TR-135
1985

Texas Water Resources Institute
make every drop count

Reservoir Operation in Texas

R.A. Wurbs

Texas Water Resources Institute

Texas A&M University

RESERVOIR OPERATION IN TEXAS

Project Number G-871-03
(July 1, 1983 - July 31, 1984)

Project Number G-935-02
(July 17, 1984 - July 31, 1985)

Grant Numbers

14-08-0001-G-871
14-08-0001-G-935

Principal Investigator

Ralph A. Wurbs

The research on which this report is based was financed in part by the United States Department of the Interior as authorized by the Water Research Development Act of 1978 (P.L. 95-467).

Technical Report No. 135
Texas Water Resources Institute
Texas A&M University
College Station, Texas 77843

June 1985

ACKNOWLEDGEMENTS

This is one of several reports prepared in conjunction with a two-year research project sponsored by the Texas Water Resources Institute entitled "Optimum Reservoir Operation for Flood Control and Conservation Purposes." The study was supported by federal funds provided by the Department of Interior and nonfederal matching funds provided by the Texas Water Resources Institute and the Center for Energy and Mineral Resources of the Texas A&M University System. Dr. Ralph A. Wurbs, the principal investigator for the project and author of this report, is a faculty member of the Civil Engineering Department at Texas A&M University. Michael N. Tibbets, L. Moris Cabezas, and Lonnie C. Roy authored and coauthored other reports in conjunction with the overall research project. Their contributions to the project also influenced this particular report. Their work was supported through graduate research assistantships funded by the project. Quana L. Childs participated in the development of Appendix A, working as an undergraduate research technician. Moris Cabezas prepared the graphs in Appendix B. Mrs. Joyce A. Hyden typed the report.

Many people in the reservoir management community in the state contributed information for this report. The author visited with personnel in the offices of several of the agencies and telephoned numerous others. These discussions, as well as agency reports and other printed material provided, were indispensable to the study effort. Personnel of the Fort Worth District of the Corps of Engineers were called upon particularly frequently. The study also relied heavily on information, including the reservoir map in the back of this report, provided by the Texas Department of Water Resources. The author appreciates the generous sharing of expertise and information of all the individuals contacted during the course of the study.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

Effective management of its surface water resources is essential to the continued growth and prosperity of the state of Texas. Rapid population and economic growth combined with depleting ground water reserves are resulting in ever increasing demands being placed upon the surface water resources. The climate of the state is characterized by floods and droughts. Reservoirs are necessary to control and utilize the highly variable streamflow. Numerous reservoirs have been constructed to facilitate management of the surface water resources of the various river basins of the state. The operation of these essential water control facilities is examined in this report. Reservoir operation is viewed here from the perspective of deciding how much water to store and to release or withdraw for flood control and various conservation purposes. The report is intended to provide a comprehensive, indepth description of how reservoirs are operated in Texas.

The following chapter briefly describes the general environment for reservoir development and management in the state, in terms of the water resource and the demands that people place upon the resource. Chapter 3 and Appendix A provide a detailed inventory of the major reservoirs in the state. The reservoirs are managed within a complex institutional framework. Reservoir management organizations and programs and water rights considerations are outlined in Chapter 4. An overview of reservoir operations in each major river basin is presented in Chapter 5. Chapter 6 examines the practices and procedures followed in determining the amount of water to store and to release or withdraw from a reservoir for various purposes under various operating conditions. Issues and problem areas are identified, and future directions are suggested. The last chapter provides a summary of reservoir operation in Texas.

CHAPTER 2
SURFACE WATER RESOURCES OF TEXAS

Reservoirs are operated in Texas in an environment of hydrologic variability and ever increasing demands. Streamflow in the state is highly variable and subject to extremes of floods and droughts. Consequently, reservoirs are required to provide flood protection and dependable water supplies. Essentially all the surface water used for beneficial purposes is regulated by reservoirs. Rapid population and economic growth is resulting in ever increasing demands being placed upon the state's water resources and the institutions and facilities available to control and utilize the water resources. In terms of total water use in the state at the present time, more ground water is used than surface water. However, depletion of ground water reserves is resulting in a shift to a greater reliance on surface water. Basic information describing the physical, hydrologic, and economic environment for surface water management in Texas is presented in this chapter.

