mobil home parks, etc.
5. This is an estimate of what the federal grant assistance will provide the State of Texas based upon the annual federal appropriations since fiscal year 1983.

* Estimated Sewerage Facility Needs as of April 24, 1984, Construction Grants and Water Quality Management Division, Texas Department of Water Resources.

Section III

Planning Portion of the Fiscal Year 1984 Priority List

The projects listed on the following pages have established a definite sewerage facility need for a period between 1985 and 1988. All of the projects have received a federal grant to develop a facility plan which encompasses:

1. A defined service area.
2. Infiltration and inflow analysis.
3. An environmental assessment.
4. Analysis of various waste treatment processes.
5. A cost-effective analysis to determine the most economical method of treatment which will meet the stream standard.

Some projects have also received a federal grant to develop detail plans and specifications in addition to facility plan funds.

When these entities entered the Construction Grant program, they anticipated receiving a federal grant for 75 percent of the grant-eligible items for their project. However, the 1981 Amendments to the Clean Water Act enacted in December 1981 reduced the funding authorization from $5 billion to $2.4 billion dollars per year for fiscal years 1982, 1983, 1984, and 1985. The Amendments additionally reduced or eliminated many other grant-eligible items. Starting with October 1, 1984, the following changes will occur:

1. Federal grant assistance will decrease from 75 percent to 55 percent of the grant-eligible items.

2. All reserve capacity (growth) will become ineligible for both the sewerage treatment plant and the associated lines.
3. All collection lines and sewer line rehabilitation will no longer be eligible.

As a result, the entities which have anticipated the 75 percent federal participation are now faced with many difficult financial decisions.

All the projects which are not funded in fiscal year 1984 (Contingency not funded and Planning) will be funded at 55 percent for only the population living in the service area on the date the grant is made.

Projects are listed in alphabetical order by population category. The categories are: A = 0-3,500; B = 3,501-10,000; C = 10,001-25,000; D = 25,001-100,000; E = 100,001-500,000; and F = 500,000-up.

TEXAS DEPARTMENT OF WATER RESOURCES

Municipal Facilities Construction Grant Priority List
Planning Portion

Project Name	Project Sequence	Population Category	Project Description[1]	Total Project Cost
Agua Dulce	1415-03	A	STP Improvements	$ 368,000
Alto	1628-03	A	New Interceptors	943,000
Alvarado	1392-03	A	Collection System	352,000
Bartlett	1631-03	A	STP Improvements	782,000
Bell Co. WCID No. 2	1724-03	A	STP Expansion and Linework	516,000
Blossom	1338-03	A	STP Replacement	547,000
Brookshire MWD	1620-03	A	STP Expansion	1,250,000
Brookside Village	1281-03	A	New Sewerage System	1,875,000
Caddo Mills	1639-03	A	STP Improvements	547,000
Canton	1499-03	A	STP Improvements	1,500,000
Celina	1418-03	A	STP Replacement	1,094,000
Clifton	1500-03	A	Relief Interceptors	508,000
Combes	1646-03	A	New Sewerage System	469,000
Crosby MUD	1726-03	A	STP Expansion	469,000
DeLeon	1384-03	A	New Interceptor	430,000
Dilley	1039-03	A	STP Improvement	313,000
Dublin	1476-03	A	STP Replacement	484,000
Fate	1365-03	A	STP Replacement	1,563,000
Franklin	1597-03	A	STP Improvements	313,000
George West	1652-03	A	Replace Interceptors	3,907,000
Glenn Heights	1411-03	A	Collection System	328,000
Godley	1654-03	A	STP Expansion	157,000
Granger	1729-03	A	STP Improvements	1,344,000
Harris Co. WCID Fondren Road	1503-03	A	STP Improvements	1,758,000
Henderson Co. MWA	1712-03	A	STP Improvements	410,000
Hooks	1428-03	A	STP Improvements	547,000
Hughes Springs	1719-03	A	STP Improvements	938,000
Joaquin	1283-03	A	New Sewerage System	1,953,000
Keene	1590-03	A	STP Improvements	991,000
Kemp	1277-03	A	STP Expansion	2,344,000
Kountze	1381-03	A	New Interceptor	1,250,000
Krugerville	1551-03	A	New Sewerage System	313,000

See footnote at end of table.

