THE NATION'S WATER RESOURCES 1975-2000

Volume 4: Texas-Gulf Region

Second National Water Assessment by the U.S. Water Resources Council

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Foreword

The Water Resources Planning Act of 1965 (Public Law 89-80) directs the U.S. Water Resources Council to maintain a continuing study of the Nation's water and related land resources and to prepare periodic assessments to determine the adequacy of these resources to meet present and future water requirements. In 1968, the Water Resources Council reported the results of its initial assessment. The Second National Water Assessment, a decade later, provides a comprehensive nationally consistent data base for the water resources of the United States. The results of the Second National Water Assessment were obtained by extensive coordination and collaboration in three phases.

<u>Phase I: Nationwide Analysis</u>

The Council member agencies researched, analyzed, and prepared estimates of current and projected water requirements and problems and the implications of the estimates for the future.

<u>Phase II: Specific Problem Analysis</u>

Regional sponsors, one for each of the 21 water resources regions, surveyed and analyzed State and regional viewpoints about (1) current and future water problems, (2) conflicts that may arise in meeting State and regional objectives, and (3) problems and conflicts needing resolution.

<u>Phase III: National Problem Analysis</u>

The Council conducted this final phase in three steps: (1) An evaluation of phases I and II, (2) an analysis that identified and evaluated the Nation's most serious water resources problems, and (3) the preparation of a final report entitled "The Nation's Water Resources--1975-2000."

The final report of the Second National Water Assessment consists of four separate volumes as described below. These volumes can assist Federal, State, local, and other program managers, the Administration, and the Congress in establishing and implementing water resources policies and programs.

Volume 1, <u>Summary</u>, gives an overview of the Nation's water supply, water use, and critical water problems for "1975," 1985, and 2000 and summarizes significant concerns.

Volume 2, <u>Water Quantity, Quality, and Related Land Considerations</u>, consists of one publication with five parts:

Part I, "Introduction," outlines the origin of the Second National Water Assessment, states its purpose and scope, explains the numerous documents that are part of the assessment, and identifies the individuals and agencies that contributed to the assessment.

II, "Water-Management Problem Profiles," identifies ten general water problem issues and their implications and potential consequences.

Part III, "Water Uses," focuses on the national perspectives regarding existing ("1975") and projected (1985 and 2000) requirements for water to meet offstream, instream, and flow-management needs. State-regional and Federal perspectives are compared.

Part IV, "Water Supply and Water Quality Considerations," analyzes the adequacy of fresh-water supplies (ground and surface) to meet existing and future requirements. It contains a national water budget; quantifies surface- and ground-water supplies, reservoir storage, and transfers of water within and between subregions; describes regional requirements and compares them to supplies; evaluates water quality conditions; and discusses the legal and institutional aspects of water allocation.

Part V, "Synopses of the Water Resources Regions," covers existing conditions and future requirements for each of the 21 water resources regions. Within each regional synopsis is a discussion of functional and location-specific water-related problems; regional recommendations regarding planning, research, data, and institutional aspects of solving regional water-related problems; a problem-issue matrix; and a comparative-analysis table.

Volume 3, Analytical Data, describes the methods and procedures used to collect, analyze, and describe the data used in the assessment. National summary data are included with explanatory notes. Volume 3 is supplemented by five separately published appendixes that contain data for the regions and subregions:

Appendix I, Social, Economic, and Environmental Data, contains the socioeconomic baseline ("1975") and growth projections (1985 and 2000) on which the water-supply and water-use projections are based. This appendix presents two sets of data. One set, the National Future, represents the Federal viewpoint; the other set, the State-Regional Future, represents the regional sponsor and/or State viewpoint.

Appendix II, Annual Water Supply and Use Analysis, contains baseline water-supply data and baseline and projected water withdrawal and water-consumption data used for the assessment. Also included are a water adequacy analysis, a natural flow analysis, and a critical-month analysis.

Appendix III, Monthly Water Supply and Use Analysis, contains monthly details of the water-supply, water-withdawal, and water-consumption data contained in Appendix II and includes an analysis of monthly water adequacy.

Appendix IV, Dry-Year Conditions Water Supply and Use Analysis, contains both annual and monthly baseline and projected water-withdrawal and water-consumption data for dry conditions. Also, a dry conditions water-adequacy analysis is included.

Appendix V, Streamflow Conditions, contains detailed background information on the derivation of the baseline streamflow information. A description of streamflow gages used, correction factors applied, periods of record, and extreme flows of record, are given for each subregion. Also included is the State-Regional Future estimate of average streamflow conditions.

Volume 4, Water Resources Regional Reports, consists of separately published reports for each of the 21 regions. Synopses of these reports are given in Volume 2, Part V.

For compiling and analyzing water resources data, the Nation has been divided into 21 major water resources regions and further subdivided into 106 subregions. Eighteen of the regions are within the conterminous United States; the other three are Alaska, Hawaii, and the Caribbean area.

The 21 water resources regions are hydrologic areas that have either the drainage area of a major river, such as the Missouri Region, or the combined drainage areas of a series of rivers, such as the South Atlantic-Gulf Region, which includes a number of southeastern States that have rivers draining directly into the Atlantic Ocean and the Gulf of Mexico.

The 106 subregions, which are smaller drainage areas, were used exclusively in the Second National Water Assessment as basic data-collection units. Subregion data point up problems that are primarily basinwide in nature. Data aggregated from the subregions portray both regional and national conditions, and also show the wide contrasts in both regional and national water sources and uses.

The Second National Water Assessment and its data base constitute a major step in the identification and definition of water resources problems by the many State, regional, and Federal institutions involved. However, much of the information in this assessment is general and broad in scope; thus, its application should be viewed in that context, particularly in the area of water quality. Further, the information reflects areas of deficiencies in availability and reliability of data. For these reasons, State, regional, and Federal planners should view the information as indicative, and not the only source to be considered. When policy decisions are to be made, the effects at State, regional, and local levels should be carefully considered.

In a national study it is difficult to reflect completely the regional variations within the national aggregation. For example, several regional reviewers did not agree with the national projections made for their regions. These disagreements can be largely attributed either to different assumptions by the regional reviewers or to lack of representation of the national data at the regional level. Therefore, any regional or State resources-management planning effort should consider the State-regional reports developed during phase II and summarized in Volume 4 as well as the nationally consistent data base and the other information presented in this assessment.

Additional years of information and experience show that considerable change has occurred since the first assessment was prepared in 1968. The population has not grown at the rate anticipated, and the projections of future water requirements for this second assessment are considerably lower than those made for the first assessment. Also, greater awareness of environmental values, water quality, ground-water overdraft, limitations of available water supplies, and energy concerns are having a dramatic effect on water-resources management. Conservation, reuse, recycling, and weather modification are considerations toward making better use of, or expanding, available supplies.

CONTENTS

Physiography 1
Description 1
Geology 1
Topography 4
Climate 5
People and the Resources 7
Population 7
Economy 7
Natural Resources 9
Agriculture 10
Energy 11
Navigation 12
Environment: Outdoor Recreation and Wildlife 13
Surface Water 16
Ground Water 16
Water Withdrawals 16
Water Consumption 20
Instream Uses 21
Water Supply and Demand 21
Comparative Analysis 21
Problems 25
Water Supply Problems 25
Water Quality 26
Flooding 27
Drainage 28
Storm and Flood Waters 28
Salinity in the Soil Profile 29
Erosion and Sedimentation 29
Water-oriented Recreation 31
Land Subsidence 32
Saline-water Encroachment 33
Estuarine Management 34
Water Resources Management 34
Individual Severe Water and Related Problems 37
Summary 59
Conclusions and Recommendations 61

Illustrations

Figure 12-1. Region Map 2
Figure 12-2. Present Land Use 3
Figure 12-3. Navigation System 14
Figure 12-4. Environmental Resources 15
Figure 12-5. Streamflow 17
Figure 12-6. Major Aquifers 18
Figure 12-7. Withdrawals and Consumption 19
Figure 12-8a. Problem Map 40
Figure 12-8b. Problem Matrix 41

Physiography

Description

The Texas Gulf Region extends from the Gulf of Mexico northwestward for some 650 miles into the Great Plains Province (Figure 12-1). Almost all of the region (94 percent) lies within the State of Texas, although small portions of Louisiana (1 percent) and New Mexico (5 percent) are also included. The total area of the region is about 177,700 square miles.[1] Only a very small portion of the region consists of water surface.

The region extends from north to south some 500 miles from the Red River to just north of the Lower Rio Grande Valley of Texas. From east to west, the region extends nearly 650 miles, just west of the Texas and New Mexico border to east of the Sabine River.

Much of the region consists of the drainage areas of the Sabine, Neches, Trinity, San Jacinto, Brazos, Colorado, Lavaca, Guadalupe, San Antonio, and Nueces Rivers. These rivers drain in a general northwest to southeast course to the Gulf of Mexico.

The natural vegetation varies from short grasses in the semiarid northwestern section to continuous forests in the eastern portion (Figure 12-2). Tall grasses and small groves of trees predominate in the central portion of the region.

Geology

The western edge of the Texas Gulf Region lies along the Texas and New Mexico border in the High Plains. This topographic plain overlies the Pliocene age Ogallala Formation, which is a series of coalescing alluvial fans composed of sand, clay, silt, and gravel. The upper few feet of Ogallala are cemented by caliche, forming a resistant "caprock" which underlies wind-blown sand dating from the Quaternary age.

East of the High Plains is an area known as the Osage Plains, which overlies westward-dipping Triassic age red to green sandstone and shale of the Dockum Group. Most of the exposed rocks are westward-dipping Permian age "redbeds" (red sandstone and shale) with a few scattered, thin beds of limestone, dolomite, and gypsum. These grade eastward into older Pennsylvanian age sandstone, shale, and bituminous coal. The Pennsylvanian formations underlie a broad area of much younger Cretaceous age limestone, clay, and sandstone formations.

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1 This is the sum of the areas of counties used to approximate the hydrologic area of the region. Land use and other socioeconomic data are related to this area. The drainage area within the hydrologic boundary is 181,440 square miles.

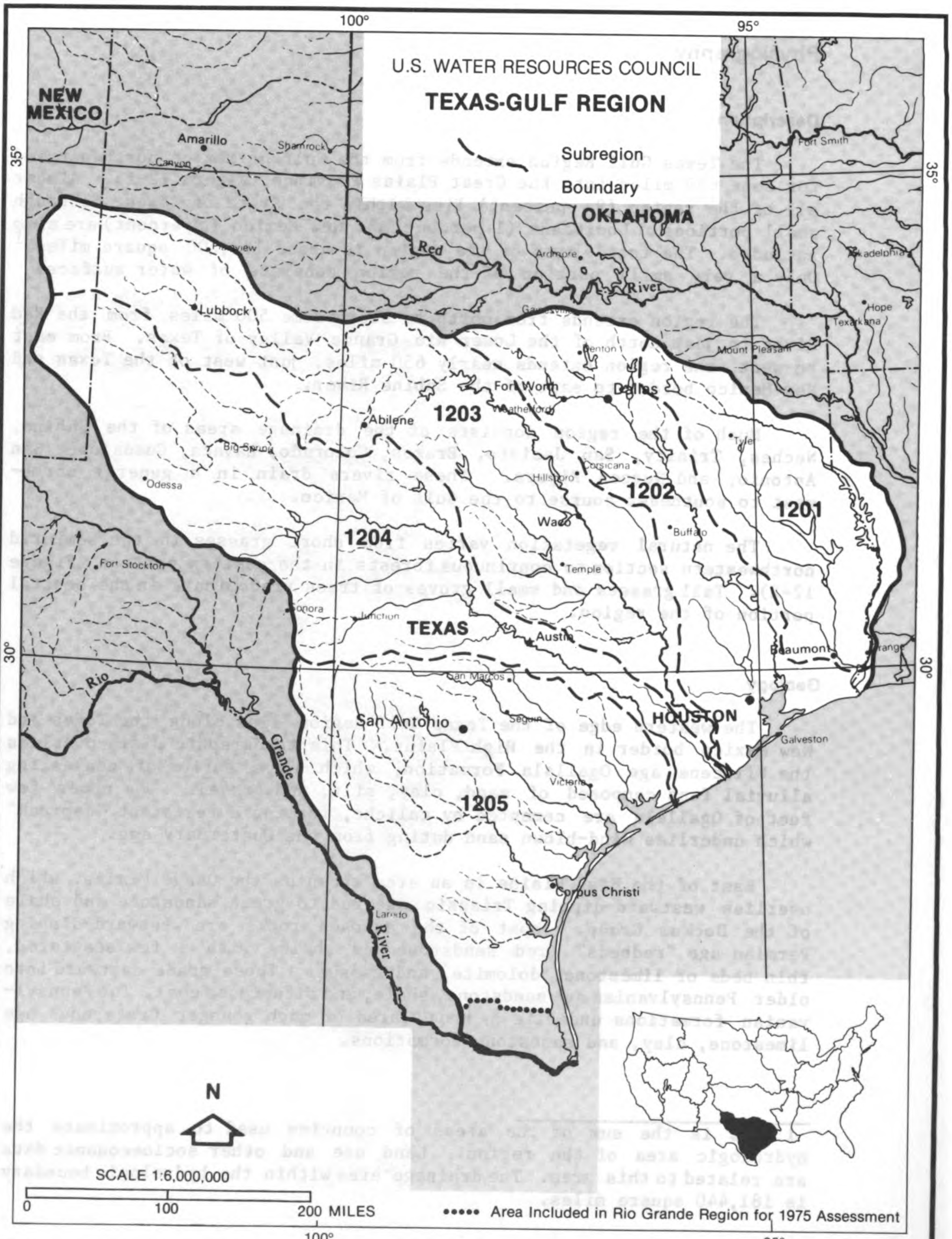


Figure 12-1. Region Map

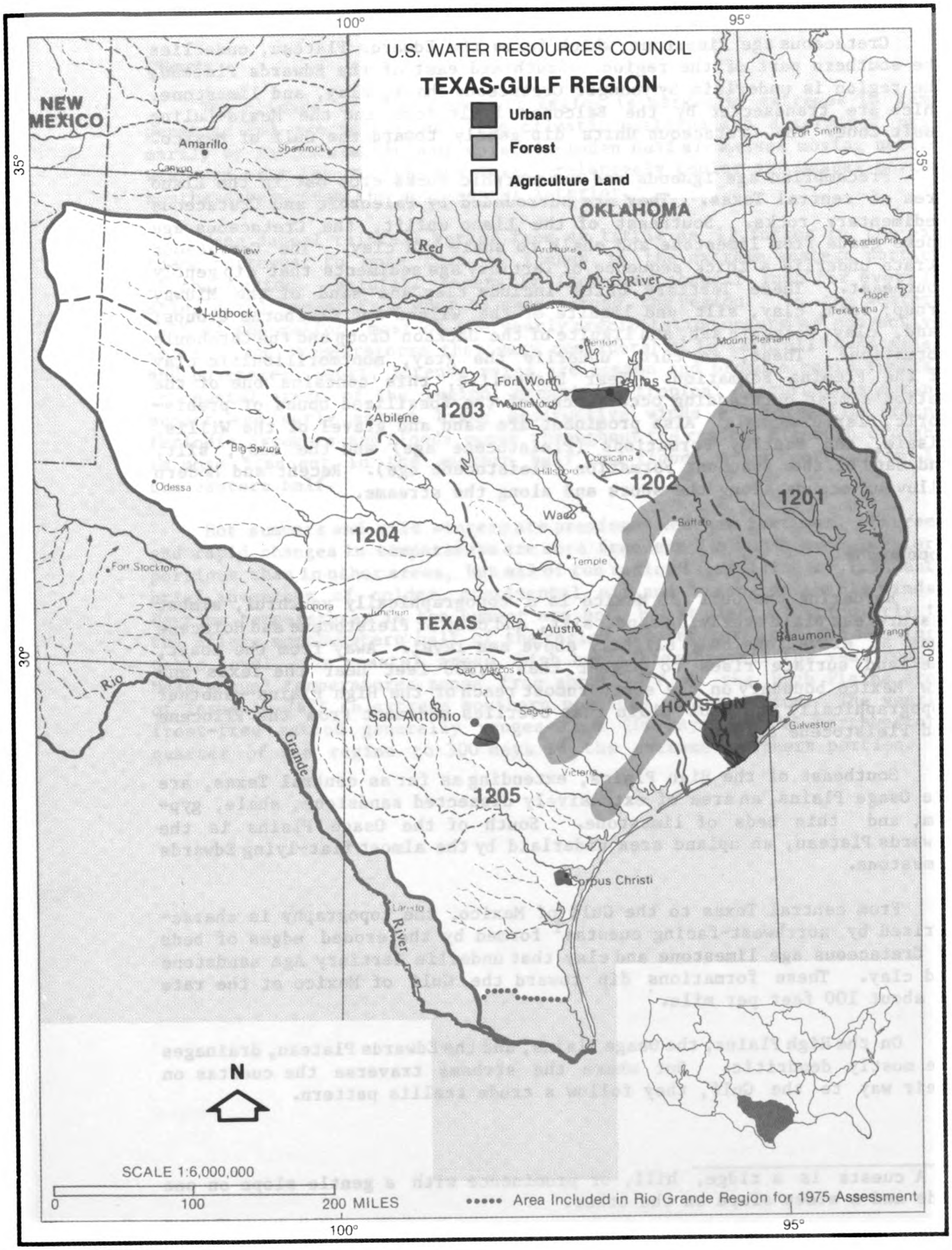
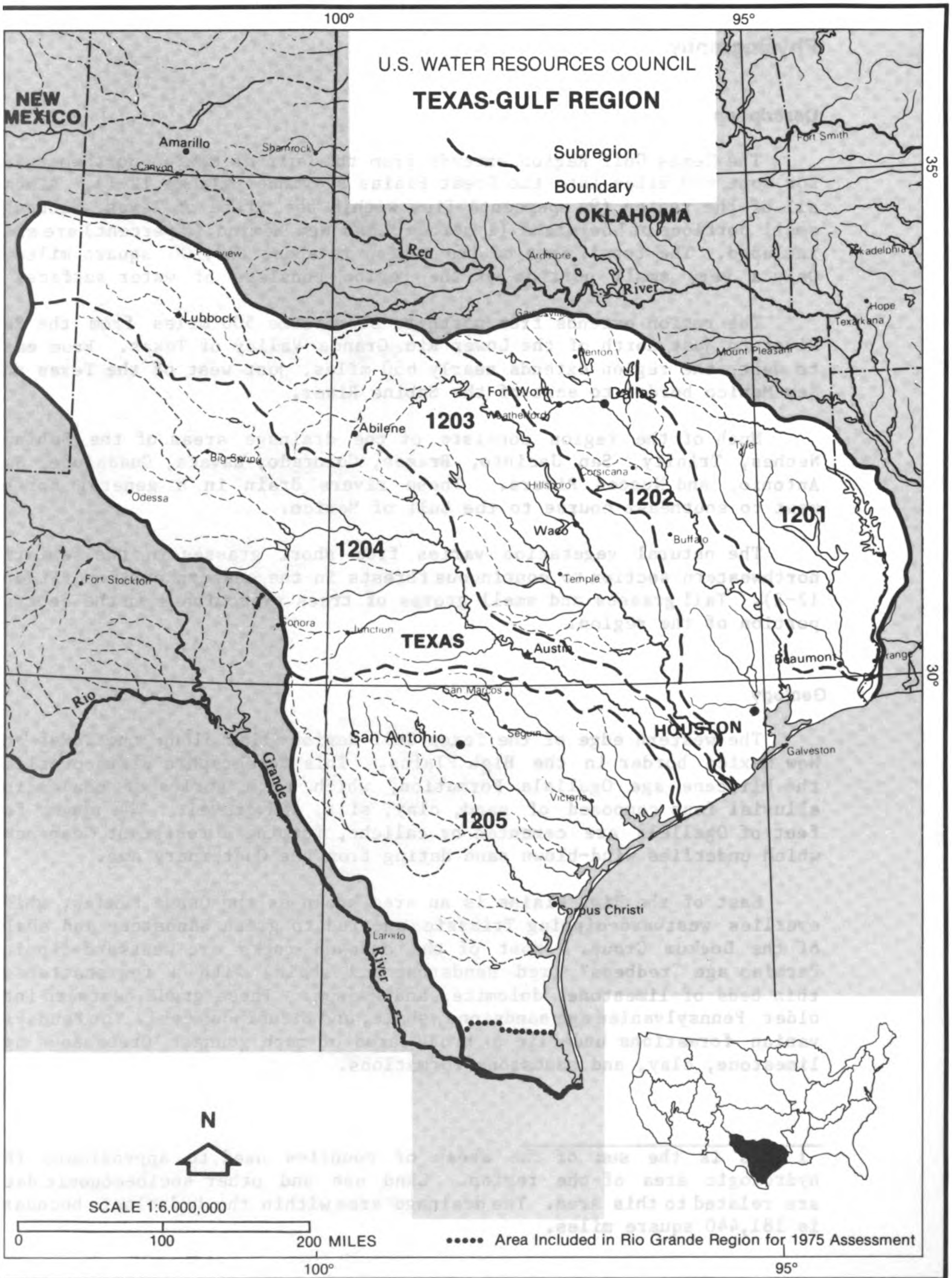