River Basins

Texas has about 3,700 designated streams with a combined length of about 80,000 miles (Texas Department of Water Resources, 1984). The state is divided into 15 major river basins and eight coastal basins which are listed in Table 1 and delineated on the Texas Department of Water Resources map provided as Plate 1. Eight of the major river basins are contained entirely within the state, and the other seven are interstate.

The Canadian River heads in northern New Mexico and flows across the Texas Panhandle into Oklahoma where it confluences with the Arkansas River. The 1,360 mile long Red River rises in New Mexico near the Texas boundary, flows across the Texas Panhandle, becomes the Texas-Oklahoma boundary for 400 miles and the Texas-Arkansas boundary for 40 miles, and then flows through Arkansas and Louisiana to its confluence with the Mississippi River. The Sulphur River and Cypress Creek are both tributaries of the Red River with their upper basins lying in northeastern Texas. The 360-mile long Sabine River originates in Texas and provides a 290 mile segment of the Texas-Louisiana boundary before reaching its mouth at Sabine Lake. Both the Brazos and Colorado River Basins originate in New Mexico and extend in a southeasterly direction through the center of Texas. Most of the watershed area and all of the reservoirs in the Brazos and Colorado Basins are in Texas. The Trinity, Neches, San Jacinto, Lavaca, Guadalupe, and San Antonio River Basins are located entirely within the state and flow to the Gulf of Mexico. The San Antonio River is actually a tributary of the Guadalupe River but the confluence is near the Gulf.

The 1,900 mile Rio Grande River rises in Colorado, flows the north-south length of New Mexico and forms the international United States (Texas)-Mexico boundary for 1,250 miles. The Rio Grande is the longest river in Texas. Depending on methods of measurement, the Rio Grande is the fourth or fifth longest North American river, exceeded only by the Missouri-Mississippi, McKenzie-Peace, St. Lawrence and possibly Yukon. Since all of these except the Missouri-Mississippi are partly in Canada,

TABLE 1
RIVER BASINS

BASIN	AREA IN TEXAS	AREA OUTSIDE OF TEXAS	1980 TEXAS POPULATION	POPULATION DENSITY
	(square miles)	(square miles)		(persons/sq.mile)
Major Basins				
Canadian	12,700	35,000	167,500	13
Red	24,460	23,570	506,000	21
Sulphur	3,560	190	154,000	43
Cypress	2,810	100	118,200	42
Sabine	7,430	2,330	407,300	55
Neches	10,010	---	506,300	51
Trinity	17,970	---	3,216,000	179
San Jacinto	5,600	---	2,369,200	423
Brazos	43,000	2,570	1,529,900	36
Colorado	39,890	1,970	1,060,700	27
Lavaca	2,310	---	43,900	19
Guadalupe	6,070	---	243,400	40
San Antonio	4,180	---	1,054,400	252
Nueces	16,950	---	153,500	9
Rio Grande	48,260	133,960	780,900	16
Coastal Basins				
Neches-Trinity	770	---	203,700	265
Trinity-San Jacinto	250	---	80,200	325
San Jacinto-Brazos	1,440	---	536,800	373
Brazos-Colorado	1,850	---	81,700	44
Colorado-Lavaca	940	---	25,600	27
Lavaca-Guadalupe	1,000	---	39,900	40
San Antonio-Nueces	2,650	---	98,700	37
Nueces-Rio Grande	10,440	---	853,400	82
Total	264,540	199,690	14,231,200	54

the Rio Grande is the second-longest river entirely within or bordering the United States (A.H. Belo Corp., 1984). The snow-fed flow of the Rio Grande is used for irrigation in Colorado and New Mexico. Rio Grande water is impounded in Elephant Butte Reservoir in New Mexico to provide irrigation for 150 miles of valley above and below the city of El Paso. Extensive irrigation practically exhausts the water supply, and flow virtually ceases at the downstream end of the El Paso irrigated valley except in seasons of above-normal flow. The Rio Grande becomes a perennially flowing stream again downstream as tributaries enter the main river. About three-fourths of the inflow below El Paso comes from the Mexican side.