Municipal Facilities Construction Grant Priority List
Planning Portion—Continued

Project Name	Project Sequence	Population Category	Project Description[1]	Total Project Cost
Leander	1730-03	A	New Sewerage System	2,500,000
Liverpool	1717-03	A	New Sewerage System	1,229,000
Marion	1556-03	A	STP Replacement	469,000
Melissa	1616-03	A	New Sewerage System	910,000
New Deal	1402-03	A	New Sewerage System	541,000
Nueces Co. WCID No. 4	1558-03	A	STP Expansion	1,250,000
Pineland	1559-03	A	STP Improvements	313,000
Rogers	1680-03	A	STP Replacement	677,000
Royse City	1443-03	A	New Interceptor	438,000
San Augustine	1598-03	A	STP Improvements	782,000
San Saba	1450-03	A	STP Improvements	625,000
Southside Place	1417-03	A	STP Replacement	1,166,000
Teague	1593-03	A	Improve 2 Existing STP's	938,000
Timpson	1689-03	A	STP Improvements	999,000
TRA-Riverside	1334-03	A	New Sewerage System	1,250,000
Trinidad	1582-03	A	STP Improvements	471,000
Trinity Bay Conser.	1115-04	A	Eminence, Hankamer	2,110,000
Trinity Bay Conser.	1115-23	A	Smith Point	1,407,000
Troy	1583-03	A	STP Replacement	1,036,000
Tuscola	1518-03	A	New Sewerage System	1,069,000
Van Alstyne	1692-03	A	STP Improvements	547,000
Victoria Co. WCID No. 2	1584-03	A	New Sewerage System	820,000
West Jefferson Co. MWD	1662-03	A	New Sewerage System	15,630,000
Wills Point	1488-03	A	STP Improvements	1,406,000
Winnsboro	1136-13	A	Interceptors and Collector	1,953,000
				$ 71,099,000
Anthony	1731-03	B	STP Improvements	$ 313,000
Bell Co. WCID No. 3	1600-03	B	STP Improvements	665,000
BRA-Sugarland	1635-03	B	STP Improvements	13,281,000
Dayton	1540-03	B	STP Expansion	1,875,000
Diboll	1501-03	B	Relief Interceptor	1,133,000
Gilmer	1653-03	B	STP Improvements	2,291,000
Hearne	1658-03	B	STP Replacement	813,000
Katy	1550-03	B	STP Expansion	3,125,000
LaPorte	1176-13	B	New Sewerage System	1,875,000
Lampasas	1732-03	B	New Sewerage Improvement	2,969,000
Manvel	1555-03	B	New Sewerage System	3,980,000
McGregor	1427-03	B	STP Replacement	2,199,000
Memphis	1668-03	B	New Collectors	63,000
Pittsburg	1742-03	B	STP Replacement	1,016,000
Robinson	1484-03	B	STP Improvements	2,813,000
Rowlett	1436-03	B	Relief Interceptor	2,969,000
San Juan	1563-03	B	New Interceptors	625,000
Sealy	1720-03	B	STP Expansion	782,000
				$ 42,787,000

See footnote at end of table.