Figure 12-2. Present Land Use



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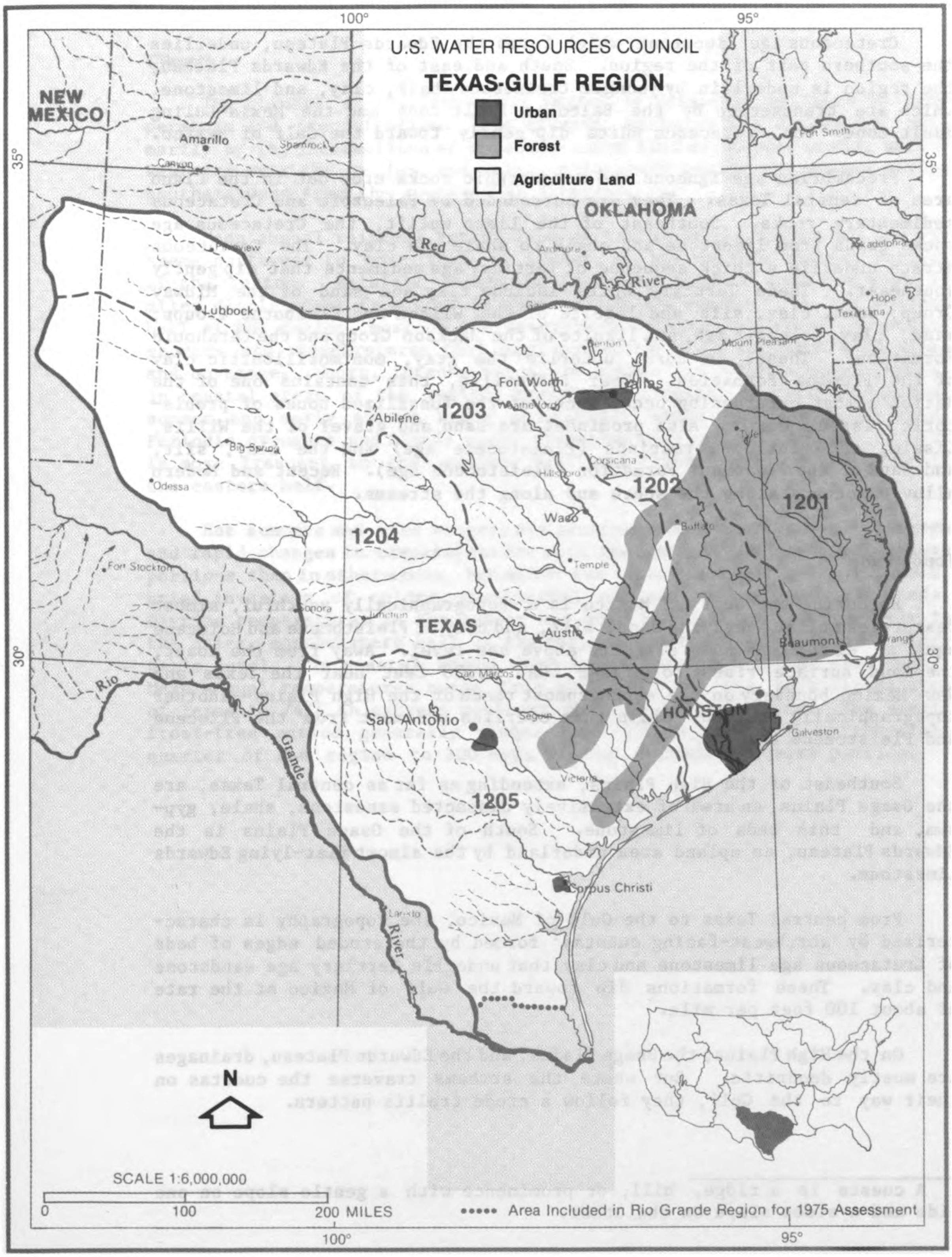


Figure 12-2. Present Land Use

Cretaceous age limestone, which forms the Edwards Plateau, underlies the southern part of the region. South and east of the Edwards Plateau, the region is underlain by younger Cretaceous chalk, clay, and limestone, which are transsected by the Balcones Fault Zone and the Mexia-Luling Fault Zone. The Cretaceous units dip gently toward the Gulf of Mexico.

Precambrian age igneous and metamorphic rocks crop out in the Llano area of central Texas. They are surrounded by Paleozoic and Cretaceous sedimentary rocks. Southeast of the Llano uplift, the Cretaceous age rocks grade from limestone and chalk to shale and clay. The Cretaceous strata underlie a thick sequence of Tertiary age sediments that dip gently southeast. These Tertiary units include clay and sand of the Midway Group; sand, clay, silt and lignite of the Wilcox and Claiborne Groups; sand, clay, volcanic ash, and lignite of the Jackson Group and the Catahoula Formation. These, in turn, underlie the gray, montmorillonitic clay of the Fleming Formation. Near Burkeville, this contains one of the Nation's most outstanding occurrences of the fossilized bones of prehistoric, large mammals. Also prominent are sand and gravel of the Willis, Lissie, and Bentley Formations (Pleistocene age) and the clay, silt, and sand of the Beaumont Formation (Pleistocene age). Recent and Modern alluvium occurs along the shore and along the streams.

Topography

Bordering the Gulf of Mexico is a topographically youthful, almost featureless plain overlying sand, silt, and clay of Pleistocene and Holocene ages at elevations only slightly above sea level. Away from the coast, the land surface rises to higher than 4,200 feet near the Texas and New Mexico boundary on the southernmost reach of the High Plains--another topographically youthful plain that overlies sediment from the Pliocene and Pleistocene ages.

Southeast of the High Plains, extending as far as central Texas, are the Osage Plains, an area of extensively dissected sandstone, shale, gypsum, and thin beds of limestone. South of the Osage Plains is the Edwards Plateau, an upland area underlaid by the almost flat-lying Edwards Limestone.

From central Texas to the Gulf of Mexico, the topography is characterized by northwest-facing cuestas[1] formed by the eroded edges of beds of Cretaceous age limestone and clay that underlie Tertiary Age sandstone and clay. These formations dip toward the Gulf of Mexico at the rate of about 100 feet per mile.

On the High Plains, the Osage Plains, and the Edwards Plateau, drainages are mostly dendritic. But where the streams traverse the cuestas on their way to the Gulf, they follow a crude trellis pattern.

1 A cuesta is a ridge, hill, or prominence with a gentle slope on one side and a steep slope on the other.

Climate

The climate of the Texas Gulf Region is marked by extremes in temperature and precipitation. The climatic patterns are determined primarily by the interactions of moisture-laden Gulf air masses moving northwestward over the region and drier, relatively cooler air masses moving southeastward from the continental interior.

Mean annual rainfall varies from as little as 12 inches in the extreme northwest to more than 55 inches in the extreme eastern portion of the region. Rainfall generally increases about 1 inch for every 15 miles displacement from west to east across the region. In the western half of the region, most of the yearly precipitation occurs as convective showers and thunderstorms that vary considerably in rainfall quantities and coverage. Short, intense rains are common and produce rapid runoff. In coastal areas of the region, occasional tropical disturbances during summer and early autumn bring destructive winds and torrential rain. Periodic droughts and floods occur throughout the region, although drought is more frequent in the western half and floods occur more often in the eastern half.

Hot summers and mild winters are prominent weather features. Extreme and rapid changes in temperature are more frequent in northern and western portions than in other areas, but all of the region is typified by frequent, brief invasions of colder, continental air and strong northerly winds. Daytime temperatures in the summer are hot, but at night, particularly in the drier, northwestern half of the region, temperatures cool to a comfortable level. In coastal areas, high humidities prevail the year round. Mean annual temperatures range from about 58°F in the High Plains area of Texas to 74°F in extreme southern portions of the region. The yearly frost-free period generally ranges from 200 days in the northwestern quarter of the region to 300 days in the extreme southern portion.

People and the Resources

Population

The Texas-Gulf Region encompasses an area which in recent years has become the second fastest growing area in the Nation after Florida. From 1950 through 1975, the region's population increased by over 3.6 million, or 57.0 percent. The average annual increase from 1960 to 1975 was 2 percent.

Estimated 1975 population (NF data) is 9.9 million, which is 4.6 percent of the national total. Metropolitan areas account for 79.4 percent of the regional total. The three major urban centers are Dallas/Fort Worth, Houston, and San Antonio, Texas. Although the metropolitan areas added over 600,000 people from 1960 to 1970, the most rapid rate of increase (46 percent) occurred in cities of between 25,000 and 100,000 population.

Rural population decreased in the fifties, but since 1960 the rural population has remained relatively constant at approximately 2 million, or about 20.0 percent of the regional total in 1975. However, the percentage of rural-to-total population is decreasing at about 2.4 percent per year as the metropolitan areas increase their share of the regional population by about 1.5 percent annually.

Increases in the regional population primarily resulted from natural increase (births minus deaths). However, in recent years in-migration from outside the region has become a major factor in population growth. From 1960 to 1970, natural increase accounted for 90 percent of the population growth, but since 1970 in-migration accounted for 40 percent of the growth. The Texas Gulf Region covers vast open lands where population densities range between 8 and 18 persons per square mile to industrial urban areas such as Dallas and Houston where population density is between 320 and 380 persons per square mile. The rural coastal areas have higher densities than other rural areas, ranging from 20 to 40 persons per square mile.

According to NF estimates, by the year 2000, the population is expected to exceed 12.9 million, a 30 percent increase in twenty-five years. Metropolitan areas are expected to account for 84 percent of the regional population. The rural areas are not projected to lose population, but their share of the total is expected to decrease to 16 percent. By the year 2000, the Texas Gulf Region is projected to increase its share of national population to 4.8 percent.

Economy

The historic economic base of the region was agriculture and oil and gas extraction. In the last 25 years, however, the economy has diversified so that trade, manufacturing, and services each contribute similar dollar amounts to the personal incomes of the population.

A wide range of economic activity occurs within the region, and sources of earnings of the 4 million employed persons reflect the diversification of the area's economy. Total personal income in 1975 was $57.5 billion or about $5,800 per capita, measured in 1975 dollars. Total earnings in 1975 were distributed about as follows: agriculture, 4 percent; manufacturing, 21 percent; mining (the direct extraction of fuel and nonfuel materials not including ancillary services and transportation) 3 percent; and other sources (transportation, communications, utilities, trade, services, finance, construction, and government), 72 percent (see Table 12-1.) The importance of the oil and gas industry is masked because the manufacture of petroleum-based products is not included in the mining category. The direct employment in oil and gas extraction is several times smaller than the total employment of the petroleum industry. Much of the related employment and earnings is included in the construction, manufacturing, utilities, transportation, and "other" categories.

The region contains major manufacturing establishments which contribute significant output to the Nation's economy. Practically all of the petrochemical and petroleum refining capacity in Texas is located in the Texas Gulf Region, primarily along the Texas Gulf Coast. Texas's petroleum processing industry ranks above all States in value of output of petroleum-based products, and Texas is the third leading chemical producing State after California and New Jersey. These two industries contribute almost $1.4 billion annually in earnings to employees and produce over $4 billion (1972 dollars) in value added to raw materials each year. Other major manufacturing industries are machinery, transportation equipment, fabricated metals, and electrical apparatus. The major water-using manufacturing industries (paper, food, chemicals, petroleum refining, and metals) contribute about 37 percent of total regional earnings.

The Houston area was the second ranking metropolitan area of the Nation in terms of growth in value added by manufacture in 1967 to 1972 and was sixth in total new capital expenditures in 1972.

Personal income from agriculture is approximately 4 percent of the Nation's total farm income. An estimated 50 percent of the total production is exported to the rest of the Nation and other countries. Growth of agriculture has been made possible by irrigation, especially in the southern High Plains, where over 60 percent of the cash receipts are derived from sales of irrigated crops. The Nation's leading rice producing region, which also requires irrigation, is located along the Texas Gulf Coast.

The Dallas/Fort Worth metropolitan area ranks eighth among metropolitan areas in wholesale sales. This particular area also contains many durable goods manufacturing plants.

Earnings from the "other" category, which consists of the service and marketing sectors, are distributed, in terms of total regional earnings, as follows: trade, 18 percent; government, 17 percent; services, 16 percent; transportation, communications, and public utilities, 8 percent; construction, 7 percent; and financial sectors, 6 percent.

The natural resources of the region and the diversification of its economy should contribute to further expansion of employment and economic activity. New locations or expansions of individual industries expand the State's economic base because of the interindustry linkages between producers, suppliers, and consumers of goods and services. The magnitude of the impact of increased production varies with each industry depending upon the extent of the linkages within the region. Thus, relatively small increases in sectors such as mining have a high total impact on dependent industries such as petroleum refining and chemicals, which heavily depend upon petroleum raw materials. Total employment (which exceeded 4 million in 1975) is expected to increase slightly faster than the population in general, and is projected to reach 5.8 million by the year 2000. Earnings, however, will be more than double the 1975 level as per capita income doubles. The largest source of anticipated growth of earnings is the "other" category. This includes the rapidly expanding wholesale and retail trade sectors, which market the agricultural and manufactured products, and the sectors that provide services directly, such as financial and professional services. The chemical and paper industries are anticipated to be the fastest growing manufacturing sectors from 1975 to 2000. Due to depleting oil and natural gas reserves, earnings from mining are expected to increase only 22 percent over the same period. Agriculture, which is increasingly limited by the availability of water, is projected to account for only 1.6 percent of total regional earnings by 2000.

Table 12-1.--Texas-Gulf Region earnings--1975, 1985, 2000
(million 1975 dollars)

Earnings sector	1975	1985	2000
Manufacturing----------------	9,589	14,373	23,759
Agriculture------------------	1,738	1,690	1,934
Mining-----------------------	1,355	1,485	1,656
Other------------------------	33,142	50,817	90,844
Total----------------------	45,824	68,365	118,193

Natural Resources

Utilization of the abundant and varied natural resources of the Texas Gulf Region--land, water, mineral, and fishing resources--has stimulated regional economic growth and made the region a major net exporter of goods and services. About 77 percent of the land is used for cropland, pasture, and other agricultural purposes. The remainder is in woodland, urban areas, water, transportation, and other uses. The agricultural land, however, is expected to decline to about 70 percent of the area by the year 2000 (Table 12-2).

Table 12-2.-- Texas-Gulf Region surface area and 1975 land use

Surface area or land use type	1,000 acres	Percentage of total surface area
Surface area		
Total	113,726	100.0
Water	2,692	2.4
Land	111,034	97.6
Land use		
Cropland	25,021	22.0
Pasture & range	58,632	51.6
Forest & woodland	20,176	17.7
Other agriculture	2,160	1.9
Urban	2,485	2.2
Other	2,560	2.2

Mineral resources also account for a large share of the natural resource base. The leading mineral resources are petroleum and natural gas. The region accounts for a major percentage of the Texas resource reserve. In 1974 it was estimated that the liquid hydrocarbon reserves were 13.8 billion barrels, and natural gas reserves were 78.5 trillion cubic feet. This made up 34 percent and 33 percent of the national reserves of liquid hydrocarbons and natural gas, respectively.

Another important mineral resource being developed in Texas is lignite, a low grade of coal. Nearly all lignite reserves in Texas are located within the region. The estimated State reserve of lignite near the surface (less than 200 feet deep) is about 10.4 billion short tons. Deeper reserves approximate 100.0 billion short tons.

A third important mineral resource is the large deposit of uranium being mined in Karnes and Live Oak Counties, which are situated between San Antonio and Corpus Christi. Finally, several other nonmetallic mineral resources are found. Among the most important are cement, sulfur, sand, gravel, salt, and stone.

Production of metals is relatively insignificant, comprising less than 1 percent of the total mineral production. Some of the metals produced include iron and magnesium.

Agriculture

The region's total agricultural land use base is projected to decline slightly from 85.8 million acres in 1975. The SRF data indicate that about 10.2 million acres of pasture and rangeland will be converted to urban, recreation, transportation, and other uses. In 1975, cropland (feed crops, food crops, and all other crops) accounted for 22.5 percent of the land in the Texas-Gulf Region. Forest and woodland comprised 18.2 percent; pasture, range, and other agriculture made up 54.8 percent; and urban and other uses took 4.5 percent.

Table 12-3.--Projected changes in cropland and irrigated farmland in the Texas-Gulf Region -- 1975, 1985, 2000
(1,000 acres)

Land category	1975	1985	2000
Total cropland------------------	25,021	24,938	24,585
Cropland harvested--------------	13,442	20,026	17,942
Irrigated farmland--------------	4,770	4,188	3,440

The NF estimates a decrease from about 4.8 million acres in 1975 to about 3.4 million acres in 2000, largely as a result of declining ground-water levels. Efficiency of on-farm irrigation water use is expected to increase from about 65 percent in 1975 to 80 percent in 2000. Irrigation water requirements are projected to decrease from 11,538 mgd in 1975 to 7,427 mgd in 2000 for mean annual conditions. Water requirements to meet the demands of the livestock industry are expected to increase from 180 mgd in 1975 to 228 mgd in 2000.