Municipal Facilities Construction Grant Priority List
Planning Portion—Continued

Project Name	Project Sequence	Population Category	Project Description[1]	Total Project Cost
Bay City	1388-03	C	Relief Interceptor	$ 5,469,000
Copperas Cove	1705-03	C	STP Improvements	3,516,000
Dallas Co. WCID No. 6	1355-03	C	Relief Interceptor	3,282,000
Freeport	1606-03	C	STP Replacement	2,344,000
Jacksonville	1510-03	C	STP Improvements	7,500,000
League City	1426-03	C	New Intercepts and Rehabilitation	7,872,000
Pharr	1676-03	C	New 1.5 million gpd Plant	2,735,000
Port Lavaca	1396-03	C	STP Replacement	2,344,000
South Houston	1490-03	C	STP Improvements	4,688,000
Vernon	1519-03	C	STP Replacement	2,235,000
Vidor	1413-03	C	New STP's and Line Work	14,105,000
Weslaco	1693-03	C	STP Replacement	4,688,000
				$ 60,778,000
Baytown	1151-04	D	Collector Lines	$ 4,000,000
Baytown	1498-03	D	STP Improvements	15,625,000
BRA-Temple/Belton	1535-03	D	STP Improvements	28,125,000
Bryan	1523-04	D	Improve STP	1,900,000
Bryan	1523-05	D	Interceptor Rehabilitation	2,435,000
Cibolo Creek MA	1643-03	D	STP Expansion	6,641,000
Galveston	1201-03	D	STP Improvements	20,313,000
GBRA Victoria	1438-03	D	STP Improvements	13,641,000
Harlingen	1657-03	D	STP Improvements	7,813,000
Laredo	1456-03	D	STP Improvements	15,625,000
Lufkin	1553-03	D	STP Improvements	1,719,000
McAllen	1515-13	D	New STP	9,375,000
Memorial Village WA	1494-03	D	STP Expansion	9,549,000
North Texas MWD	1349-03	D	STP Improvements	23,438,000
Orange	1255-03	D	Improve 2 Plants	9,204,000
Paris	1248-03	D	STP Expansion	19,593,000
Port Arthur	1045-03	D	STP Improvements	51,563,000
Texarkana	1158-05	D	STP Replacement	6,250,000
				$246,809,000
BRA-Waco Metro	1229-13	E	Relief Interceptor	$ 235,000
BRA-Waco Metro	1229-23	E	Relief Interceptor	1,563,000
Corpus Christi	1214-33	E	Infiltration/Inflow	6,563,000
El Paso/PSB	1542-03	E	STP Improvements	17,188,000
El Paso/PSB	1542-25	E	Collector Lines	14,485,000
El Paso/PSB	1542-27	E	Collector Lines	500,000
El Paso/PSB	1542-33	E	Collector Lines	625,000
El Paso/PSB	1542-35	E	Collector Lines	313,000
El Paso/PSB	1542-37	E	Relief Interceptor	313,000
El Paso/PSB	1542-39	E	Relief Interceptor	313,000
El Paso/PSB	1542-41	E	Relief Interceptor	1,953,000
El Paso/PSB	1542-43	E	Relief Interceptor	469,000

See footnote at end of table.

Municipal Facilities Construction Grant Priority List
Planning Portion—Continued

Project Name	Project Sequence	Population Category	Project Description[1]	Total Project Cost
El Paso/PSB	1542-45	E	Relief Interceptor	235,000
El Paso/PSB	1542-47	E	Relief Interceptor	782,000
El Paso/PSB	1542-49	E	Relief Interceptor	7,500,000
El Paso/PSB	1542-51	E	Relief Interceptor	2,500,000
El Paso/PSB	1542-53	E	Relief Interceptor	1,250,000
El Paso/PSB	1542-55	E	Relief Interceptor	196,000
El Paso/PSB	1542-57	E	Relief Interceptor	625,000
El Paso/PSB	1542-59	E	Relief Interceptor	157,000
El Paso/PSB	1542-61	E	Relief Interceptor	313,000
Garland	1300-03	E	STP Expansion	13,282,000
TRA-10 Mile Creek	1186-03	E	STP Improvements	3,438,000
				$ 74,798,000
Dallas	1104-13	F	Relief Interceptor	$105,469,000
Dallas	1144-03	F	Southside STP Expansion	43,907,000
Dallas	1144-73	F	Diversion Interceptor	47,427,000
Dallas	1144-83	F	Relief Interceptor	37,540,000
Ft. Worth	1323-03	F	Improve STP Phase I	135,938,000
Ft. Worth	1323-13	F	Improve STP Phase 2	76,563,000
Ft. Worth	1323-23	F	Improve STP Phase 3	89,063,000
Houston	1020-13	F	STP Rehabilitation	352,000
Houston	1205-21	F	NE Homestead	6,407,000
Houston	1205-29	F	Northside Phase IC	15,625,000
Houston	1205-31	F	Northside Phase II	46,407,000
Houston	1205-33	F	FWSD No. 17 STP	860,000
Houston	1205-35	F	West District STP	6,250,000
Houston	1205-47	F	Relief Interceptor	66,000
Houston	1206-03	F	Sims Bayou STP	69,835,000
Houston	1206-13	F	Southeast STP	8,275,000
Houston	1206-23	F	Sagemont STP	3,282,000
Houston	1206-33	F	Gulf Meadows STP	5,985,000
Houston	1206-43	F	Easthaven STP	527,000
Houston	1206-53	F	Collector Lines	1,289,000
Houston	1206-63	F	Chocolate Bayou STP	7,188,000
Houston	1206-73	F	Collector Lines	2,079,000
Houston	1206-83	F	WCID No. 47 STP	3,594,000
Houston	1206-93	F	Collector Lines	957,000
Houston	1207-03	F	STP Improvements	50,000,000
San Antonio	1211-12	F	STP Contract 2	69,844,000
San Antonio	1211-14	F	STP Contract 3	65,625,000
San Antonio	1211-16	F	STP Contract 4	90,938,000
San Antonio	1211-17	F	Salado Creek STP Rehabilitation	17,188,000
San Antonio	1211-39	F	Package E	4,844,000
San Antonio	1211-41	F	Package F	14,649,000
San Antonio	1211-43	F	Package G	5,000,000
San Antonio	1211-45	F	Package H	3,438,000
San Antonio	1211-47	F	Package I	1,875,000
San Antonio	1211-49	F	Package J	3,282,000
San Antonio	1211-53	F	Sewer System Rehabilitation	26,875,000
				$1,068,443,000

[1]STP = Sewerage Treatment Plant

SELECTED REFERENCES

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American Fisheries Society. *Proceedings of the Symposium and Specialty Conference on Instream Flow Needs,* 2 vols. Edited by J. F. Osborn and C. H. Allman. Bethesda, Maryland. September 1976.

"API/AGA Pipeline Report." *Oil and Gas Journal* 79 (June 1981): 79.

Belden Associates. "A Statewide Public Opinion Study Regarding the Texas Water Plan: Summary Report." Conducted for the Governor's Task Force on Water Resource Use and Conservation and the Texas Department of Water Resources. Dallas, Texas. July 1982.

Bellamy, Thomas R. and Cecil Hutchins, Jr. *Southern Pulpwood Production 1979.* U.S. Department of Agriculture, Forest Service Resource Bulletin SE-57. Washington, D.C.: Government Printing Office, 1981.

Black & Veatch. "Six State High Plains-Ogallala Aquifer Area Study: Energy Price Projections." Regional Study Element B-8. 1980.

Bolon, P. "Power from the Dead Sea via Solar Ponds." *Popular Science* 219 (April 1981): 84-86.

California Department of Water Resources. Water Conservation in California. Bulletin 198. May 1976.

Camp Dresser & McKee, Incorporated. "13a Assessment of the Texas Portions of the Texas Gulf Region and the Red River Basin." A report prepared for the Texas Department of Water Resources and the U.S. Water Resources Council. Contract No. 9331-110. September 1981.

Chase Econometrics, Incorporated. *Long-Term Regional Forecasts: State and Metropolitan Areas.* Vol. 3, *The West.* Bala Cynwyd, Pa.: Chase Econometrics, Inc., 1981.

"Choosing Our Energy Future." *EPRI Journal 5* (September 1980): 6-11.

Data Resources, Incorporated. *U.S. Long-Term Review: Winter 1981-82.* Lexington, Mass.: McGraw-Hill, Inc., 1981.

Dubois, Deane. "Monthly Uranium Industry Newsletter." Corpus Christi, Texas. Issues 1975-82. (Mimeographed).

Electric Reliability Council of Texas. "Information Report by the Electric Reliability Council of Texas on Coordinated Bulk Power Supply Programs to the Office of Emergency Operations of the U.S. Department of Energy. In accordance with Code EP-411." April 1, 1982.

Engineering-Science, Incorporated. "Manufacturing Water Demand and Return Flow Projections." Prepared for the Texas Water Development Board. Austin, Texas. 1976.

_______ "Updated Projections on Future Changes in Manufacturing Water Use in Texas." Austin, Texas. 1982.

Fisher, W. L. *Texas Energy Reserves and Resources.* Bureau of Economic Geology Geological Circular 78-5. Austin: The University of Texas at Austin, 1978.

Flack, J. E. et al. *Achieving Urban Water Conservation: A Handbook.* Fort Collins, Colo.: Colorado Water Resources Research Institute, 1977.