Energy

The Texas Gulf Region is one of the major energy producing and processing areas in the United States. A large portion of the 3 billion barrels of crude oil and 8 trillion cubic feet of natural gas produced in Texas in 1975 was produced in the region. Refinery capacity exceeds 4 million barrels per day.

In 1975 there were 433.6 megawatts of installed hydroelectric generating capacity, 29,204 megawatts of steam electric generating capacity, and 1,128 megawatts of gas turbine and internal combustion engine capacity in the region -- a total installed capacity of 30,765 megawatts of electric generating capacity operated for public distribution. Over 122,800 gigawatt hours (gWh) of electricity were generated in 1975 using fossil fuel. Of this total, 14 percent used wet towers for cooling, 27 percent used once-through cooling or fresh-water systems, 4 percent used a combination of towers and once-through cooling, 33 percent used single purpose reservoirs, and 29 percent used saline coastal water sources. In addition, private industry has 2,510.6 megawatts of steam electric capacity and 530.3 megawatts of gas turbine and internal combustion engine capacity for "in plant" use.

By 1985 the region will have over 49,000 megawatts of installed capacity, which will generate about 275,000 gigawatt-hours of electricity; projections indicate that installed capacity will exceed 98,000 megawatts and generation will approach 825,000 gigawatt-hours by the year 2000 (Table 12-4). Nuclear power will generate 75 percent and fossil fuel nearly 25 percent of the electricity produced in the year 2000 according to these projections.

Table 12-4.--Texas-Gulf Region electric power generation--1975, 1985, 2000 (gigawatt-hours)

Fuel Source	1975	1985	2000
Fossil	122,873	215,690	205,180
Nuclear	0	58,166	618,420
Conventional hydropower	1,121	823	916
Total	123,994	274,679	824,516

The region has significant lignite reserves in the Carrizo, Yegua-Jackson, and Manning formations. Near-surface deposits (200 feet deep or less) exceed 10 billion tons. Geothermal sources, in the form of geo-pressured sands along the Texas and Louisiana Gulf Coast, offer some potential, but estimates of developable energy sources decline as more is learned about the geology of these formations. Solar and wind energy sources also offer some potential. The insolation rate averages from 1,500 Btu per day per square foot in the eastern part of the region to over 1,800 Btu per day per square foot in the western part. An experimental solar-thermal steam electric powerplant is being planned for Crosbyton, Texas, near Lubbock. Several universities in the region are exploring wind power. These technologies, however, are still in the developmental stage. Wave heights and tidal amplitudes along the Texas and Louisiana Gulf Coast are small when compared to those in other parts of the world and are not thought to offer a great potential.

Based on current estimates of the recoverable reserve, there is enough lignite to support 41,000 megawatts of steam electric generating capacity with an average plant life of 30 years. In addition to the 10 billion tons of near-surface lignite, vast amounts of deep-basin deposits (200 feet deep or greater) may be recoverable in the future through in-situ gasification or other emerging technologies. There are scattered subbituminous coal deposits in several parts of the Texas Gulf Region, but these are generally considered uneconomical to mine.

Uranium deposits are found throughout the Texas Gulf Region. Deposits occur in the Garza County Triassic Rocks, in the Llano uplift, and in the southern coastal plains. Total resources are estimated between 16,000 and 50,000 tons, equal to a little over 5 percent of the Nation's supply. The south Texas plains deposits are presently being mined.

Navigation

The major ports in the Texas Gulf Region are among the busiest in the Nation. Cargo amounting to well above 200 million tons moves through docking facilities each year. Supplementing the ports, the Gulf Intracoastal Waterway parallels the Texas coast from the Sabine River to Brownsville. Barge movement of bulk commodities along this channel has enhanced the development of a vast industrial complex, not only surrounding the major port facilities, but all across the coastal plain. The majority of navigation within the region takes places in these ports and on the waterway (Figure 12-3).

The Trinity River Project, authorized in 1965, proposes a major inland navigation facility: a multipurpose channel for flood control and navigation connecting a series of major conservation reservoirs on the Trinity River by means of a series of navigation dams and locks. This project would provide navigation from Galveston Bay to Dallas and Fort Worth. Annual benefits to be derived from this waterway, which have been submitted to the Congress by the Corps of Engineers, were recently revised. They still compare favorably with construction costs.

The waterborne commerce system along the Texas Coast is vast and complex. Waterways are a vital force in the economic life of the region. Most major industries need and seek to locate at sites accessible to low-cost water transportation. For future development to keep pace with economic needs of the region, adequate financing must be available for channel construction, facility development, and operating and maintaining ports and shallow draft canals.

Environment: Outdoor Recreation and Wildlife

Recreational land resources in the Texas Gulf Region include more than 1.7 million acres of parkland, approximately 702 miles of accessible Gulf Coast and bay shoreline, and approximately 67 million acres of privately owned land available periodically for hunting. Water resources include over 1.1 million surface acres of major lakes and reservoirs; approximately 12,000 miles of rivers, streams, and bayous; approximately 2.1 million surface acres of salt-water bays; and an estimated 2,264 miles of Gulf and bay shoreline (Figure 12-4).

The U.S. Fish and Wildlife Service of the U.S. Department of the Interior administers 10 national wildlife refuges in Texas having 154,343 acres. The Texas Parks and Wildlife Department administers 11 fish hatcheries, 12 wildlife management areas, 2 waterfowl refuges, and 7 scientific areas. Combined, these State-administered areas have 207,361 acres of land devoted to fish and wildlife conservation.

Texas has approximately 142 species of indigenous mammals. Five are listed in the Federal Register as endangered species: the black-footed ferret, Florida manatee, red wolf, ocelot, and bighorn sheep. They are endangered because of predator control and habitat destruction. Game mammals contribute significantly to recreation for hunters. The most important game animals include white-tailed deer, American antelope, mule deer, and javelina.

In addition to mammals, about three-fourths, or 540 species, of the birds found in the United States are native to Texas. Game birds include the wild turkey, mourning dove, quail, pheasant, and a wide variety of waterfowl. Most of these species have a wide range and offer excellent hunting over most of the State. Among endangered species in Texas are

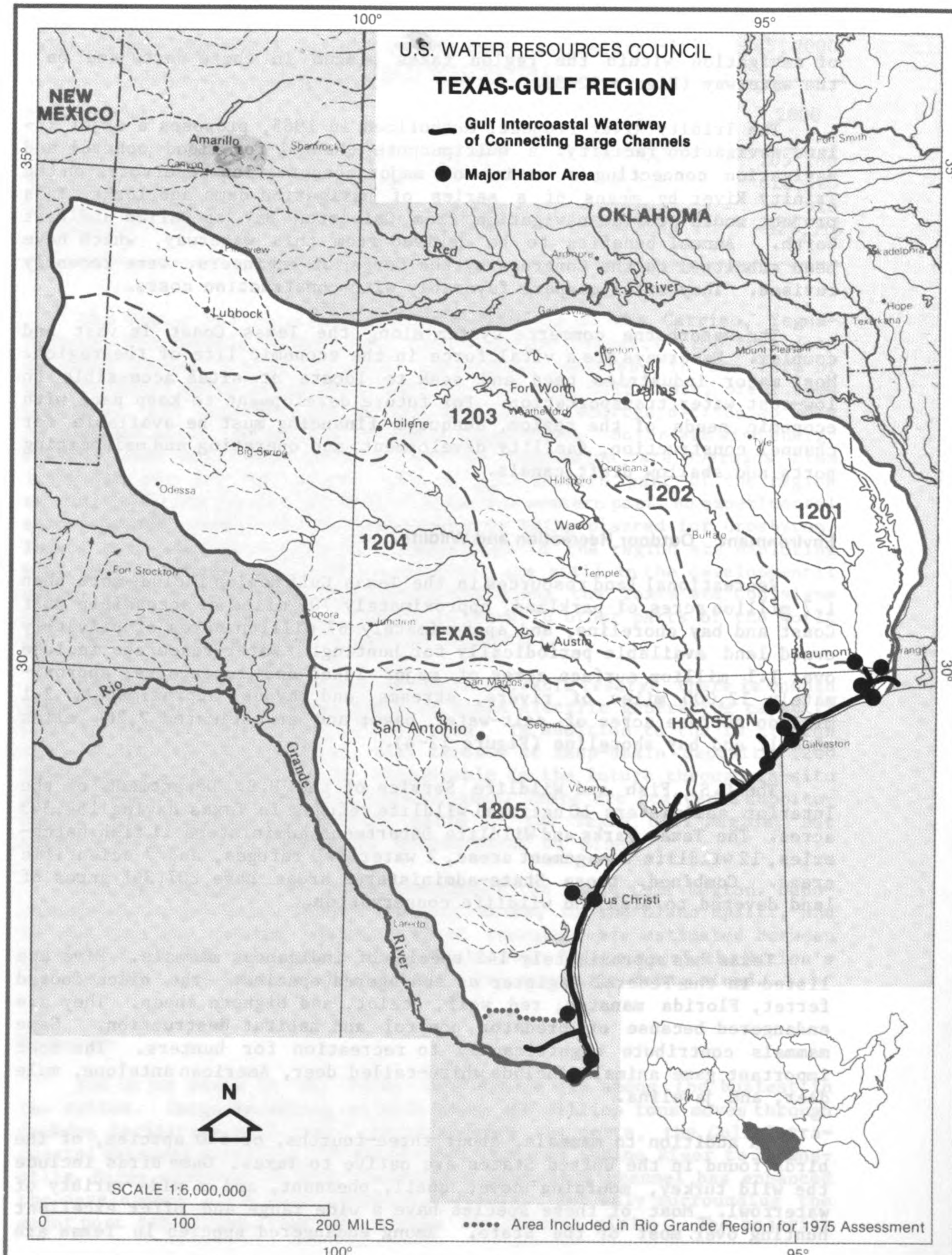


Figure 12-3. Navigation System

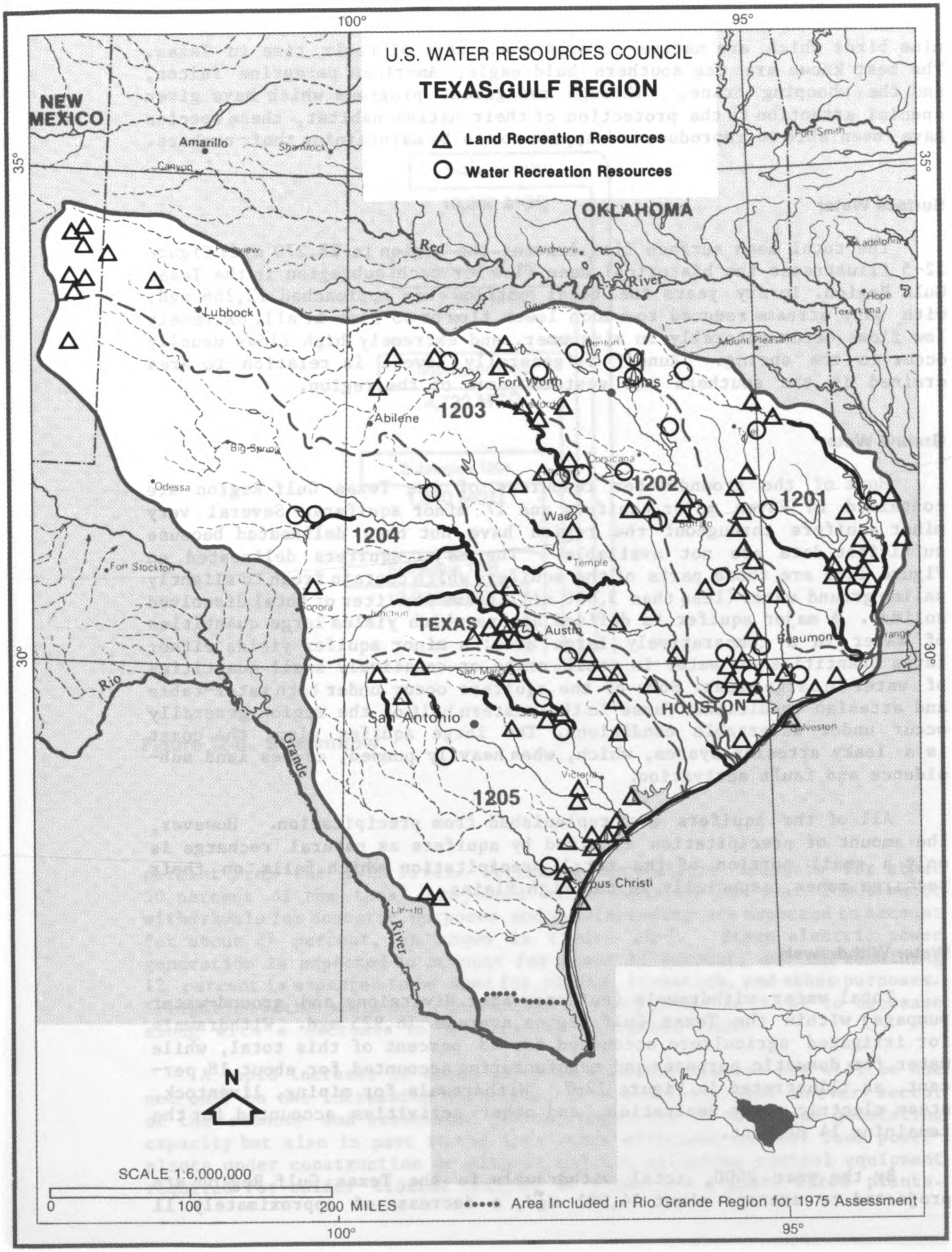


Figure 12-4. Environmental Resources

nine birds which are native to or spend a part of their time in Texas. The best known are the southern bald eagle, American peregrine falcon, and the whooping crane. Through management programs which have given special attention to the protection of their native habitat, these species have been able to reproduce and appear now to be maintaining their numbers.

Surface Water

The total mean surface flow leaving the region is 28,270 mgd. Figure 12-5 illustrates the historical mean flow for each subregion in the Texas Gulf Region. In dry years the total outflow has approached 12,266 mgd, with many streams reduced to a much lower flow or no flow at all. Extremely low flows occur generally in midsummer, and extremely high flows usually occur in the spring. Runoff is generally lowest in relation to area drained in the southern and western parts of the region.

Ground Water

Most of the ground-water resources of the Texas Gulf Region are contained in seven major aquifers and 17 minor aquifers. Several very minor aquifers throughout the region have not been delineated because sufficient data are not available. The major aquifers delineated on Figure 12-6 are those parts of the aquifers which contain fresh to slightly saline ground water (less than 3,000 milligrams per liter of total dissolved solids). A major aquifer is defined as one which yields large quantities of water in a comparatively large area; a minor aquifer yields either large quantities of water in small areas or relatively small quantities of water in large areas. Some of the aquifers occur under both water-table and artesian conditions. Those in the western half of the region generally occur under watertable conditions. The large aquifer along the coast is a leaky artesian system, which, when heavily pumped, causes land subsidence and fault activation.

All of the aquifers are replenished from precipitation. However, the amount of precipitation received by aquifers as natural recharge is only a small portion of the total precipitation which falls on their recharge zones, especially in the High Plains.

Water Withdrawals

Total water withdrawals (surface-water diversions and ground-water pumpage) within the Texas Gulf Region average 16,925 mgd. Withdrawals for irrigated agriculture accounted for 68 percent of this total, while water for domestic purposes and manufacturing accounted for about 18 percent, as illustrated in Figure 12-7. Withdrawals for mining, livestock, steam electric power generation, and other activities accounted for the remaining 14 percent.

By the year 2000, total withdrawals in the Texas Gulf Region are projected to average about 14,991 mgd, a decrease of approximately 11

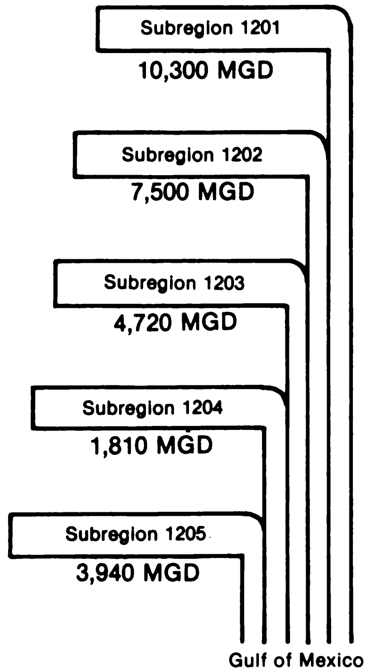


Figure 12-5. Streamflow

percent from the 1975 level. Irrigated agriculture accounts for about 50 percent of the total projected withdrawals in the year 2000; water withdrawals for domestic purposes and manufacturing are expected to account for about 27 percent, as shown in Figure 12-7. Steam electric power generation is expected to account for about 11 percent, and the remaining 12 percent is expected to be used for mining, livestock, and other purposes. Irrigation withdrawals and consumption are projected in the NF to decrease along with a decrease in the area of irrigated land.

A rapid increase in steam electric generation water use will be due not only to the increasing quantities of electricity used in every sector of the economy and associated planned expansion of base-load generating capacity but also in part to the less water-efficient nuclear fuel power-plants under construction or planned and air pollution control equipment required for sulfur dioxide control at coal- and lignite-fired plants.

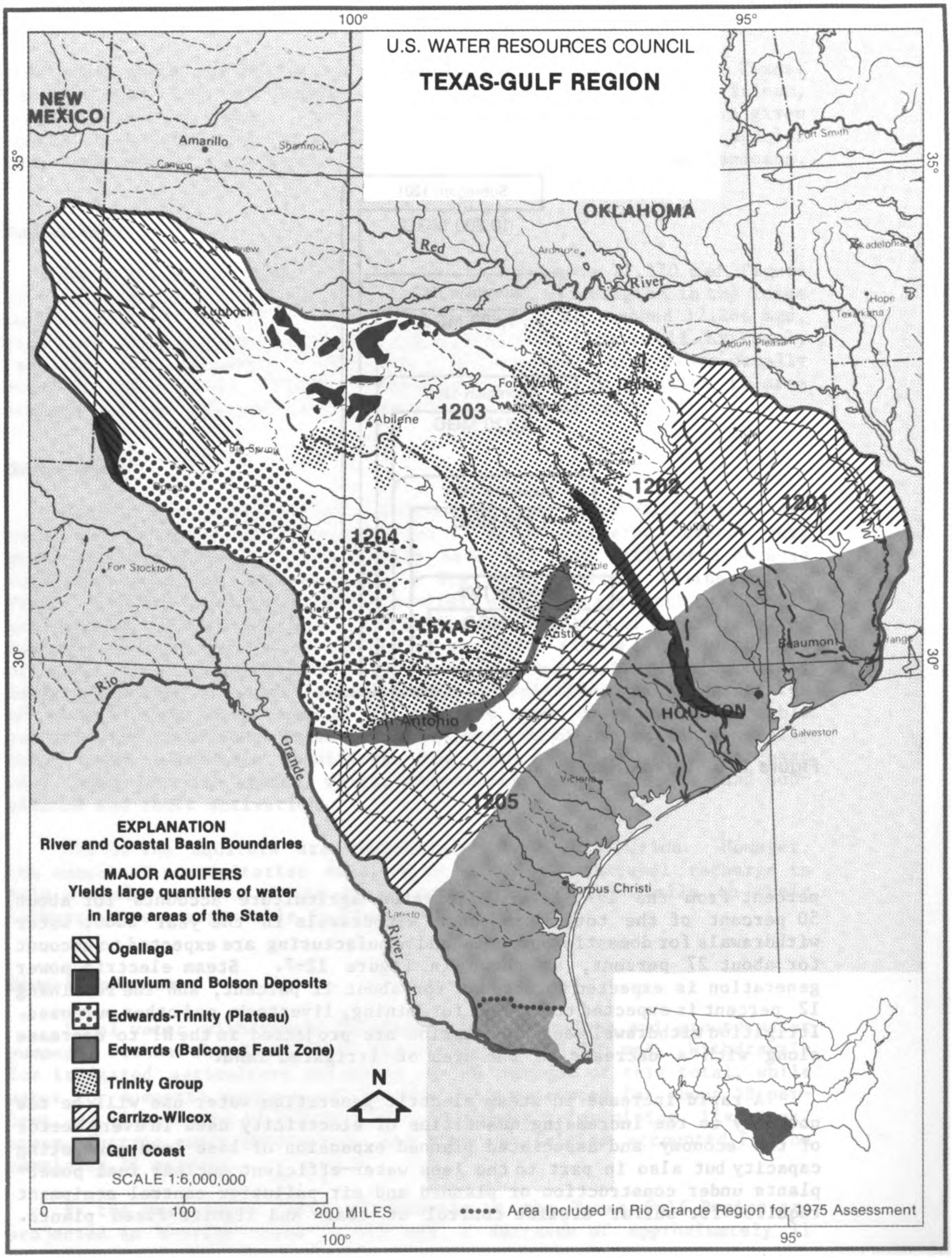
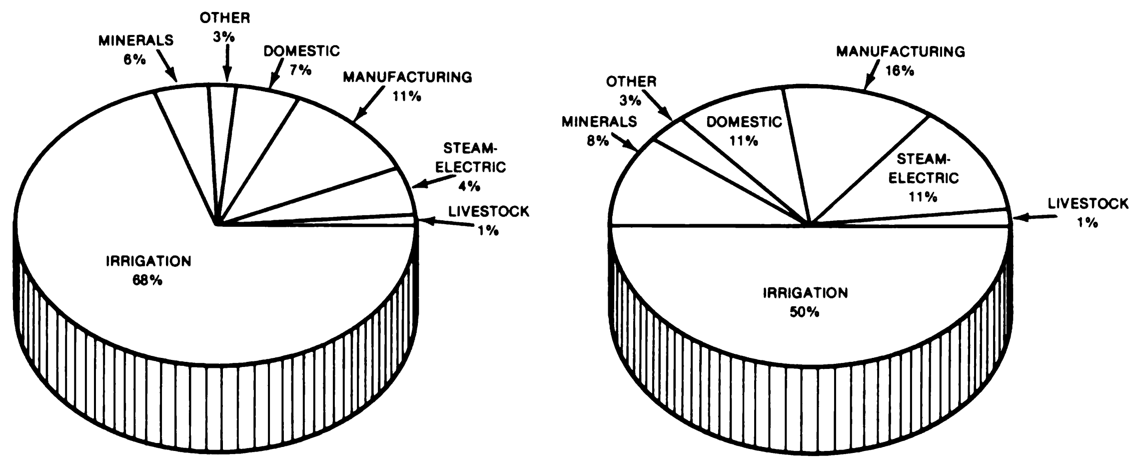


Figure 12-6. Major Aquifers

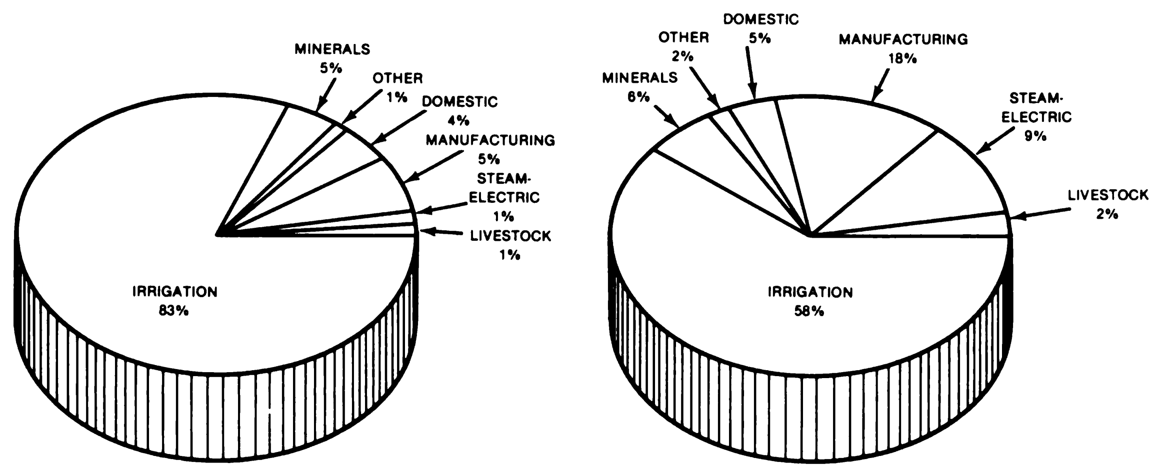
ANNUAL FRESHWATER WITHDRAWALS



1975
Total Withdrawals — 16,925 MGD

2000
Total Withdrawals — 14,991 MGD

ANNUAL FRESHWATER CONSUMPTION



1975
Total Consumption — 11,259 MGD

2000
Total Consumption — 10,529 MGD

Figure 12-7. Withdrawals and Consumption

In 1975 surface-water diversions averaged 9,703 mgd, or about 57 percent of the total withdrawals. Ground-water pumpage averaged 7,222 mgd, or about 43 percent of the total withdrawals. By the year 2000, surface water is projected to account for a larger proportion of total withdrawals which reflects the growing importance of surface water to the Texas Gulf Region. Ground-water supplies throughout the region are diminishing rapidly because pumpage exceeds natural recharge by a wide margin in most aquifers. To meet projected water requirements, the region must increasingly depend on surface-water supplies.

Water Consumption

Consumptive water use by the various categories in 1975 is illustrated in Figure 12-7. Total water consumption (withdrawals minus return flows) within the Texas Gulf Region averaged 11,259 mgd in 1975, about 66.5 percent of the total withdrawals. Stated another way, the average return flow for all uses was about 5,666 mgd, or about 33.5 percent of the total withdrawals. Irrigation accounted for 83 percent of the total consumptive use in the Texas Gulf Region. Domestic and manufacturing users accounted for 4 percent and 5 percent, respectively. The remaining 8 percent was consumed by mining, livestock, steam electric generation, and other uses.

Consumptive use in the Texas Gulf Region appears quite high. This is understandable because irrigated agriculture is the dominant water user, and irrigation return flows, expressed as a ratio of irrigation withdrawals, are relatively small compared to similar ratios for municipal and manufacturing return flows. The ratio of return flow to withdrawal varies widely among users and depends on many variables. In general, the ratio for manufacturing users ranges between 60 and 70 percent, the ratio for municipal users ranges between 40 and 50 percent, and the ratio for irrigation ranges from as low as 0 to as high as 40 percent and averages only about 10 percent throughout the region.

Consumptive use by the various users projected for the year 2000 is illustrated in Figure 12-7. By the year 2000, total consumptive use is projected to average 10,529 mgd, or about 70 percent of the projected total withdrawals. Consumptive use by irrigated agriculture is projected to account for 58 percent of the total consumptive use. Domestic and manufacturing users are projected to account for 5 percent and 18 percent, respectively, of the total. Steam electric generation is projected to account for 9 percent. The remaining 10 percent represents consumptive use for mining, livestock, and other purposes. Reservoir and pond evaporation is an additional depletion not included in these percentages.

The ratios of return flow to withdrawal for irrigation, domestic, and steam electric generation uses will not change significantly between the years 1975 and 2000. However, consumptive use as a percentage of withdrawal by manufacturing industries is expected to increase substantially. By the year 2000, it is projected that about 78 percent of the manufacturing withdrawals will be consumptively used. With increasingly restrictive effluent standards imposed by Public Law 92-500 and the high costs of treatment to comply with those standards, it is anticipated that many industries will find it more cost-effective to increase the efficiency of this water use.

Instream Uses

In view of the increasing competition for fish and wildlife habitat and increased demands for outdoor recreation, water resources, parks, nature areas, and wilderness areas, water resources development programs of the Texas Gulf Region are including these factors. Comprehensive assessments are made of the quantity and benefits of water-oriented recreation associated with each project and of the water requirements to support fish, wildlife, and outdoor recreation. Adverse effects resulting from development can be kept at a minimum through sound environmental planning, which includes the determination of instream flow needs for the aquatic system.

Determining fish and wildlife instream water requirements involves analysis of hydrology in terms of quantity, quality, and flow duration. Any water resource development inevitably affects the water quality and, in turn, the biota of the ecosystem. Concomitant streamflow and biological studies are used to predict the impact of water resources development. The ability to predict changes in fish and wildlife resources caused by habitat alterations is essential to the planning and will provide decision-makers with the information necessary for determining instream flow needs for fish and wildlife resources. Further efforts in the field of fish and wildlife resources management will enhance the State economy, provide additional recreation, and assure the continued existence of these natural resources.

Water Supply and Demand

The Texas Gulf Region, with its growing population and its vast agriculture and manufacturing capacities, depends on an adequate water supply. Because of declining ground-water resources and increasing water demands, the future water supply for the region will become critical in many areas.

As noted in the following section, "Comparative Analysis," the region may experience a water supply shortage in a drought year. This problem is further compounded by the geographic distribution of the demands and the supply. Surpluses exist in the eastern part of the region, and severe shortages exist in the western part. Regional studies conclude that the domestic, manufacturing, mining, and steam electric demands can be met through the year 2000; however, new surface-water projects and conveyance facilities must be completed and in operation at that time.

Comparative Analysis

Table 12-5 compares the National Future (NF) and State-Regional Future (SRF) estimates of streamflows and water use in the Texas-Gulf Region under base conditions. In 1975, total NF withdrawals exceed total SRF

Table 12-5--Socioeconomic and volumetric data summary: the Texas-Gulf Region

Category	1975		1985		2000	
	NF	SRF	NF	SRF	NF	SRF
SOCIOECONOMIC DATA (1000)						
Total population	9,911	10,233	11,162	12,470	12,907	15,990
Total employment	4,109	4,022	4,827	5,180	5,767	6,769
VOLUMETRIC DATA (mgd)						
-Base conditions-						
Total streamflow	33,951	NE	33,951	NE	33,951	NE
Streamflow at outflow point(s)	28,270	26,368	23,554	22,097	23,135	18,152
Fresh-water withdrawals	16,925	10,510	15,932	13,212	14,991	16,991
Agriculture	11,718	7,397	9,530	8,230	7,655	9,499
Steam electric	724	296	1,000	712	1,713	1,508
Manufacturing	1,932	1,177	2,559	1,466	2,444	2,273
Domestic	1,207	1,427	1,380	2,556	1,621	3,379
Commercial	283	a	317	a	300	a
Minerals	1,044	194	1,133	234	1,245	284
Public lands	<1	19	2	14	2	15
Fish hatcheries	17	NE	11	NE	11	NE
Other	0	<1	0	<1	0	33
Fresh-water consumption	11,259	8,161	10,227	10,005	10,529	12,490
Agriculture	9,527	6,726	7,794	7,487	6,328	8,558
Steam electric	99	149	270	357	991	752
Manufacturing	571	387	1,003	551	1,917	1,073
Domestic	413	794	467	1,485	541	1,936
Commercial	94	a	103	a	118	a
Minerals	555	100	588	119	632	146
Public lands	<1	NE	2	NE	2	NE
Fish hatcheries	0	NE	0	NE	0	NE
Other	0	5	0	6	0	24
Ground-water withdrawals	7,222	7,172	NE	4,961	NE	3,398
Evaporation	1,705	1,743	1,875	1,964	1,992	1,972
Instream approximation						
Fish and wildlife	22,917	NE	22,917	NE	22,917	NE

NE - Not estimated.

[a] SRF domestic water use includes commercial and institutional requirements.

withdrawals by 6,415 mgd, primarily because of differences in water withdrawals for irrigation, manufacturing, and mining. Total NF consumption exceeds total SRF consumption by 3,098 mgd in 1975. The difference in irrigation data seems to account for most of the discrepancy between the SRF and the NF.

Significant differences also appear in the percentages of withdrawals consumed for domestic, steam electric power generation, and irrigation uses. For each of these uses, the percentage of withdrawals consumed is significantly lower for the NF data. On the whole, the SRF data indicate about 78 percent of the withdrawals are consumed, while the NF data indicate about 67 percent.

Total SRF withdrawals projected for the year 2000 exceed total NF withdrawals by 2,000 mgd, due primarily to differences in domestic, manufacturing, mining, and irrigation withdrawal projections. Total SRF consumption exceeds total NF consumption by 1,961 mgd, primarily because of differences in domestic, manufacturing, mining, and irrigation uses.

On the whole, SRF data on consumptive use as a share of withdrawal for 2000 is about 74 percent, while the NF data indicate approximately 70 percent. Consumptive use as a percentage share of withdrawal for major uses are as follows: NF consumptive use for domestic uses remains at about 34 percent during the period 1975 to 2000, while SRF consumptive use remains about 56 percent during the same period. NF consumptive use for manufacturing increases from 30 percent in 1975 to 78 percent by the year 2000, while SRF data increase from 33 percent to 47 percent during the same period. NF consumptive use for agriculture remains at about 82 percent from 1975 to 2000, while SRF consumptive use for irrigation remains at about 90 percent.

Although both SRF data and NF data indicate an increase in water use efficiency among manufacturing industries, the NF data indicate a much greater increase. There does not appear to be much change in the SRF and NF ratios for domestic and agricultural uses.

The SRF estimated streamflow at the outflow point under base conditions is 26,368 mgd. The NF estimated streamflow is comparable at 28,270 mgd. Basically, SRF and NF used the same methodology to analyze the flow characteristics at the farthest downstream gaging station(s) in each subregion and to compute the ungaged runoff below the farthest downstream gaging station(s) in order to derive the streamflow. However, the SRF and NF analyses were performed independently. Consequently, the difference between the SRF and NF streamflow figures is most probably due to differences in the selection of the periods of record for the streamflow data.

Table 12-6 shows estimated flow withdrawals and consumption for 80 percent exceedance or dry year conditions.

Table 12-6.--Streamflow and water use data for 80 percent exceedence conditions

Category	1975		1985		2000	
	NF	SRF[a]	NF	SRF[a]	NF	SRF[a]
VOLUMETRIC DATA (mgd) -Dry year conditions-						
Streamflow at outflow point(s)	12,266	11,900	6,583[b]	7,630	6,362[b]	3,685
Fresh-water withdrawals	18,298	10,510	17,030	13,212	15,851	16,991
Agriculture	13,091	7,397	10,628	8,230	8,515	9,499
Steam electric	724	296	1,000	712	1,713	1,508
Manufacturing	1,932	1,177	2,559	1,466	2,444	2,273
Domestic[a]	1,207	1,427	1,380	2,556	1,621	3,379
Commercial	283	NA	317	NA	300	NA
Minerals	1,044	194	1,133	234	1,245	284
Public lands	<1	19	2	14	2	15
Fish hatcheries	17	NE	11	NE	11	NE
Other	0	<1	0	<1	0	33
Fresh-water consumption	12,462	8,161	11,194	10,005	11,295	12,490
Agriculture	10,730	6,726	8,761	7,487	7,094	8,558
Steam electric	99	149	270	357	991	752
Manufacturing	571	387	1,003	551	1,917	1,073
Domestic[a]	413	794	467	1,485	541	1,936
Commercial	94	NA	103	NA	118	NA
Minerals	555	100	588	119	632	146
Public lands	<1	NE	2	NE	2	NE
Fish hatcheries	0	NE	0	NE	0	NE
Other	0	5	0	6	0	24
Ground-water withdrawals	7,222	7,172	NE	4,961	NE	3,398
Net evaporation	1,705	1,743	1,875	1,964	1,992	1,972
Instream approximation Fish and wildlife	22,917	NE	22,917	NE	22,917	NE

NE - Not estimated
NA - Not available
[a]SRF domestic water use includes commercial and institutional requirements.
[b]Subregions 1203 and 1204 demands may exceed subregion water supply in future dry years. The major decline indicates conditions without ground-water mining.

Problems

Water Supply Problems

Rapid population expansion and economic development, coupled with a scarce water resource, have resulted in numerous existing and anticipated water supply deficiencies within the Texas Gulf Region. In much of the region, there is little excess storage capacity in surface-water reservoirs to meet water demands during critical periods of drought. Furthermore, ground water, historically the reserve that has supplied large areas within the region with water, is being consumed more rapidly than it is being replaced through natural recharge.

Heavy industrialization and population increases have resulted in steadily rising water requirements for the large cities. Some smaller cities within the Dallas-Fort Worth metropolitan area and the city of Corpus Christi are facing short-term water supply problems. These cities depend predominantly on surface-water supplies from nearby reservoirs. These existing supplies will not satisfy forecasted water requirements to the year 2000, and, unless additional reservoirs are constructed, severe water shortages may occur. However, this potentiality is well recognized and is being addressed in existing local long-range water supply plans.

Rural areas are also confronted with supply problems. A significant portion of the region's population still resides in rural areas, and the population of these areas is beginning to increase after decades of decline. Rural water systems generally have difficulty meeting drinking water standards in providing dependable, uninterrupted service. Their relatively small size and low density of service-area population result in high costs per customer. The newly enacted Federal Safe Drinking Water Act specifies standards for all public water supplies that many rural and small community systems have not met. They can only meet the standards in the future by installing new, expensive water supply treatment systems.

The heavy pumpage from most of the fresh-water aquifers in the region has resulted in the withdrawal of ground water in excess of recharge. This "mining" of stored water has resulted in water-level declines and, in some cases, deterioration of water quality.

The Carrizo Aquifer in south Texas has experienced extreme water-level declines of 400 feet over the past five decades, and annual pumpage averages twice the annual recharge. This ground-water mining has caused and will cause reversals in the hydraulic gradient of the aquifer, thus allowing poorer quality water into areas previously having good quality water.

Similarly, heavy pumpage of the Gulf Coast Aquifer in Jackson County on the central Texas coast has reduced ground-water levels and reduced base flows in the Lavaca and Navidad Rivers, and saline water has encroached into areas previously having good water quality.

The extensive pumpage of the Hensell and Hosston Aquifers in the mid-Brazos River Basin for municipal and industrial purposes has resulted in the mining of the aquifers' storage, thereby causing severe water-level declines and associated saline water encroachment. Continued ground-water pumpage above the average annual availability will reduce well yields and may in some cases further degrade water quality in existing supplies.

Ground water from the Ogallala Formation is the predominant source of water for the Texas and New Mexico High Plains area. The Ogallala does not receive appreciable recharge. Consequently, heavy pumpage has resulted in an average annual decline in the water table underlying irrigated acreage of approximately 3.5 feet. Severe water-level declines have occurred over other portions of the formation as well. In all areas of the Ogallala, the underlying water supply is expected to be exhausted in 30 to 50 years.