Flour Engineers and Constructors, Incorporated. "Desalting Plans and Progress: An Evaluation of the State-of-the-Art and Future Research and Development Requirements." Prepared for the U.S. Department of the Interior, Office of Water Research and Technology. January 1978.

Freese and Nichols, Incorporated. "Study of Water Supply for Increased Greenbelt Systems Service Area." Prepared for the Greenbelt Municipal and Industrial Water Authority and Red River Authority of Texas. May 1981.

Gilkey, Millard M. and Ronald B. Stotelmeyer. *Water Requirements and Uses in New Mexico Mineral Industries.* U.S. Department of the Interior, Bureau of Mines Information Circular No. 8276. Washington, D.C.: Government Printing Office, 1965.

_______ *Water Requirements and Uses in Wyoming Mineral Industries.* U.S. Department of the Interior, Bureau of Mines Information Circular No. 8328. Washington, D.C.: Government Printing Office, 1967.

Griffiths, J. F. and G. Ainsworth. *One Hundred Years of Texas Weather: 1880-1979.* College Station: Texas A&M University, 1981.

Grubb, Herbert W. "Federal Agency Participation in Water Resources Programs and Projects in Texas." Statement presented to the Texas Lieutenant Governor's Task Force on New Federalism, Austin, Texas, 19 March 1982.

———. "Coordination and Planning Among River Authorities and Water Districts Existing Within the Same River Basin." Statement presented to the Water Subcommittee, Natural Resources Committee of the Texas House of Representatives, Austin, Texas, 3 June 1982.

Hale, William N. *Water Requirements and Uses in Montana Mineral Industries.* U.S. Department of the Interior, Bureau of Mines Information Circular No. 8305. Washington, D.C.: Government Printing Office, 1966.

Henry, W. K., D. M. Driscoll, and J. P. McCormack. *Hurricanes on the Texas Coast.* College Station: Texas A&M University, 1980.

High Plains Associates. "Six State High Plains Ogallala Aquifer Regional Resources Study Report." Final report to the U.S. Department of Commerce and the High Plains Study Council. March 1982.

High Plains Study Council. "A Summary of Results of the Ogallala Aquifer Regional Study, with Recommendations to the Secretary of Commerce and Congress." Review copy. July 1982.

High Plains Underground Water Conservation District No. 1. *A Summary of Techniques and Management Practices for Profitable Water Conservation on the High Plains.* Report 79-01. 1979.

Holmes, George H., Jr. *Water Requirements and Uses in Nevada Mineral Industries.* U.S. Department of the Interior, Bureau of Mines Information Circular No. 8288. Washington, D.C.: Government Printing Office, 1966.

"HPI Construction Boxscore." *Hydrocarbon Processing* Section 2 (February 1982): 13-16.

International Petroleum Encyclopedia: 1981. Tulsa, Okla.: Pennwell Publishing Co., 1981.

Kaiser, W. R., W. B. Ayres, and L. W. LaBrie. *Lignite Resources in Texas.* Bureau of Economic Geology Report of Investigations No. 104. Austin: The University of Texas at Austin, 1980.

Kaufman, Alvin and Mildred Nadler. *Water Use in the Mineral Industry.* U.S. Department of the Interior, Bureau of Mines Information Circular No. 8285. Washington, D.C.: Government Printing Office, 1965.

Kim, J. R. and R. H. McCuen. "The Impact of Demand Modification." *Journal of American Water Works Association* 69 (February 1977): 92-95.

Little, Arthur D. Incorporated. "Final Report—Study Element B-2: National and Regional Prices Impact Assessment, High Plains-Ogallala Aquifer Area Study." 1982.

Long, Emory G. "Presentation to the [Texas] Lieutenant Governor's Task Force on New Federalism." Statement presented in Austin, Texas, 19 March 1982.

Moore, Charles V. and Trimble R. Hedges. "A Method for Estimating the Demand for Irrigation Water." *Agricultural Economics Research* 15 (October 1963): 131-35.

Muller, Daniel A. and Robert D. Price. *Ground Water Availability in Texas: Estimates and Projections Through 2030.* Report 238. Austin: Texas Department of Water Resources, 1979.