Water Quality

Problems of water quality and pollution in the Texas Gulf Region can be attributed to both natural occurrences and human activity. Natural salinity is a severe problem in the upper Colorado River Basin and in the Brazos River Basin and has been detailed in another section of this report.[1] In these areas, natural salt pollution consists primarily of sodium chloride from salt springs and salt flats in the drainage areas. To some extent the entrance of high salinity waters into flowing waters has been facilitated by improper oil well drilling many years ago. Wells which were improperly plugged have allowed large quantities of salt water to move from saline zones into fresh ground and surface waters of the State. Many of these problem sites have been discovered and properly plugged as time and funds have allowed. The residual effects, however, continue to plague development of water resources in the upper Brazos and upper Colorado Basin, and the chemical quality of the rivers during low flow periods will be slow to improve.

Much of the pollution found in streams of the Texas Gulf Region originates from highly populated urban areas including Dallas-Fort Worth, Houston-Galveston, San Antonio, and others. In the Trinity River below Dallas, natural flows are minimal during the summer, and sewage from the metropolitan area makes up a large portion of river flow. A similar situation exists in the San Antonio River below the San Antonio metropolitan area. This waste affects water for some distance downstream. In the Houston-Galveston metropolitan area, water quality problems are aggravated by urban development, including intensively developed industry. The Houston area is drained almost entirely by a small and sluggish stream known as Buffalo Bayou, channelized to form the Houston Ship Channel

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[1] Efforts are being made to alleviate the problem. The Corps of Engineers has an authorized project to construct detention reservoirs below the sources of contamination.

in its lower reaches. Although much of the pollution in the Houston Ship Channel has been cleaned up, considerable work remains to be done. Additional treatment will also be necessary to clean up municipal waste water in many other areas of the region.

Many of the urban areas in the Texas Gulf Region are being studied as part of Section 208 of the Water Quality Management Planning Process which is set forth in the Federal Water Pollution Control Act Amendments of 1972. Section 208 Planning Areas include Houston-Galveston, Dallas-Fort Worth, San Antonio, Beaumont-Port Arthur, Corpus Christi, and Temple-Belton in the Texas Gulf Region.

According to data from the U.S. Geological Survey, small amounts of pesticides are widely distributed in surface waters in the Texas Gulf Region. Some of the widely distributed pesticides are 2, 4, 5-T found at 96 sites, diazinon at 80 sites, 2, 4-D at 78 sites, dieldrion at 77 sites, Silvex at 47 sites, DDT at 67 sites, lidane at 57 sites, DDD at 51 sites, DDE at 50 sites, and chlordane at 38 sites (1968 to 1972 data).

Seasonally, water quality problems occur in lakes throughout the region, as described in another section of this report (Haskell and Jones Counties, Carrizo Aquifer, and salt-water intrusion along the Texas coast). State agencies continue to monitor and attempt to remedy these problems. Many are of natural origin, but have been aggravated by human activities.

Flooding

Flooding is a common problem in the Texas Gulf Region. Many floods have taken lives and inflicted millions of dollars in damages to urban and rural developments, agriculture, transportation, industry, and public utilities. Because of the wide variation in the climate and physiography of the region, the magnitude and character of floods differ widely both within and among the major river basins. Flooding can occur as the result of overflows of normal stream channels, or it can occur in localized areas where storm runoff ponds in low areas and natural or manmade drainage systems are inadequate to handle runoff.

In the eastern part of the region, where rainfall is abundant, streams flow through broad, flat valleys bordered by timber and dense growths of vegetation. Stream channels commonly have gentle slopes and small capacities, following meandering courses from their headwaters to the Gulf. Runoff is comparatively slow and stream velocities are generally low. These conditions generally produce broad, flat-crested floods, which move slowly in the lower reaches of the river basins and inundate the land for prolonged periods. Agriculture and ranching are generally hampered by these slow moving floods. Below major reservoirs, flood peaks have been reduced, but prolonged periods of spills and flood releases have delayed the drying of low-lying areas and have adversely affected agricultural operations.

In the central and western parts of the region, ground and tree cover is sparse. Intense grazing by domestic and wild animals has led to very poor range conditions that inhibit absorption of rainfall. Shallow soils overlying impervious layers of rock have limited capacities to hold surface water. Heavy rainfall in these areas causes flash floods. Runoff is rapid with high peak flows, high stream velocities, and short periods of land inundation. This type of flood takes human life and devastates developments on flood plains. Velocities are strong enough to remove any obstacles in the path of the flood. Cars are washed off roads, houses are ripped from their foundations, and bridges are washed out.

The most serious regionwide flooding in recent years occurred in 1957. Almost every major river and principal tributary reached flood stage during a period beginning in April and continuing through June. Flood conditions existed for as long as 80 days on many major rivers. Numerous local floods of a more severe nature have occurred in recent years.

Hurricanes are a major influence on the flood problems. Coastal areas are subjected to flooding from heavy rain and from tidal surge, while inland areas may receive tremendous amounts of rainfall as the dying storm centers move inland. Hurricane-related flooding has caused most of the extremely costly disasters in the region.

Flood protection measures include control through flood-storage capacity in existing and proposed reservoirs on streams and rivers, channel modification, levee works, and nonstructural measures such as a relocation of people and property from flood-endangered areas. Communities throughout the region are rapidly becoming involved in planning and flood-plain management. These local programs can perhaps prevent unwise use of flood plains and reduce the future flood damage to developments already located on and near flood plains.

Drainage

Many developed urban and agricultural areas of the Texas Gulf Region have problems with drainage of storm and flood waters and removal of salts from irrigated soils. Drainage problems arise as urban areas expand. A combination of poor subsurface conditions, soil types, flat terrain, and lack of outlets results in drainage difficulties in coastal plains areas.

Storm and Flood Waters

Much of the eastern third of the region has poor drainage. The land frequently includes flooded river valleys, marshlands, and tidewater swamps which have low elevation relative to the elevation of possible outlets for natural or artificial drainage. Drainage improvements have not been proposed for tidewater areas, and it is recommended that these areas be maintained as habitat for waterfowl and wildlife, and as spawning and nursery areas for economically important aquatic life. Other areas subject to frequent flooding will require the construction of facilities to prevent flooding before drainage improvement can be effective.

Drainage survey reports prepared by the U.S. Soil Conservation Service indicate that drainage is inadequate on more than 6 million acres in the region. One major problem is establishing major outlets to serve drainage systems for large areas along the Texas coast. Hardin, Liberty, Montgomery, Brazoria, Matagorda, Wharton, Colorado, and Jackson Counties, Texas, are some of the areas where drainage improvements are needed.

Extensive systems of drainage ditches and associated facilities are needed to connect local farm drainage systems with major outlets and natural drainage courses. Projects of this magnitude require extensive study, planning, and coordination. Large acreages in the bottomlands of the Sabine, Neches, Trinity, Brazos, San Bernard, Guadalupe, and Nueces River Basins cannot feasibly be drained until the floods that occur on these streams are brought under control. Floods would damage the drainage installations.

Salinity in the Soil Profile

A saline soil contains sufficient soluble salts to impair its productivity, but does not contain excessive exchangeable sodium. Salts accumulate in irrigated areas from the salt added in the irrigation water, from salts in the soil, and from high ground- or perched-water tables. All waters contain some dissolved salts. The original source of the salt is the earth's crust. Small amounts of salt are dissolved from the rocks in the weathering process and carried away with moving water. Evaporation of exposed water in streams and reservoirs removes pure water and leaves the heavier salts to accumulate. Drainage waters from irrigation and effluent from municipal and industrial use increase the salt load of streams and reservoirs.

Salinity is a major problem in some of the irrigated areas of the Texas Gulf Region. In the rolling plains of north-central Texas, from 5 to 20 percent of the irrigated areas are affected. In the irrigated Rio Grande Plain of the Winter Garden and Coastal Bend areas, 5 to 20 percent of the soils are affected by salinity. In the western Rio Grande plain and along the coast to Beaumont, about 50 percent of the area has saline soils. Inland from the coastal fringe of the Coast Prairie and in the Brazos River Valley, where the irrigated areas have loamy to clay soils, less than 1 percent are salt affected. Currently east Texas, central Texas, the Edwards Plateau, and most of the High Plains are without widespread salt problems.

Erosion and Sedimentation

Erosion and sedimentation are serious problems in many areas. Erosion is the wearing away of the land surface by water and wind, and sedimentation is the deposition of the worn away material. Erosion and sedimentation are twin problems, and the control of erosion provides sediment control.

Most of the region is susceptible to water erosion. Wind erosion occurs on semiarid lands and along the Gulf Coast in the humid part of the region. The extent and severity of the erosion are dependent upon the land use, the kind and amount of vegetative cover, the erodibility of the soil, the slope gradient, and the amount, intensity, and distribution of the rainfall. Erosion is much accelerated on cropland and on overused grassland where the grass cover has been depleted and brush and weeds make up the present cover. However, erosion on lands undergoing development for highways, houses, shopping centers, schools, industrial parks, and airports is about 10 times the rate of erosion on croplands.

Serious water erosion has taken place throughout the humid area of the region. Extensive gully erosion is a particular problem in some local areas of the West Cross Timbers, Blackland Prairies, and East Texas Timberlands. Some areas have been stabilized with mechanical treatment and supported by vegetative cover. Much steep land has been taken out of cultivation and established in perennial grasses for erosion control.

Wind erosion in the semiarid part of the region occurs on unprotected soil surfaces--both cropland and grassland. In cropland areas without adequate vegetative cover, solid blowing takes place and is most severe on the sand-coarse textured soils in areas where precipitation is variable, droughts are frequent, and windspeeds, temperatures, and evaporation rates are high.

Shoreline erosion is an important problem along the Gulf Coast because of the active loss of land, as well as the damage and destruction of piers, dwellings, highways, and historical landmarks. Shoreline or beach erosion is as variable as the beach material and the weather and waves which act upon it. Sand dunes along the Texas coast without adequate vegetative protection are highly susceptible to wind damage.

Sediment loads transported by streams in the Texas Gulf Region are determined by weather, climate, and geology which vary widely across the region. Short periods of flooding and long periods of low flow best describe the general nature of streams in this region. These characteristics are minimized somewhat in the higher precipitation area of the eastern portion of the region and aggravated in the low precipitation area of the western portion. All but the largest streams in west Texas approach an ephemeral character. Flow characteristics therefore set the timing of sediment movement. A random sample from the record of four years of sediment collected at the stream gaging station on the Brazos River near South Bend just upstream from Possum Kingdom Reservoir showed that the majority of sediment was transported in very short periods of time. For the record examined, an average of 83 percent of the sediment moved in the highest thirty-day period of an annual cycle. The pattern of each of the scattered four years selected was very similar. The time distribution of volume transport at this gaging site should approximate a mean for the region. There would ordinarily be less concentration east of this point and greater concentration west of this point.

Particle size of the sediments moved by streams in the region is largely in the category of fine sand, silt, and clay. Particle-size distribution of the sediment varies from stream to stream, and physical and chemical makeup of the sediment reflect the origin of the soil material. The Sabine, Neches, Trinity, San Jacinto, and smaller streams in the east and southeast portions of the region move suspended loads containing more than 30 percent sand. The Brazos, Colorado, San Antonio, Guadalupe, and Nueces carry less sand and a greater percentage of silts and clays.

Annual sediment production rates for drainage areas of 2,000 square miles vary within the region from a low of less than 0.10 acre-foot per square mile in the High Plains land resource area (northwest) to more than 1.5 acre-feet per square mile in the upper headwaters of the Brazos River in the Rolling Plains land resource area (northwest-central). Within a particular land resource area smaller drainage areas tend to produce higher rates of sediment production per square mile than larger drainage areas.

Large reservoirs situated on the major streams within the region approach a 100 percent trap efficiency for settlement of sediments reaching them. This has naturally reduced the sediment loads in the lower reaches of the major streams. Sediment records also reflect a reduction in sediment loads in a number of areas where land use changes have afforded better vegetal soil protection than existed for many years. An evaluation in detail is needed to estimate significant changes in production rates from those areas. Sedimentation in the streams of the Texas Gulf Region, with some exceptions, does not directly produce maintenance problems in waterways and harbors. Although considerable expense is necessary on a continuing basis to maintain these facilities, the preponderance of waterway facilities is located in the tidal areas and thus is more affected by bottom shoaling from traffic and tide currents. Disposal of sediments dredged in maintenance work is a major problem.

Water-oriented Recreation

Growth in population, income, leisure time, and mobility are all contributing to an increased demand for water-oriented outdoor recreation. Almost 42 million visitors utilized Corps of Engineers water projects in Texas for recreation in 1976. This was a 44 percent increase over the 29 million recreationists in 1973. Another measure of the expansion in water-oriented recreation is boat registrations, which increased 200 percent from 1967 to 1976.

Water-oriented recreation in Texas includes reservoir recreation and coastal recreation. Each type poses different problems and is amenable to different solutions. Recreation at reservoirs has increased, along with the population and the availability of facilities. But the water surface available for recreation is already deficient in some areas. In other areas, crowding and its effect on the environment point out the need for planning to assure adequacy of future reservoir recreation facilities.

Maintenance of water quality in reservoirs is an important consideration in water-oriented recreation. The presence of municipal or industrial wastes can have a negative effect. Other factors, such as water level, can affect the quality of fishing, and in turn, affect participation rates.

Because water use in outdoor recreation is nonconsumptive, and user fees are either nominal or nonexistent, recreation benefits are frequently ignored or underestimated. Spending money for travel expenses, recreation equipment, meals, and lodging stimulates business in towns near reservoirs and also in the home towns of recreationists.

Economic benefits from recreation are also crucial to the economy of the Texas Gulf Coast, where water-oriented outdoor recreation activity is increasing. Between 1975 and 2000, demand for water-oriented recreation is projected to increase about 42 percent. Direct and indirect expenditures for recreation will grow even faster and become a larger and larger portion of the consumer dollar. But these expenditures will depend in part on the maintenance and enhancement of the quality of the bays and estuaries. Freshwater inflows are a part of the delicate ecological balances necessary for these areas to be used as nurseries for fin fish and shellfish. The productivity of the bays has a direct impact on the quality of sport fishing, and ultimately on the economy of the area.

Land use competition on the coast could cause future supply problems. Presently, less than one percent of the total land area in 17 coastal counties is available for public outdoor recreation, and only 17 percent of that land is developed. Lack of public access development along the coast could aggravate supply problems. Presently, 72 percent of the bay frontage and 56 percent of Gulf frontage is inaccessible.

In Texas, water-oriented recreation problems such as maintenance of water quality and adequate supply underscore the need for advance planning and coordination among public agencies at various levels of government.

Land Subsidence

Land subsidence is a very serious problem in the Houston-Galveston area. In this area, relatively concentrated and large ground-water withdrawals for municipal, manufacturing, and irrigation purposes has drastically reduced the artesian pressure in the Gulf Coast Aquifer. Since the aquifer is a leaky artesian system, water is drained from the interbedded clays, causing considerable compaction of the clays, which results in the subsidence of the land surface. Land subsidence has exceeded one foot or more in an area of about 2,500 square miles. From 1943 to 1973, maximum subsidence was between 7.5 and 8.0 feet in the Deer Park-Channelview area of eastern Harris County along the Houston Ship Channel. During the same period, water level declines ranged from about 200 feet to over 300 feet.

Subsidence has done considerable damage to homes, commercial buildings, sewers, pipelines, underground cables, city streets, bridges, highways, railroads, drainage structures, and airport runways in Harris County. Subsidence in the western shore area of Galveston Bay has resulted in permanent inundation locally of lands which 30 years ago were well above high tide. Also, large developed areas along the bay are now subject to disastrous flood damages from the large surging tides associated with the hurricanes, common to the Gulf Coast of Texas. Subsidence near streams has expanded the areas of their flood plains. Surface drainage has become less effective, and, in some cases, drainage has been reversed. The damages caused by subsidence are not only serious in the urban areas but can become serious in rural areas causing damage to pipelines, underground cables, highways, and bridges.

The remaining Gulf Coast Aquifer area, especially the area from the coast inland 60 or 70 miles, has the subsurface geohydrologic setting for the degree and extent of land subsidence that has occurred in the Houston-Galveston area. However, current and historical withdrawals from wells in the remaining Gulf Coast area, described above, are not as great or as concentrated as in the Houston-Galveston area.

Land subsidence is also caused by production of oil and gas. These areas of subsidence are more local and in most instances are associated with oil and gas production related to salt domes. Between 1917 and 1926, more than three feet of subsidence occurred in the Goose Creek Oil Field in Harris County. During the same period, about 1.4 feet of fault movement was also observed in the field. Other oil and gas fields in which subsidence has occurred in Harris County are the South Houston, Clinton, McKawa, Blue Ridge, and Webster Fields. The Saxet Oil Field in Nueces County near Corpus Christi has had very large amounts of subsidence.

Saline-water Encroachment

The most serious occurrences of saline-water encroachment in the Texas Gulf Region are in the Gulf Coast Aquifer, especially in areas adjacent to the coast. Generally in these areas, fresh to slightly saline ground water underlies and overlies moderately saline to saline ground water. When this wedge or layer of fresh to slightly saline water is heavily pumped and its pressure is reduced, moderately saline and saline waters intrude into the fresh-water aquifer, and the water quality gradually deteriorates.

Numerous ground-water users in the Gulf Coast area have had to reduce pumping their well or well fields and move inland to establish facilities or develop a surface-water supply. Some of these users include Houston, Galveston, Texas City, Freeport, Port Lavaca, and some municipalities and industries in the Beaumont-Port Arthur-Orange area. The reason for their changes in water supply is adverse changes in ground-water quality, primarily because of saline-water encroachment. Some of these water quality changes were probably also caused by initially poor well construction or deteriorated well construction.

The potential for saline-water encroachment is very high along the Gulf Coast in such areas as Kingsville in Kleberg County and Point Comfort in Calhoun and Jackson Counties.

The inland areas within the Texas Gulf Region having the greatest potential for future saline-water encroachment due to heavy pumping are probably the San Antonio Region (Edwards Aquifer) and the Winter Garden District in Dimmit, Savala, Frio, and LaSalle Counties (Carrizo-Wilcox Aquifer).

Estuarine Management

Management of Texas estuarine systems will require consideration of fresh-water inflows, water quality, fishery production, and the effects of human activities within the systems and their contributing river basins. The overall objective of Texas estuarine management, with respect to fresh-water resources, is to assure that sufficient quantities of fresh-water inflow can be seasonally provided at appropriate geographic locations to maintain Texas bays and estuaries at acceptable levels of productivity, in concert with prevailing State and national coastal fishery standards.

Under the Federal Fishery Conservation and Management Act of 1976, national coastal fishery standards are established using the "optimum sustainable yield" (OSY) concept. This concept represents an attempt to manage resources on the basis of all relevant economic, biological, and environmental factors. The principal difficulty with the OSY concept is one of practical definition leading to a workable management scheme. However, regardless of the definition chosen, water resources for the bays and estuaries of Texas will continue to be a vital element of concern in future management plans.

With adequate control of inland water resources, it would be possible to substantially regulate the seasonal fresh-water inflow regimes for the benefit of Texas estuarine systems and their living resources. However, at present the legal and institutional framework within which such management could be performed remains unclear.

Water Resources Management

In addition to problems of flooding, ground-water depletion, natural salt pollution in ground-water and surface-water resources, land subsidence, saline-water encroachment, water pollution, drainage, etc. are the difficulties of developing and managing water resources to meet foreseeable water requirements.

A major problem in Texas is the location of existing demands for water in relation to the location of available supplies. In many areas where existing ground-water supplies are being depleted, or in which current surface-water supplies are beginning to be exceeded by demands, supplemental supplies are available only at great distances. This problem is compounded by a limited availability and poor character of dam and reservoir sites. Thus, supplemental water supplies, either surface or ground, will often have to be transported great distances to meet demands.

Among the problems in planning for redistribution of available surface-water resources is the existing water rights held under State laws. For the most part these rights represent a reasonable allocation of available waters from surface streams. There are, however, some permits that are obviously and incontestably in excess of projected requirements for water. The Texas Legislature in 1967 enacted the Water Rights Adjudication Act to deal administratively with this problem. The act authorized the Texas Water Rights Commission to orderly review water rights throughout the State. Pursuant to this act, the Texas Water Rights Commission is responsible for initiating river segment adjudications of all claims to surface water except for domestic and livestock use. At the judicial conclusion of each segment evaluation surface-water rights are recognized to the extent proved, which generally equates to the historic maximum annual water usage up to the extent authorized.

Under Texas law, ground waters are the property of the surface owner. A local management technique for some aspects of ground-water development has been provided through creation of underground water conservation districts. The rationale behind the creation of these districts, with relatively broad administrative and taxing powers, was that in a State so large and diverse as Texas, the problems and needs of local areas could probably be met more effectively through local government.

Individual Severe Water and Related Problems

The Texas Natural Resources Department as the regional sponsor for the Texas Gulf Region in conjunction with the New Mexico Interstate Stream Commission and the Louisiana Department of Transportation and Development identified severe water and related land resource problems. Each problem was also described and evaluated. The list of problems follows:

<u>Problem Title</u>

Water Quality Problems in the Beaumont-Port Arthur Metropolitan Area, Texas

Water Supply Problems in the Upper Trinity River Basin, Texas

Water Quality Problems in the Dallas-Fort Worth area, Texas (Trinity River and Tributaries)

Land Subsidence in the Houston-Galveston Metropolitan Area, Texas

Water Quality Problems in the Houston, Texas, Metropolitan Area

Ground-water Quality Problems in Haskell and Jones Counties, Texas

Brazos Basin Salinity Problems above Possum Kingdom Reservoir in Texas

Ground-water Availability and Quality Problems in the Carrizo Aquifer, Winter Garden Area, Texas

Regional Ground- and Surface-water Management Problems Associated with the Edwards (Balcones Fault Zone) Aquifer, Texas

Jackson County, Texas, and Vicinity Ground-water Problems

Water Supply Problems in the Corpus Christi, Texas, Metropolitan Area

Pollution, Recreation, Flooding, and Salt-water Intrusion Problems in Louisiana

Upper Colorado River Salinity Problems in Texas

Water Supply Problems in the Mid-Brazos River Basin in Texas

Problem Title

Problems Associated with the Fresh-water Inflows to the Texas Bays and Estuaries

Water Supply and Quality Problems in Small Cities and Rural Communities in Texas as a Consequence of Implementing the 1974 Safe Drinking Water Act

Flood and Hurricane Problems in Texas

Ground-water Depletion Problems in the Texas High Plains

Water Supply, Flooding, and Erosion Problems in Louisiana

Water Supply and Related Problems in Curry, Roosevelt, and Lea Counties, New Mexico

The following map (Figure 12-8a) indicates the general location of each problem in the Texas Gulf Region. A description of each problem and the effects of the problem follows the problem area map. A tabulation of the type of problems is given in Figure 12-8b. The figure also illustrates the problems identified for each assessment subregion by Federal agency representatives.

Water Quality Problems — Beaumont-Port Arthur Metropolitan Area, Texas

Orange and Jefferson Counties are included in the Beaumont-Port Arthur Metropolitan Area. This area is highly industrialized and contains large population centers. Several thousand acres of cropland also are irrigated in the area. Large diversions of fresh water from the Neches River and navigation improvements in the area have intensified water quality problems. Salt water migrates up the Neches River and has necessitated the construction of a salt-water barrier upstream of Beaumont. In addition, urban runoff and return flows often constitute the majority of flow in the Neches River.

This area constitutes a large industrial complex known as the Golden Triangle. It is a center for heavy industry and has been a major oil-producing region since the turn of the century. This large industrial complex has contributed to the water quality problem by its large water demand and its effluent. Industrial water is supplied to industries in Jefferson County by the Lower Neches Valley Authority (LNVA) and the city of Beaumont, which supplies many industries located in that city. The LNVA has a system of canals which serves much of Jefferson County.

During the rice-growing season, the LNVA supplies water to irrigate approximately 78.5 million acres of rice in Jefferson and portions of Liberty and Chambers Counties.

The LNVA and the city of Beaumont divert water from the Neches River and Pine Island Bayou north of Beaumont. Most of this water is distributed throughout Jefferson County and is ultimately discharged as waste water into the streams and drainage canals of the Neches-Trinity Coastal Basin. The Neches River and Sabine River empty into Sabine Lake, which was reportedly fresh prior to the first channel improvement in the area, the dredging of Sabine Pass, which occurred shortly before 1900. The navigation improvements coupled with diminished river flows caused by upstream diversion has allowed salt-water currents to ascend far upstream of Beaumont. There is not sufficient flow in the Neches River to flush out the salt water since diversions often equal the river flow.

To protect the fresh-water intakes on the Neches River and Pine Island Bayou from salt-water contamination, temporary salt-water barriers must be constructed. The LNVA constructs sheet piling barriers across the Neches River and Pine Island Bayou. The barriers are normally required during late summer and early fall due to increased diversion rates during the rice irrigation season. It has been necessary to install the barriers almost every year since 1948, and the barriers, which are removed when they are no longer needed, have remained in place for as long as 6 months.

With the salt-water barriers in place, the Neches River essentially becomes a dead-end navigation and waste disposal channel. The flow below the barriers results from treated industrial and municipal effluent return flows, a little fresh-water inflow from a small drainage area, and tidal action.

Urbanization also poses serious water quality degradation problems over and above the disposal of domestic and industrial wastes. The development of pervious open lands into impervious urban surfaces increases runoff rates and scour erosion, introducing into the urban drainage contaminants that far exceed natural pollutants added to runoff by solution and erosion in rural areas. Urban "shock" pollution resulting from stormflow conditions can appreciably raise BOD and COD levels, and frequently introduce nitrogen, phosphorus, and bacteria into surface runoff.

Water Supply Problems — Upper Trinity River Basin, Texas

The upper Trinity River Basin and the contiguous counties lying within the adjacent Brazos and Red River Basins face serious water supply problems unless supplemental sources are made available in the near future. Counties included in the area are Collin, Cooke, Dallas, Denton, Ellis, Hood, Hunt, Johnson, Kaufman, Parker, Tarrant, and Wise.

The region includes the Dallas-Fort Worth metropolitan area--a center of finance, insurance, transportation, manufacturing, petroleum interests,

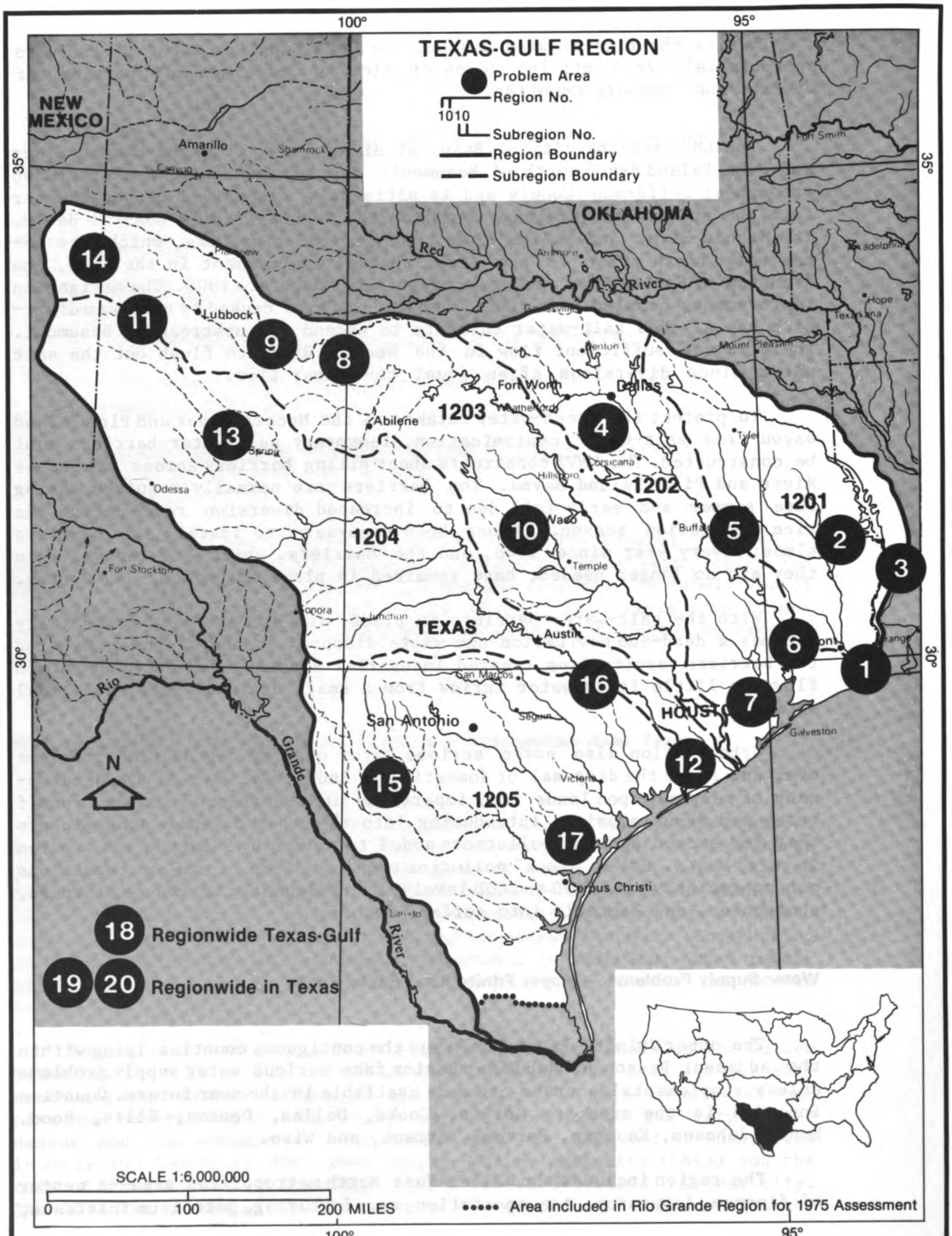

Figure 12-8a. Problem Map

TEXAS-GULF REGION (12)

PROBLEM MATRIX

Problem area		Problem issues: O= Identified by Federal Agency Representatives; X= Identified by State-Regional Representative														
No. on map	Name	Water quantity				Water quality				Related lands						
		Fresh surface	Ground	Marine and estuarine	Surface/depth	Fresh surface	Ground	Marine and estuarine	Surface/depth	Flooding	Drainage	Erosion and sedimentation	Dredge and fill	Subsidence	Water related use conflicts	Other
Subregion 1201	Sabine-Neches			O				O		O		O				
Area 1	Beaumont-Port Arthur Metropolitan Area, Texas					X	X	X				X	X			
2	Sabine River, Louisiana	X								X		X				
3	Sabine River, Louisiana	X								X		X				X
Subregion 1202	Trinity-Galveston Bay	O	O	O			O	O		O		O				O
Area 4	Upper Trinity River Basin, Texas	X	X													
5	Dallas-Fort Worth (Trinity River & Tributaries), Tex.					X										X
6	Houston-Galveston Metropolitan Area, Texas	X	X	X		X	X			X	X	X		X		X
7	Houston Metropolitan Area, Texas					X	X	X				X	X			
Subregion 1203	Brazos		O			O				O						
Area 8	Haskell and Jones Counties, Texas						X									X
9	Brazos Basin above Possum Kingdom Reservoir, Tex.					X					X					X
10	Mid-Brazos River Basin, Texas		X				X									
11	Texas High Plains, Texas		X													
Subregion 1204	Colorado (Texas)		O			O									O	
Area 12	Jackson County and Vicinity, Texas						X		X	X				X		
13	Upper Colorado River, Texas	X	X			X	X									
14	Curry, Roosevelt, & Lea Counties, New Mexico	X	X				X			X		X				
Subregion 1205	Nueces-Texas Coastal		O			O						O				
Area 15	Carrizo Aquifer (Winter Garden Area), Texas		X				X									X
16	Edwards (Balcones Fault Zone) Aquifer, Texas	X	X			X	X									X
17	Corpus Christi Metropolitan Area, Texas	X	X			X	X			X		X				X
Regionwide in Texas-Gulf Area 18	Texas Bays and Estuaries, Texas	X		X		X		X		X		X	X		X	
Regionwide in Texas Area 19	Small Cities & Rural Communities, Texas	X	X			X	X			X						
20	Texas, Statewide: Flood Problems & Hurricanes									X		X			X	X

Figure 12-8b. Problem Matrix

and agriculture--and numerous satellite cities and communities whose population and economic base are rapidly expanding. The area's population, currently totaling about 3 million, is projected to grow to about 5.5 million by 2000.

Currently, municipal and manufacturing water use within the region amounts to approximately 592,000 acre-feet per year (528 mgd), of which about 518,000 acre-feet (452 mgd) is supplied by surface-water sources. Ground-water aquifers, which currently provide about 74,000 acre-feet annually (66 mgd) to the area, primarily for municipal and industrial purposes, include the Trinity Group and the Woodbine Aquifers--both of Cretaceous age. Wells completed in the deeper, thicker parts of the Trinity Aquifer yield up to 2,000 gpm, although wells completed in the thinner sections commonly produce less than 1,000 gpm. Although dissolved solids concentrations are generally low enough to be acceptable for municipal use, excessive fluoride concentrations constitute a problem in many parts of the aquifer. The most severe problem, however, results from declining pumping levels (pumping lifts exceed 1,000 feet in many wells) due to pumpage in excess of recharge in the Dallas-Fort Worth area and the natural low transmissibility of the aquifer. Many cities and industries which formerly used this aquifer have already converted to surface-water supplies. This trend is continuing.

Twenty-seven major reservoirs currently serve this problem area. Three of the reservoirs are used exclusively for steam electric powerplant cooling. Many of the reservoirs are relatively small and have correspondingly low yields. Additionally, a number of the larger reservoirs are Federal projects constructed principally for flood control and have relatively small conservation storage capacities. Two new Federal projects, Lakeview and Aubrey Reservoirs have been authorized for construction. When completed, these projects will provide additional flood control and water supply for the area. Lakeview Reservoir will also provide additional flood control storage.

On the basis of State/regional projected needs, supplies available from existing reservoirs in the area, existing diversion facilities from Lake Tawakoni in the adjacent Sabine River Basin, and completion of authorized Federal projects will allow the region to meet its water needs to the year 2000. However, during a possible recurrence of critical-period droughts, the region would experience severe water shortages before the year 2000 unless supplemental sources and associated conveyance facilities are developed. Construction of proposed raw-water conveyance facilities from Lake Palestine in the Neches River Basin to the city of Dallas will provide additional supplies when completed.

Water Quality Problems — Dallas-Fort Worth, Texas (Trinity River and Tributaries)

The Trinity River in the vicinity of the Dallas-Fort Worth metropolitan area suffers from pollution of its waters as indicated by both chemical and bacteriological analyses. Counties affected by this problem include Collin, Dallas, Denton, Ellis, Kaufman, and Tarrant. Because of low streamflows, partially caused by upstream impoundments and by the diversion of streamflows through municipal water systems, municipal effluents from both Dallas and Fort Worth often comprise the bulk of streamflow in the Trinity downstream of the metropolitan area. Poor water quality conditions occur in the West Fork from Fort Worth to Dallas and in the East Fork from Lake Hubbard Dam to the confluence with the main stem of the Trinity River. Although the river tends to purify itself as it flows downstream, some quality problems are experienced all the way downstream to Lake Livingston.

The primary effects of effluent domination in the Trinity River are suppressed oxygen levels and high concentrations of BOD, ammonia, volatile suspended solids, phosphate, and fecal coliforms. At some points, sludges that contain high concentrations of carbon, nitrogen, and phosphorus accumulate on the river bottom. When the river rises rapidly, these sludges are suspended in the water and add heavy shock loads of pollutants, often resulting in extensive fish kills. Urban runoff also contributes significantly to the inflow of pollutants. Because of these 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 and noncontact recreation, domestic water supply, and industrial use without pretreatment. Game fish are generally unable to live and propagate in the Trinity River and tributaries below the metropolitan area because of the low dissolved oxygen levels which on occasion reach zero.

Downstream, the headwaters of Lake Livingston also have occasional low dissolved oxygen concentrations, high fecal coliform counts, and excessive aquatic growth. Algal blooms and excessive growth of water hyacinth and duckweed are evidence of water quality problems resulting from over-nourishment of lake waters by incoming pollutants; however, the main pool of Lake Livingston and the other lakes of the basin only occasionally have water quality problems.

All of the major waste-water treatment plant owners in the upper Trinity River Basin are currently upgrading their treatment facilities. This is expected to result in a significant improvement in the quality of the Trinity River.

Land Subsidence in the Houston-Galveston Metropolitan Area, Texas

Lake surface subsidence in the Houston-Galveston area causes permanent inundation and intense temporary flooding, which damages property. Overdrafting of the ground-water aquifer, which results in subsidence, also leads to salt-water encroachment and damage to some of the fresh-water aquifers.

Subsidence in the bay shore has already permanently inundated lands previously above normal tide elevations and has subjected extensive additional lands to tidal inundations. Subsidence in the vicinity of fresh-water streams has extended the area of their flood plains. Surface drainage has become less effective and in some areas drainage patterns have been reversed as a result of subsidence. There is a severe flood risk in this area.

From 1906 to 1973, land-surface subsidence of one foot or more has occurred in an area of approximately 2,500 square miles. The maximum subsidence that has occurred locally during this period has been 8.5 feet. The land-surface subsidence has generally resulted from the withdrawal of large quantities of ground water in the area. The water levels in the artesian aquifers have declined significantly, resulting in a decrease in hydraulic pressure in the system, dewatering and compaction of the clay beds which are interspersed with the water-bearing sands in the subsurface, and, finally, land-surface subsidence.

Pumping of ground water in the Houston-Galveston region has steadily increased. As a result, the rates of artesian pressure decline and subsidence have accelerated. Subsidence is expected to continue at a rate dependent on the decline in pressures resulting from future ground-water pumpage. Surface water from the adjacent Trinity River Basin and the Brazos River in the Brazos River Basin are presently being diverted for use in southern Harris County. This switch from ground-water to surface-water supplies has resulted in a slight recovery of artesian pressure and has thereby decreased the rate of subsidence. Additional surface-water supplies must be developed and used to replace ground-water sources to further reduce the effects of subsidence.