National Water Supply Improvement Association. *Desalting Plants Inventory Report No.7.* Prepared by Techno-Economic Services. Ipswich, Mass. May 1981.

Nelson, E. "ED/EDR at Dell City, Texas." *Journal of the National Water Supply Improvement Association* 5 (January 1978): 1-5.

"OGJ Report: Petrochemical Report." *Oil and Gas Journal* 80 (March 1982): 81-124.

Orton, Robert B. "Climates of the States: Texas." *Climates of the States in Two Volumes: A Practical Reference Containing Basic Climatological Data of the United States.* Vol. 2, *Western States.* Port Washington, N.Y.: Water Information Center, Inc., 1974.

Pace Company Consultants and Engineers, Incorporated. "Pace Petrochemical Service." March 1982.

Parsons, Ralph M. Company. "Preliminary Feasibility and Economics of Desalting Brackish Waters in Candidate Areas of West Texas." Prepared for the Texas Water

Development Board and the Office of Saline Water, U.S. Department of the Interior. OSW Contract 14-01.0001-1459. Los Angeles. 1968.

Plaut, Thomas R. *A Supply Side Model of the Texas Economy and Economic and Population Forecasts to the Year 2000.* Bureau of Business Research BP-82-2. Austin: The University of Texas at Austin, n.d.

Potomac River and Trails Council. *Easy Ways to Save Water, Money, and Energy at Home.* Publication FRD-14. Frederick, Md.: Potomac River and Trails Council, 1980.

"Pulp and Paper Mills Tabulation." *Lockwood's Directory of the Paper and Allied Trades 1980-81.* New York: Vance Publishing Corporation, 1981.

Red River Compact Commission. *Red River Compact: Arkansas, Louisiana, Oklahoma, Texas.* May 1978.

Reed, G. D. "Drought-Related Water Conservation Efforts in Missouri." *Journal of the American Water Works Association* 74 (March 1982): 121-125.

Sabine River Authority. *Proceedings of Seventh Joint Meeting: Sabine River Authority of Texas and Sabine River Authority of Louisiana.* Shreveport, Louisiana: n.p., 1961.

"Saving Water in the Home." *Consumer Reports* 43 (May 1978): 296-302.

Smith, S. Renner. "Frugal Flushers." *Popular Science* 220 (March 1982): 54.

Southwest Power Pool. "Regional Reliability Council Coordinated Bulk Power Supply Program: April 1, 1982: A Report to the Office of Emergency Operations, U.S. Department of Energy Under EP-411." 1982.

Southwest Research Institute. *The Potential Contribution of Desalting to Future Water Supply in Texas,* 4 vols. Prepared for the Texas Water Development Board and the Office of Saline Water, U.S. Department of the Interior. SWRI Project No. 1692. Houston, Texas. November 1966.

Texas Advisory Commission on Intergovernmental Relations. *Handbook of Governments in Texas.* Austin, Texas. 1973. (Loose-leaf.)

Texas Agricultural Extension Service. *Texas Crop Budgets.* Developed by Extension Economists-Management. MP-1027. 1980. (Loose-leaf.)

Texas Crop and Livestock Reporting Service. *1980 Texas County Statistics.* 1981.

Texas Department of Water Resources. "An Overview of Texas Water Resource Problems and Water Resource Issues: As Related to Securing Pubic Input to Revise and Amend the Texas Water Plan." Austin, Texas. February 1982.

________ *Chemical and Physical Characteristics of Water in Estuaries of Texas.* Annual publication. Volumes 1967-1977.

________ *Erosion and Sedimentation by Water in Texas.* Report 268. Austin, Texas. February 1982.

________ *Hazardous Waste Management in Texas.* Publication Series C-10. Austin, Texas. July 1982.

________ *Inventories of Irrigation in Texas: 1958, 1964, 1969, 1974, and 1979."* Report 263. Austin, Texas. October 1981.

________ *Municipal and Industrial Water Conservation in Texas.* Publication Series LP-17. Austin, Texas. May 1977.

________ *Present and Future Surface Water Availability in the Colorado River Basin, Texas.* Publication Series LP-60. Austin, Texas. June 1978.