Water Quality Problems in the Houston, Texas, Metropolitan Area

The Houston metropolitan area is composed primarily of Harris County and parts of the adjacent Chambers and Galveston Counties. Water quality problems are wastes from domestic and industrial sources, the periodic lack of dissolved oxygen in surface waters of the ship channel and bays, and salt-water encroachment due to excessive ground-water pumpage.

The Houston metropolitan area is drained almost entirely by a small and sluggish stream known as Buffalo Bayou which has been channelized to form the Houston Ship Channel in its lower reaches. Its tributaries include small, intermittent bayous such as Brays Bayou, Hunting Bayou, Greens Bayou, and Sims Bayou. The Port of Houston, a deep-water harbor, was established in 1914. This harbor usually ranks second or third annually in tonnage among the deep-water ports of the United States. In addition to the Port of Houston, the Ports of Galveston and Texas City are situated adjacent to Galveston Bay. In 1971 the Galveston Bay area handled a cumulative tonnage of over 90 million short tons, making it one of the world's most heavily used waterways. Most shipping involves either the transport of raw materials to industrial complexes in Texas City and along the Houston Ship Channel or the export of intermediate and final products from these industries to domestic and foreign destinations. Since World War II, Houston and the Houston Ship Channel industrial complex as well as the ports of Galveston and Texas City have undergone tremendous growth. The channel and bays have received wastes from domestic and industrial sources. These wastes, together with the sluggish flow characteristics of the waterway and tidal action, have overloaded the natural purification capacity of the estuary.

From Morgan's Point (Mile 0) to the Turning Basin (Mile 24), the ship channel is a dredged-out portion of Buffalo Bayou. The channel's depth is approximately 40 feet, with a minimum bottom width of about 100 yards. During critical periods in the summer, there is often no dissolved oxygen from Mile 10 to Mile 24, a distance of 14 miles. During the winter, the area deficient in oxygen is often reduced to an 8-mile segment from Mile 16 to Mile 24.

Historically, the Houston-Galveston metropolitan area has obtained a large portion of its water supply from the Gulf Coast Aquifer. During the early days of Houston's development, the entire municipal supply came from this source, and industries locating in the area developed their own wells to tap the abundant and good quality ground-water supply. Pumpage from the Gulf Coast Aquifer from 1890 through 1970 has caused a decline in the potentiometric surface (water level) in excess of 400 feet near the Houston Ship Channel and the upper end of Galveston Bay. This reversal of the regional hydraulic gradient has caused the interface between fresh and saline water to move toward this area. The present location of the salt-water interface is not well known; however, problems are now developing in the vicinity of Texas City and Galveston in Galveston County and near the coast in Chambers County.

Ground-water Quality Problems in Haskell and Jones Counties, Texas

Relatively high concentration of nitrogen--locally, extremely large amounts--are present in the ground-water supplies of the Seymour Aquifer of Haskell and Jones Counties, as well as in other counties of north-central Texas. In addition to the nitrate problem, the salinity of this water supply (primarily sodium chloride) has also increased in recent years. The Seymour is the principal aquifer of the area and is used extensively for irrigation, domestic, and livestock purposes, and to a lesser extent, as a municipal supply.

Comprehensive investigations of the hydrology, ground-water resources, and water quality problems in Runnels, Haskell, and Jones Counties strongly indicate the high nitrogen concentrations are principally the result of natural phenomena. The increasing nitrate content in local areas apparently is related to land use and land treatment measures as well as extended periods of above-average precipitation with corresponding rise of water levels in the aquifer. High nitrate content in ground water renders it unsafe for human consumption and, when extremely high, for livestock consumption. When the water is used for municipal purposes, the nitrate content must be reduced, and this increases the water treatment costs.

Studies completed and presently underway indicate that local salinity problems are related to rising water levels, past oil and gas exploration and production, salt-water disposal methods, and/or possibly intrusion of saline water from underlying aquifers. High salinity in ground water restricts its use locally for human consumption because of the undesirable taste. When it is used for municipal purposes, high salinity may increase costs of treatment.

Brazos Basin Salinity Problems Above Possum Kingdom Reservoir in Texas

At present, full utilization of the water resources of the main stem of the Brazos River is not possible because of the adverse effects of natural salt pollution from sources located within its principal upper basin tributaries. The quality of Brazos River main stem water is seriously degraded by emissions from major natural salt sources in the upper Brazos River Basin downstream from the Caprock Escarpment. This natural salt pollution consists mainly of sodium chloride from salt springs and salt flats within the drainage area of the Salt Fork Brazos and, to a lesser extent, the Double Mountain Fork Brazos Rivers in the upper Brazos basin, principally in Garza, Kent, and Stonewall Counties.

Chloride concentrations constitute over one-half the total dissolved solids concentrations of the Brazos River flows downstream of the natural salt pollution sources. The sources of up to 70 percent of the chloride entering the river are readily identifiable in a relatively localized area of the Salt Fork Brazos River. Sulfate, the second most prolific contaminant in the Brazos, is also acquired from gypsum-bearing Permian age formations by runoff from the drainage areas of both the Salt and Double Mountain Forks of the Brazos River.

Numerous salt flats are located within the drainage system. The most prominent are Dove Creek Salt Flat (Salt Croton Creek) of north-central Stonewall County, Hot Springs Salt Flat (Croton Creek) of eastern Kent County, and Short Croton Salt Flat (Short Croton Creek) also located in eastern Kent County. Salt flats, as the name implies, are relatively flat except for small islands of Permian age rocks that extend above the level of the salt flat floor. Generally, these flats are encrusted with a thin layer of salt crystals which are dissolved and flushed into the associated streams by runoff.

There are few springs in the upper slopes of the salt-producing area, but those found are usually fresh-water springs that flow only intermittently. Lower slopes have more springs and seeps with varying water quality, depending on whether the fresh- or salt-water aquifer is above, below, or at about the level of the spring or seep. Springs occur in many of the stream bottoms and salt flats, discharging under artesian pressure into the overburden or from open joints in the shale or gypsum beds. Most of the springs of the salt flats discharge only salt water, but a few springs discharge a mixture of waters from both salt-water and fresh-water aquifers.

The location of the salt sources is such that pollution from them affects the entire main stem of the Brazos River. This is by far the most serious water quality problem in the Brazos River Basin. Although the amount of water carrying dissolved minerals into the main stem of the river is fairly insignificant compared to the total amount of water the river empties into the Gulf of Mexico, it is enough to make the water in the river generally unsuitable for domestic use for a significant distance. Higher quality tributary flows and tributary reservoir releases become polluted as they enter the main stem of the Brazos River.

Water presently flowing in the main stem of the Brazos River is undesirable for municipal supply and is not used for this purpose except in emergency. During critical years, however, cities such as Waco and Marlin have used Brazos River water as supplemental supplies. Presently, in the lower reach of the Brazos River, river water is used for irrigation and industrial purposes. This is possible because of large inflows of good quality water from tributaries within the region; however, during some periods, the flow remains poor in quality even in the lower reaches of the Brazos River.

Ground-water Availability and Quality Problems in the Carrizo Aquifer, Winter Garden Area, Texas

The Winter Garden area of Texas lies southwest of the San Marcos River and within the Guadalupe, San Antonio, Nueces, and Rio Grande Basins. It consists of all or parts of Atascosa, Bexar, Caldwell, Dimmit, Frio, Gonzales, Guadalupe, Karnes, La Salle, Live Oak, McMullen, Maverick, Medina, Uvalde, Webb, Wilson, and Zavala Counties.

The Carrizo Aquifer is the most continuous, permeable, and most heavily pumped water-bearing unit in the Winter Garden Area. Throughout most of the Winter Garden area, the Carrizo yields ground water acceptable for most irrigation, public supply, and industrial purposes. The Carrizo Aquifer ranges in thickness from 150 to more than 1,000 feet, with maximum thickness in Arascosa County and minimum thickness in Dimmit County.

The average rate of recharge to the Carrizo Aquifer in the Winter Garden area is about 100,000 acre-feet per year. Average annual pumpage from 1963 to 1969 was approximately 272,000 acre-feet. Thus, for this period about 172,000 acre-feet of water was pumped in excess of recharge, most of which came from storage. These large annual withdrawals of ground water from storage have caused declines in Carrizo water levels, which directly affect the cost of pumping water and are also related to changes in water quality within the aquifer, particularly in Dimmit, Zavala, and eastern Maverick Counties.

As a direct result of large declines in the water level, well yields are reduced. In order to meet water demands, well pumps must be set deeper, and larger motors must be installed. In some cases, new wells are needed to meet the demands. These improvements cause operating costs to spiral upward as ground-water users attempt to meet demands and, in doing so, cause additional water-level declines.

In local areas, especially in Dimmit County, saline water from the Bigford Formation is leaking through old well bores and contaminating the Carrizo Aquifer. When these wells were drilled in the 1920's and 1930's, water levels in the Carrizo Aquifer were considerably above the level of water in the saline-water sands. Because of declines in hydrostatic head, the level of the Carrizo has been significantly lowered below the level of the saline-water sands. The old wells were poorly constructed, and many have not been properly plugged and sealed. The saline water moves down their boreholes and mixes with the Carrizo water, thus degrading its quality.

Also, an extensive decline in the water level in Dimmit and Zavala Counties has caused reversals in the hydraulic gradient of the aquifer, thus allowing poorer quality water to enter areas which previously had good quality water.

Regional Ground- and Surface-water Management Problems Associated with the Edwards (Balcones Fault Zone) Aquifer, Texas

The San Antonio metropolitan area, centered in Bexar County, is the largest urban area in the Nation which depends solely on ground water for municipal and industrial needs. The source of the water is the Edwards (Balcones Fault Zone) Aquifer. San Antonio is the third largest city in the State, and the area's population, currently about 920,000, is projected to grow to about 1.3 million by the year 2000.

Studies show that the Edwards Aquifer is capable of meeting the foreseeable municipal, industrial, and agricultural needs of this area. However, this use would be detrimental to Comal and San Marcos Springs, adversely affect agriculture due to declining pumping levels, and reduce fresh-water inflows to San Antonio Bay. Also poor quality water at the southern limits of the Edwards Aquifer may be drawn into the fresh-water section of the aquifer if water levels are lowered significantly below their lowest historic level.

The Edwards (Balcones Fault Zone) Aquifer extends from central Kinney County east and northeast through Uvalde, Medina, Bexar, Comal, and Hays Counties. It consists of the Edwards and associated limestones of Cretaceous age which are in hydraulic continuity. The Edwards limestone yields large quantities of water due to its honeycombed and cavernous nature. The portion of the Edwards Aquifer pertinent to this problem area is approximately 175 miles in length extending from Brackettville in Kinney County eastward to Kyle in Hays County. Hydraulically it connects three major river basins--the Nueces, the San Antonio, and the Guadalupe.

Average annual recharge to the Edwards (Balcones Fault Zone) Aquifer from 1934 to 1974 has been computed to be approximately 562,620 acre-feet, which can be considered as the dependable annual yield without mining the aquifer. Annual discharge (pumpage and springflow) for the same period has averaged 561,900 acre-feet per year. Withdrawals from wells reached their maximum in 1971, when 407,000 acre-feet was pumped for municipal, industrial, and agricultural purposes. The primary effect of the withdrawals has been reduction in springflows during droughts. Comal Springs was dry, for the first time on record, from July through November 1956. The lowest flow for San Marcos Springs also occurred at that time. Both springs support rare and unique ecosystems, provide recreational opportunities for citizens of the entire State, and provide a large portion of the base flow of the Guadalupe River. They significantly enhance the economy of the region.

Currently, Canyon Reservoir on the Guadalupe River is the only existing source of surface water available to the area. Two authorized Federal projects, Cloptin Crossing and Cibolo Reservoirs in the Guadalupe and San Antonio River Basins, respectively, offer potential sources of supplemental water. Other proposed reservoir projects, such as the Applewhite Reservoir project on the Medina River and the Cuero Reservoir project in the Guadalupe River Basin are additional potential sources of surface water for the region.

Jackson County, Texas, and Vicinity Ground-water Problems

In Jackson County and portions of Lavaca, Wharton, and Matagorda Counties along the Texas Gulf Coast, the only source of fresh water is the Gulf Coast Aquifer, consisting of alternating and discontinuous beds of water-saturated sand and clay of Tertiary and Quaternary age. Pumpage from wells in the area has exceeded natural recharge to the aquifer, so that mining of ground water is taking place.

The Gulf Coast Aquifer is a prolific source of water. However, ground water is being extensively mined to irrigate rice fields. An estimated 95 million acre-feet of fresh ground water is in storage in Jackson County; however, most of this water is not available for development because it occurs at great depths and only a fraction of the water can be drained from the aquifer by wells. In 1974, agricultural wells in Jackson County pumped 123,146 acre-feet per year from the Gulf Coast Aquifer. This pumpage will have to be reduced to 25,000 acre-feet per year by the year 2000 if the long-term yield of the aquifer (28,343 acre-feet per year) is not to be exceeded.

The Gulf Coast Aquifer in Jackson County and parts of adjacent counties contains from 100 to more than 1,300 feet of net sand thickness containing fresh to slightly saline water. The depths to the base of slightly saline water in the aquifer is over 2,300 feet northeast of Ganado, Texas, in Jackson County. The aquifer's fresh-water zone has as much as 1,200 feet of net sand thickness in the Ganado Area. The depth of the base of fresh water in the Ganado area is more than 1,800 feet.

Land surface subsidence is an additional problem in some portions of Texas underlain by the Gulf Coast Aquifer, but it has not yet been a major factor in Jackson County. Sands of the Gulf Coast Aquifer may be compacted as the pore pressure in the fresh-water zone is reduced through pumpage.

Water Supply Problems in the Corpus Christi, Texas, Metropolitan Area

The city of Corpus Christi and the surrounding Coastal Bend area obtain their water supply exclusively from surface-water sources in the Nueces River Basin. Annual rainfall in the basin varies from 20 inches per year at the headwaters to about 30 inches per year at Corpus Christi. Surface impoundment is necessary since the natural flow of the Nueces River varies from no flow during extremely dry periods to as much as 140,000 cubic feet per second during floods.

Water requirements for the city of Corpus Christi and the surrounding towns and industries have been increasing at a steady rate. Currently, in addition to the water used for domestic and industrial purposes in Corpus Christi, the city also delivers treated water to the Reynolds Metals Company and San Patricio Municipal Water District. The San Patricio Water District in turn supplies the DuPont Chemical Company, Big 3 Industries, and the towns of Odem, Taft, Gregory, Portland, Ingleside, Port Aransas, Rockport, and Aransas Pass. Three raw-water pumping stations are located near the treatment plants, and water from these stations supplies Celanese Corporation at Bishop, Suntide Refinery near Corpus Christi, and the San Patricio Municipal Water District. The Alice Water Authority also purchases water from the City of Corpus Christi at Lake Corpus Christi for municipal use.

Present supplies are inadequate to meet future demands because of inadequate storage capacity (surface impoundments) within the basin. However, the basin yield could be significantly increased through additional impoundment. Current water demands on the city of Corpus Christi are rapidly approaching the annual dependable supply of Lake Corpus Christi, the city's only major impoundment. Ground-water withdrawals currently exceed estimated safe yield from local aquifers (primarily the Gulf Coast Aquifer). As a result of such overdrafts, long-term withdrawals will need to be reduced to avoid additional problems inherent in such ground-water mining.

Pollution, Recreation, Flooding, and Salt-water Intrusion Problems in Louisiana

This problem area involves the Sabine River Basin in portions of DeSoto and Sabine Parishes adjacent to the Toledo Bend Reservoir and portions of Vernon, Beauregard, Calcasieu, and Cameron Parishes below the Toledo Bend Reservoir. Problems include surface-water pollution, limited access to recreation facilities, flooding, and the potential of salt-water intrusion in the coastal zone.

Pollution in Toledo Bend Reservoir comes from subdivision and residential development nearby, effluent from towns and industries on tributary streams, and forestry and agricultural operations. These problems of pollution are under observation by the Sabine River Authority of Louisiana and the Louisiana Health and Human Resources Administration (the State Board of Health) and are not expected to reach any critical proportions.

Limited access to recreation areas is a problem since it results in a lack of economic activity. If adequate access to the recreation areas were provided, visitors to and users of Toledo Bend Reservoir and its fringe area for boating, camping, picnicking, swimming, skiing, and other water-related activities would increase significantly. This problem will be relieved somewhat by the completion of the Toledo Bend Forest Scenic Highway extending 95.6 miles from Logansport to Leesville, Louisiana.

Some flooding is experienced along tributaries of the Sabine River in Louisiana. Generally, structural measures to control this flooding are not feasible except in two instances, which are upper Bayou LaNana and Little San Miguel watersheds. In remaining areas, nonstructural measures are the logical method to control flood damages.

In the coastal area of Louisiana adjacent to Sabine River some flooding does occur due to tidal fluctuations. Flood damages are reported more frequently now than in the past because of the development and use of lands with extremely low elevations. Additionally, this same general area is subject to salt-water intrusion from the Gulf of Mexico, depending upon rainfall, tidal conditions, and river stages.

Upper Colorado River Salinity Problems in Texas

Within the Upper Colorado River Basin of Texas, four counties are principally affected by saline water problems. These counties are Scurry, Mitchell, Howard, and Coke.

Although surface water in most of the Colorado River Basin is relatively low in dissolved solids, inflow of saline water in the upper Colorado River Basin below Lake J. B. Thomas seriously degrades the quality of the main stem for about 100 miles downstream. The salt load contributed to the main stem within a 696 square mile drainage area is of both natural and manmade origin.

Salt water enters the main stem of the Colorado along a segment in Scurry and Mitchell Counties just below J. B. Thomas Reservoir. Early oilfield operations in this area included the construction of over 200 salt-water evaporation pits from which salt water easily seeped into the local alluvium. Also, early oil wells were improperly plugged and abandoned, thus allowing the seepage of saline water from deeper formations into fresh-water aquifers. Naturally occurring saline water in the Santa Rosa Aquifer discharges into the river below J. B. Thomas Dam and in the headwaters of E. V. Spence Reservoir. Runoff from above the salt-producing area is very low in dissolved solids. The average dissolved solids concentrations are not more than 250 mg/l in Lake J. B. Thomas, whereas below the lake on the main stem of the Colorado at Cuthbert, dissolved solids concentrations averaged near 3,000 mg/l in 1975.

Beals Creek, a comparatively large tributary which has its headwaters in a large natural depression known as Natural Dam Salt Lake, also contributes to the salt load of the Colorado River as it enters the main stem just above E. V. Spence Reservoir. Although the quality of water in the natural saline lake varies widely in response to precipitation, concentrations of dissolved solids have frequently exceeded 20,000 mg/l.

In the salt-contributing area below Lake J. B. Thomas, much of the dissolved-solids load is contributed by the base flow of the river and by runoff from local rainstorms. These high dissolved-solids concentrations in local runoff generally occur following periods during which the main stem has little or no flow. They result largely from the solution of salt deposited by evaporation of the saline base flow contributed by the Santa Rosa Aquifer.