________ "Proposed Water Quality Management Volume of the Texas Water Plan." Draft Technical Report. Austin, Texas. March 1982.

________ "Six State High Plains-Ogallala Aquifer Area Study: Energy Production Impacts." Regional Study Element A-2.6. Austin, Texas. July 1980.

________ *State/EPA Agreement for Implementation of the Continuing Planning Process and Water Quality Management Strategy.* Publication Series LP-41. Austin, Texas. 1978.

________ *State Water Quality Assessment.* Publication Series LP-98. Austin, Texas. April 1979.

________ *Texas Surface Water Quality Standards.* Publication Series LP-71. Austin, Texas. 1980.

________ *The Influence of Freshwater Inflows Upon the Major Bays and Estuaries of the Texas Gulf Coast: Executive Summary.* 2nd ed. Publication Series LP-115. Austin, Texas. September 1982.

Texas Department of Water Resources. *The State of Texas Water Quality Inventory.* 6th ed. Publication Series LP-59. Austin, Texas. 1982.

________ *The State of Texas Water Quality Management Strategy: FY '83 Baseline.* Draft. Publication Series LP-102. Austin, Texas. n.d.

________ Enforcement and Field Operations Division. Solid Waste and Spill Response Section. "Monthly Effluent Report." self-reporting effluent discharge data submitted monthly. Unpublished data.

________ Office of Public Information. "Desalting Gaining Support as Means of Increasing Potable Water Supply." *Texas Water* (July 1982): 4-5.

________ Office of Public Information. "Rivers and Streams in State Show Healthy Compliance with Standards." *Texas Water* (September 1982): 1-2.

________ Planning and Development Division. *Water Use, Projected Water Requirements, and Related Data and Information for the Standard Metropolitan Statistical Areas in Texas.* Publication Series LP-141. Austin, Texas. March 1981.

________ Planning and Development Division. Economics, Water Requirements and Uses Section. "Survey of Ground and Surface Water Use for the Calendar Year Ending December 31, 19___ ." Annual survey of municipal and industrial water use. Unpublished data. Various years.

________ Planning and Development Division. Weather and Climate Section. *Texas HIPLEX Summary Report: 1975-1980.* Publication Series LP-184. Austin, Texas. 1982.

Texas Energy and Natural Resources Advisory Council. *Texas Energy Outlook: 1980-2000.* January 1980.

Texas Forest Service. Harvest Trends 1979. Publication 122. College Station: Texas A&M University System, 1980.

________ *Harvest Trends 1980.* Publication 125. College Station: Texas A&M University System, 1981.

Texas Governor's Energy Advisory Council. *Provision of Electric Power in Texas: Key Issues and Uncertainties,* 2 vols. Technical Report No. 77-100. Prepared by the University of Texas at Austin Center for Energy Studies. March 1977.

Texas Governor's Task Force on Agricultural Development. Water Committee. "Draft Materials Pertaining to Water Conservation Financing, Water Plan, and Importation." 30 July 1982.

Texas Governor's Task Force on Water Resource Use and Conservation. Committee on Importation. "Recommendations to Texas Energy and Natural Resources Advisory Council and Governor's Task Force on Water Resources Use and Conservation." Austin, Texas. 17 August 1982.

Texas Parks and Wildlife Department. *Existing Reservoir and Stream Management Recommendations: State wide Minimum Streamflow Recommendations.* Performance Report prepared by Barry Lyons. Federal Aid Project F-30-R-4. Austin, Texas. October 1979.

________ Comprehensive Planning Branch. *1980 Texas Outdoor Recreation Plan: State Summary.* Austin, Texas. March 1981.

________ Fisheries Branch. Unpublished data.

Texas Railroad Commission. "1980 Annual Report of the Oil and Gas Division." Austin, Texas. 1981.

________ *A Survey of Secondary and Enhanced Recovery Operations in Texas to 1980.* Bulletin 80. Austin, Texas. 1981.

Texas Water Development Board. *Analytical Techniques for Planning Complex Water Resource Systems: A Summary Report.* Report 138. Austin, Texas. April 1974.

________ *Continuing Water Resources Planning and Development for Texas,* 2 vols. Draft. Austin, Texas. May 1977.

________ *Dams and Reservoirs in Texas.* Report 126. Austin, Texas. October 1974.

________ *Survey of the Subsurface Saline Water in Texas,* 8 vols. Report 157. Austin, Texas. September 1972.

________ *The Texas Water Plan.* Austin, Texas. November 1968.

"The U.S. Energy Outlook for the Year 2000." *Chemical Engineering Progress* 77 (September 1981): 9-15.

Tipee, Robert T., ed. "The Oil Surplus: A Fleeting Phenomenon?" *Oil and Gas Journal* 79 (November 1981): 141-219.

United Nations. Industrial Development Organization. *Second World-Wide Study on the Petrochemical Industry: Process of Restructuring.* (ID/WG.366/3) Second Consultation Meeting on the Petrochemical Industry. Istanbul, Turkey. 22-26 June 1981.

U.S. Army Corps of Engineers. *Water Resources Development by the U.S.Army Corps of Engineers in Texas.* Dallas, Texas. 1979.

________ "Water Transfer Elements of the High Plains-Ogallala Aquifer Area Study." Review Draft. Prepared for the U.S. Department of Commerce. 1982.

________ Fort Worth District Office. "Recreation Visitation Data." Monthly Reports.

U.S. Department of Agriculture. Forest Service. *An Analysis of the Timber Situation in the United States: 1952-2030.* 1980.

U.S. Department of Commerce. Bureau of Economic Analysis. "1980 OBERS BEA Regional Economic Projections: Methodology, Concepts, and State Data" [Machine-readable data file]. 1981.

________ Bureau of Industrial Economics. *1982 U.S. Industrial Outlook for 200 Industries With Projections to 1986.*

________ Bureau of the Census. *1977 Census of Manufacturers: Texas Geographic Area Series.* Vol. MC77-A-44. 1981.

________ Bureau of the Census. *1980 Annual Survey of Manufacturers: Origin of Exports of Manufactured Products.* Subject series M80(AS)-6.

________ Bureau of the Census. *1980 Annual Survey of Manufacturers: Origin of Exports of Manufactured Products.* Subject series M80(AS)-6.

________ Bureau of the Census. "Census of Population and Housing, 1980: Summary Tape File 1A (Texas)" [Machine-readable data file]. Prepared, produced, and distributed by the Bureau of the Census. Washington, D.C. 1981.

________ National Oceanic and Atmospheric Administration. Environmental Data Service. *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-80: Texas.* Asheville, N.C.: National Climatic Center, 1981.

U.S. Department of Energy. Energy Information Administration *1980 Annual Report to Congress.* Vol. 3, *Forecasts.* March 1981.

________ *Energy Transitions: The Forecast Through the Year 2020.* 1981.

________ *Proceedings of the Uranium Industry Seminar, October 21-22, 1981.* GJO-108(81). Grand Junction, Colorado. 1981.

U.S. Department of the Interior. Bureau of Mines. *Minerals Yearbook 1979.* Vol. 1, *Metals and Minerals.* Vol. 2, *Area Reports—Domestic.* 1980.

________ Bureau of Reclamation. *Texas Basins Project.* Austin, Texas. February 1965.

________ Geological Survey. *U.S. Geological Survey Water-Data Reports,* 3 vols. Annual publication. Prepared in cooperation with the State of Texas and other agencies. Various years.

________ Office of Water Research and Techology. *The A-B-C of Desalting.* Report No. 024-000-00836-3. 1977.

________ Office of Water Research and Technology. *Water Conservation Devices: Residential Water Conservation.* Report 024-000-00837-1. 1977.

U.S. Water Resources Council. *The Nation's Water Resources: 1975-2000.* Vol. 2, *Water Quantity, Quality, and Related Land Considerations.* Vol. 4, Regional Reports. Second National Assessment by the U.S. Water Resources Council. December 1978.

"Water Savers: New Hardware Helps You Close the Tap on Waste." *Popular Science* 220 (June 1982): 104-110.

Wesner, G. M. "Introduction to Desalting Processes." *Proceedings of the Ninth Annual National Water Supply Improvement Association Conference.* Washington, D.C.: n.p., 1981.

Wilkerson, Robert M., ed. *1981 Worldwide Petrochemical Directory.* Tulsa, Okla.: Pennwell Publishing Co., 1980.