Former waste disposal problems in oil and gas fields which have contributed to the Colorado River salinity problem have been largely rectified. The residual effects of past practices, however, continue to plague development of water resources in this part of the basin, and the chemical quality of low flows of the river, which carry much of the salt load, will be slow to improve. Also, the water stored in E. V. Spence Reservoir will continue to be marginal for most municipal and industrial uses without dilution.

Water Supply Problems in the Mid-Brazos River Basin in Texas

The problem area comprises 18 counties in the central portion of the Brazos Basin in Texas. The primary sources of ground water in the area are the Henzel and Hosston members of the Travis Peak Formation. In the Waco area most wells completed in this aquifer from 1900 to 1930 showed small to moderate amounts of water at the land surface. Since 1900, the water level has declined more than 400 feet because pumpage has exceeded recharge.

The Henzel Formation has as much as 70 feet of net sand thickness containing fresh to slightly saline water at depths from about 900 to

2,500 feet. The Hosston Formation has a maximum net sand thickness containing fresh to slightly saline water of more than 340 feet at depths from about 1,000 to 3,600 feet. Total dissolved solids of the waters from these aquifers in the Waco area range from 500 to 900 milligrams per liter.

Because of the reduction in the aquifer's artesian pressure and mining of aquifer storage, numerous cities, such as Waco, Temple, and Hillsboro, have been forced to convert their supply to surface-water sources. However, due to natural salt pollution in the upper and middle Brazos Basin, the main stem Brazos River at Waco is generally unsuitable for municipal use unless blended with high quality water. Thus, the mid-Brazos ground-water depletion problem is complicated by the Brazos Basin salinity problems above Possum Kingdom Reservoir.

Problems Associated with Fresh-water Inflows to Texas Bays and Estuaries

Texas has the most diverse coastal region in the Nation and one of the most productive series of estuarine ecosystems in the world. There are seven major estuarine systems in Texas. They are subject to the full spectrum of naturally dynamic physical, chemical, and biological processes. One fundamental aspect of the processes is the timing, magnitude, and quality of fresh-water inflows from the 15 major Texas river basins. Extensive research has shown that fresh-water inflows function primarily as: (1) a transport mechanism to bring vital nutrients and sediments to the estuarine systems, (2) a dynamic force in the periodic inundation and dewatering of the coastal wetlands, and (3) a salinity gradient control.

Bays and estuaries may be altered in the future as water requirements approach the firm yields of contributing river basins and thereby alter the fresh-water inflow to the estuarine systems. Avoiding the resulting environmental stress and reduced estuarine productivity requires the establishment of a water management criteria for these estuaries based upon the best scientific and engineering analyses.

In 1975, the 64th Texas Legislature enacted legislation directing State agencies to perform comprehensive studies of the effects of freshwater inflows upon Texas bays and estuaries and, further, to develop methods of providing and maintaining their ecosystems. Detailed evaluations of the interrelationships between fresh-water inflows and estuarine environments are now being executed under this legislation to assess the environmental impact of water resources development in Texas. Reconnaissance level investigations begun in 1967 have been expanded to broad-based scientific, engineering, and economic research on the Texas coastal region. In addition to the collection of baseline data, computerized mathematical models that simulate the environmental systems have been developed to the effects of water resources development and management policies on Texas bays and estuaries.

With adequate water resources measures, it would be possible to reduce the effects of drought and substantially control seasonal freshwater inflow quantity and quality at appropriate times and at appropriate geographic locations. Such measures are needed to maintain Texas estuarine environments at sustainable levels of productivity in accordance with the established State and Federal legislation.

Water Supply and Quality Problems in Small Cities and Rural Communities in Texas as a Consequence of Implementing the 1974 Safe Drinking Water Act

Since the passage of the Safe Drinking Water Act of 1974 (Public Law 93-523) and the subsequent issuance by the Environmental Protection Agency of the Interim Primary Drinking Water Standards, approximately 600 public water systems in Texas have been in violation of the drinking water standards. The majority of these violations result from an inability to meet maximum standards for fluoride contamination. Violations have also resulted from inability to meet the maximum standards for nitrate. The problem area extends throughout the entire State of Texas. Certain areas of west Texas and the Trans-Pecos--where ground-water quality tends to be degraded by fluoride and nitrate--are the most seriously affected.

An estimated 6 percent of the population of Texas (about 734,000 persons) reside in areas where current water supply systems cannot meet the Safe Drinking Water Standards. These water supply systems are generally small and serve rural customers in low density residential areas. The additional cost of meeting the Safe Drinking Water Standards will create financial problems on the public and private water systems involved. Rising costs of electricity, labor, and other necessities for operation are already vastly increasing plant operating costs. It is estimated that, of the 600 systems unable to meet the standards, it will be economically infeasible for 504 of these systems to invest the necessary funds to bring their systems up to standards. About 500,000 persons reside in the service areas of the 504 systems.

Flood and Hurricane Problems in Texas

Flooding occurs almost every year on one or more of the major streams of the State. Texas history records many damaging floods throughout the State. Many of these floods have resulted in the loss of human life and have caused serious economic losses to urban areas, to agriculture, to transportation, and to utilities industries.

Because of the wide variation in the climate and physiography of Texas, the magnitude and character of floods differ widely, both within and between the major river basins of the State. In eastern Texas, where rainfall is abundant, streams flow through broad, flat valleys bordered by timber and dense growths of vegetation. Stream channels commonly have gentle slopes and small capacities and follow meandering courses from their headwaters to the Gulf. Runoff is comparatively slow, and stream velocities are generally low. During periods of intense rainfall, large volumes of water accumulate in the valleys of the basins and are released slowly to the streams. These conditions generally produce broad, flat-crested floods which move slowly in the lower regions of the basins and inundate the land for long periods.

In central and western Texas, ground and tree cover is sparse. Stream slopes vary from steep to moderately steep, becoming flatter in the coastal plains. During intense rainfall, runoff is more rapid than in eastern Texas, with high peak flows, high stream velocities, and shorter periods of land inundation. Hurricanes, with high winds, heavy rainfall, tornados, and tidal surges, directly affect areas along the Gulf of Mexico. As the dying storm centers move inland, heavy rain, tornados, and flooding can affect areas several hundred miles inland from the coast.

The most serious statewide flooding in recent years occurred in 1957. From April through June, every major river and principal tributary in the State reached flood stage. Flood conditions existed for as long as 80 days on many major rivers during this period.

Ground-water Depletion Problems in the Texas High Plains

The Pliocene age Ogallala Formation occurs at or near the surface over much of the 42-county High Plains area of northwest Texas. The formation consists of alternating beds of silt, clay, sand, gravel, and caliche. The saturated zone of the aquifer ranges from a few feet to more than 500 feet thick. In the irrigation area north and west of Lubbock, the saturated interval ranges between 100 and 300 feet. South of Lubbock, the saturated zone is between 25 and 150 feet thick. The thickest saturated section is north of Amarillo and is over 500 feet.

The Ogallala Aquifer in Texas is one of the most intensely developed aquifers in the United States. Pumpage for irrigation ranges from about 5 to 10 million acre-feet annually, depending on the amount of precipitation occurring during the irrigation season, and supports more than 65 percent of irrigated acreage in Texas. This pumpage is considerably greater than the exceedingly small average annual natural recharge to the aquifer. As a result, the saturated thickness of the aquifer is declining in the Texas High Plains.

The Ogallala Aquifer will not support the present irrigation development in the Texas High Plains for the long term. Declining water levels and increasing pumping costs due to the reduction in saturated thickness will substantially reduce supplies of water for irrigation in the High Plains during the next 20 to 30 years. The decline and ultimate exhaustion of this aquifer will reduce agricultural production, lower supplies of food and natural fibers for consumer markets, raise retail prices for these commodities, and reduce employment and incomes for this area.

Detailed investigations of the Ogallala Formation are being conducted by the State, Federal agencies, universities, and local ground-water districts to determine the quantity of water in storage, to find ways to increase recharge, to increase efficient use and management of existing supplies, and to increase water conservation. The economywide, negative impacts of the exhaustion of this aquifer as a water supply for this major irrigation area is one of the most serious water-supply problems of Texas for the remainder of the 20th century.

Water Supply, Flooding, and Erosion Problems in Louisiana

This problem area includes all Louisiana parishes in the Sabine River Basin. The problems are not considered serious, and efforts are being made to resolve them. Water withdrawals from Toledo Bend Reservoir are being made or are pending for the towns of Logansport, Mansfield, and Many, Louisiana. Other towns are considering the Sabine River as a supply water source. Projected water requirements for the Sabine River Basin in Louisiana and other areas of the State are now under study as part of a statewide water resources analysis.

In Calcasieu Parish, the Sabine River Diversion Project will provide supplemental water supplies from the Sabine River to Calcasieu Parish and its Lake Charles vicinity. Present and future requirements will not be completely met by this diversion and supplemental water supply. This problem will be addressed in statewide water resources study.

Generally, there are no extremely serious water supply problems in the Sabine River Basin of Louisiana, except those portions of Cameron and Calcasieu Parishes which are influenced by salt-water intrusions from the Gulf of Mexico.

Some flooding occurs along Louisiana tributaries of the Sabine River. Generally, structural flood control measures to control this flooding are not feasible except in two instances, which are in the Upper Bayou LaNana and Little San Miguel watersheds. In remaining areas, nonstructural measures appear to be the logical methods of controlling flood damages.

Erosion is a problem on the Louisiana shoreline of Toledo Bend Reservoir. It is under observation by the Sabine River Authority of Louisiana, and no serious impact on the economy is expected.

Water Supply and Related Problems in Curry, Roosevelt, and Lea Counties, New Mexico

In the western Texas Gulf Region, the New Mexico counties of Curry, Roosevelt, and Lea are affected by water supply, water quality, and flooding problems and have limited recreational facilities. Essentially all of the water in the New Mexico portion of the Texas Gulf Region is furnished from ground-water supplies, which occur primarily in the sands and gravels of the Ogallala Formation. Large-scale pumpage of ground-water for irrigation, industrial, municipal, domestic, livestock, and power production has resulted in aquifer mining and water level decline. Without additional water supplies, the resulting drop in water levels and the small quantities of water remaining in aquifer storage will be uneconomically recoverable for irrigation. Potable ground water is generally available throughout the area; however, in a few locations the water is very hard and high in sulfates or chlorides.

Summary

The physical environment of the Texas Gulf Region, encompasing about 177,697 square miles, is marked by a wide range of geologic, topographic, and climatic conditions. This diversity has influenced the distribution and well-being of the citizens of the region. The multiple effects of this diversity must be recognized as significant in the planning and development of water and other resources. The region extends from the Gulf of Mexico northwestward some 650 miles into the Great Plains Province of the United States. Mean annual rainfall varies from 12 inches in the extreme northwest to more than 55 inches in the extreme eastern part of the region.

The estimated 1975 population was 9.9 million, with metropolitan areas accounting for almost 80 percent of the total. Since 1960 the total rural population has remained relatively constant at about 2 million. The region is one of the fastest growing areas in the Nation. It is estimated that by the year 2000 population will exceed 12.9 million.

A wide range of economic activity also occurs within the region. Over 4 million persons are employed. Major manufacturing establishments located in the region contribute significantly to the Nation's economy. Paramount among the manufacturing industries are the petroleum refining and chemical industries. Together they contribute over $4 billion in value added to raw materials annually.

Almost 50 percent of the total agricultural production is exported from the region to the rest of the Nation and other countries. The growth of agriculture has been made possible by irrigation, especially in the High Plains, where over 60 percent of cash receipts derive from the sale of irrigated crops.

The average daily water withdrawals within the region are almost 17 bgd. Irrigated agriculture used about 68 percent of this amount, while domestic and manufacturing withdrawals accounted for about 18 percent. Water used for livestock, mining, and steam electric power generation accounted for the remainder. By the year 2000, however, total withdrawals are expected to decrease to about 14.9 bgd. In the year 2000, irrigation will account for only 50 percent of the total withdrawals, while domestic and manufacturing uses will increase from the 1975 level to account for 27 percent of the total. The total consumptive use in 2000 is projected to be about 10.5 bgd or about 70 percent of the total withdrawals. This compares to a consumptive use of 11.2 bgd or 94 percent of total 1975 withdrawals.

Ground-water supplies throughout the region are diminishing rapidly because pumpage exceeds natural recharge by a substantial margin in most aquifers. The region must increasingly depend on surface-water supplies to meet the projected requirements. By the year 2000, ground water will supply only 11 percent of the total withdrawal requirements, and surface water must supply the remaining 89 percent. In 1975 ground water supplied

43 percent of the withdrawal requirements, and surface water satisfied the remaining 57 percent.

In addition to the water supply problems resulting from increased demands and diminishing ground-water supplies, numerous other severe water and related problems occur within the Texas Gulf Region. Water quality problems within the region can be attributed to naturally occurring pollution sources, such as salt springs, and to pollution from human activities. Floods throughout the region have historically taken many lives and inflicted millions of dollars in damages to urban and rural developments, agriculture, industry, and utilities. Many developed urban and agricultural areas have problems with drainage of storm and flood waters. Erosion and sedimentation along with land subsidence and saline water encroachment result in major problems in many areas. The growth in population, leisure time, and mobility have resulted in problems with providing sufficient reservoirs and lakes and for recreation. Numerous problems occur with providing fresh-water inflows at appropriate geographic locations to sustain levels of productivity in the region's estuarine systems. Legal, institutional, and hydrologic factors also contribute to difficulties related to the development and management of water resources to meet foreseeable water requirements.

Since the personal and the economic welfare of the people of the region depend directly upon a steady, daily supply of usable water, it is imperative that all possible actions be taken to insure a timely solution to water and related problems so that there is an adequate quantity of water of acceptable quality available. Bitter and costly experience has shown that to do this, Federal, State, and local entities must together formulate plans, develop facilities, and store storm and flood flows of surface water in sufficient quantities: (1) to meet the regular, daily needs on a continuing basis and (2) to sustain deliveries to meet these needs during droughts. Water from aquifers that historically have supplied large areas of the region with water is being consumed more rapidly than it is being replaced through natural processes. This phenomenon, coupled with the large and growing size of the region's total water requirements, poses many interrelated problems that must be resolved.

Conclusions and Recommendations

Increasing water supply requirements for diverse purposes together with the necessity to protect human lives and property from floods and droughts dictate that accurate water resource information and data be obtained on a continuing basis. Information and data are needed to understand the complex socioeconomic interrelationships involved. The knowledge gained from such understanding can be utilized to develop the alternative measures, which the people of the region can evaluate. They then can choose a course or courses of action that will satisfy their manifold water requirements. The interactions of the people, the environment, and the economy of the region produces complexities that will grow worse as the population grows and competition for scarce water, land, minerals, and other resources increases. To fail to develop water resources and to fail to resolve existing and emerging water resource problems involves social and economic costs of inestimable magnitudes. The failure to plan and implement timely water-resources programs, with today's large and growing population and economy, is to invite economic and social crises that could result in disasters for the people of the Texas Gulf Region.

The overwhelming national importance of water resources development and management and the extremely complex nature of the technical and institutional factors associated therewith has led to widespread local, State, and Federal government involvement in water resources planning, development, and operations. This should continue. In the past, about 80 percent of total financing of Texas water resources programs has been supplied through local political subdivisions--municipalities, water supply and improvement districts, and river authorities--and State agencies. The remaining 20 percent has been supplied through Federal programs.

The increasing pressures upon existing water resources and the increasing competition for capital with which to carry out all public programs, including water resources development, necessitates a reevaluation of the roles of each level of government. Federal participation in water resources planning and development is essential where the national interest is involved. Federal participation is needed to help resolve water resources problems: (1) involving two or more States; (2) pertaining to institutional arrangements involving interstate surface and ground waters; and (3) of financing water resources planning and development and research that is beyond the scope of local and State funding capabilities.

The Federal role in water resources development and management has increased and diversified to include a variety of agencies, programs, and purposes. Because of the differing objectives and policies of the many Federal agencies involved and the lack of consistency at the Federal level, water resources programs have not met identifiable needs on a timely basis. Inconsistency at the Federal level and insufficient funds have adversely affected State planning and development to meet water needs.

In Texas, State appropriations have been made for comprehensive statewide water resources planning since 1964, and substantial funds have been spent for data collection and planning studies. Planning objectives have been oriented toward reaching a mutually responsible relationship between Federal and State agencies concerned with water and related land resource planning and development.

Texas water planning is a continuous planning process that takes into account the rapidly changing national, State, and regional economic, social, technical, and resource conditions. The information underlying and contained within the Texas water resources programs is fundamental to local, State, and Federal water resources development and management.

The Texas Water Plan, adopted in 1969 as the official guide to State policy for water development, remains the basic framework for State water development. Since completion of the Texas Water Plan, the impact of continuously changing social, economic, environmental, and hydrologic variables, Federal statutes, policies, programs, and other water-oriented phenomena clearly indicates the need for reevaluation of the plan. Consequently, early in 1976, a work program was designed and initiated to reevaluate and update the Texas Water Plan. This effort is in programs. A two-volume draft, Continuing Water Resources Planning and Development for Texas, is currently being circulated to the people of Texas, local, State, and Federal water interests, environmental groups, and other public interest groups throughout Texas for review and comment.

A review of Federal water resources policy was initiated by the President in May of 1977. The formulation of a national water policy is highly desirable as a part of the Federal role in water resources, and should contain elements outlined below. A national water policy must respect and preserve the State's water laws and must leave the choices and decisions in the hands of governmental entities as near to the people involved as possible. Sovereignty of Texas over its in-State water has been the basis of water development and use throughout the history of the State.

The laws of the State provide, for the most part, a reasonable allocation of available surface waters. Where conflicts exist, the Water Rights Adjudication Act of 1967 provides a judicial procedure to deal with the problem. The laws of the State also provide for the ownership of water underneath private and public lands. Where interstate waters have been involved, the compact procedure has provided an acceptable vehicle to resolve the problems.

Mechanisms available under existing statutes and procedures for coordination among and between Federal agencies and the States have not been effectively utilized. Federal planning programs should be coordinated and implemented only within the guidelines of statewide and regional plans.

Existing cost-sharing procedures for Federal water resource projects, although somewhat complex and admittedly inconsistent in some respects among agencies and programs, have nevertheless been effective in Texas. While there is a need for uniformity in cost-sharing procedures and administration, the Congress through its appropriative process should remain the arbiter of the allocation of citizen tax dollars to water development and management projects. Funding sources should be as devoid of "Federal strings" as possible so that regional programs can be developed to achieve maximum efficiency of use of scarce capital, water supply, and other resources to meet regional goals and objectives.

Research and technology should be adequately funded on a long-term basis and expanded in order to develop the technology for water use efficiency in the home, in the factory, and on the farm; to evaluate long-term environmental effects of alternative types of water resources development and management programs; and to develop appropriate legal, institutional, financial, and other measures to meet changing socioeconomic conditions.

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of water and related land resources
on a comprehensive and coordinated basis
by the Federal government,
States, localities, and private enterprises
with the cooperation of all
affected Federal agencies,
States, local government, individual
corporations, business enterprises,
and others concerned.