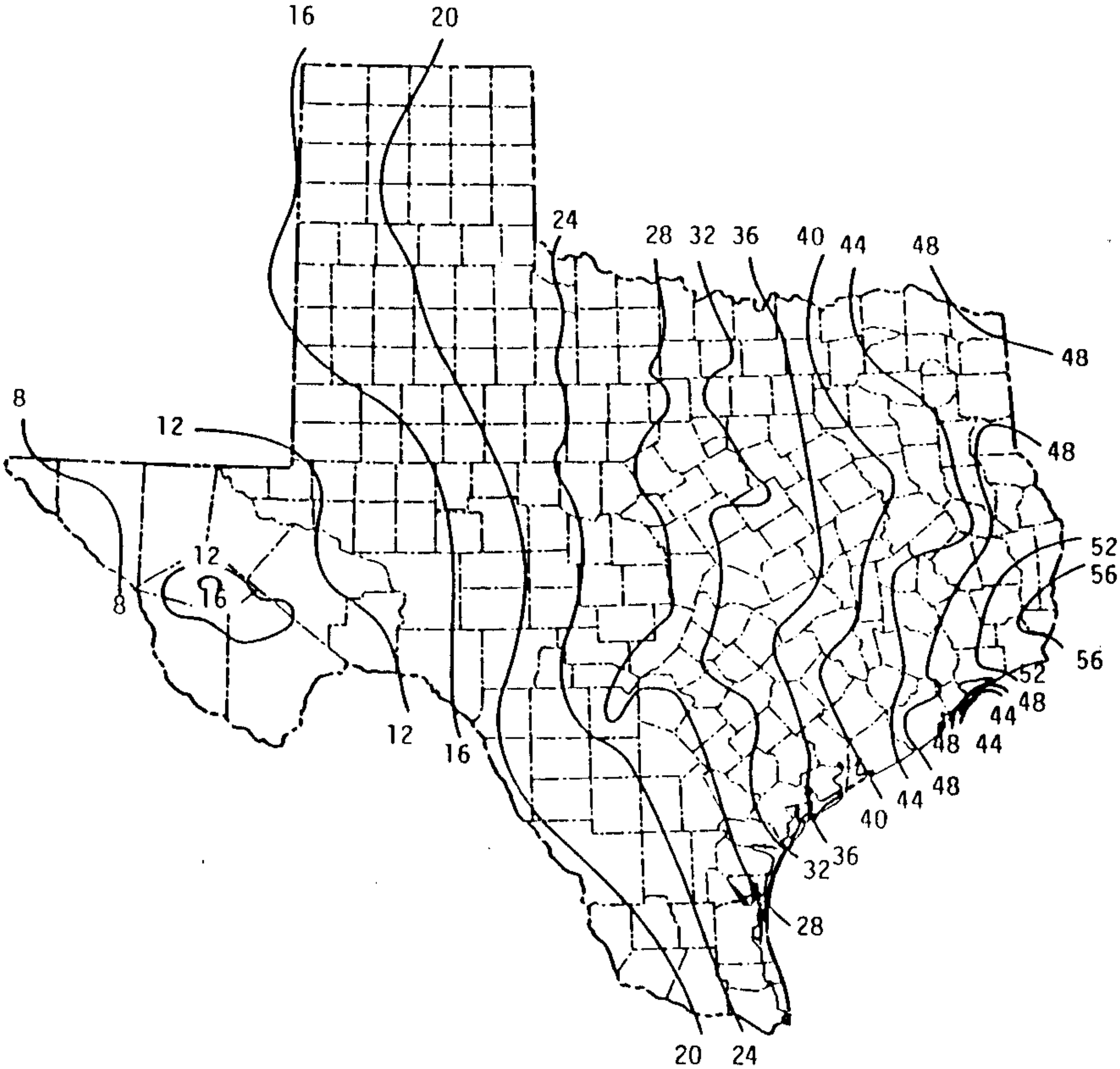
The eight coastal basins are also shown on Plate 1 and Table 1. The coastal basins encompass about 19,340 square miles or 7.3 percent of the land area of the state.

The population and population density of each basin is also included in Table 1. The population densities provide a general indication of the urban versus rural nature of a basin. The relatively small San Jacinto Basin is the most densely populated basin because it contains Houston, the state's largest city. The Dallas-Fort Worth metroplex is in the upper Trinity River Basin. The city of San Antonio is in the San Antonio River Basin. The coastal basins in the eastern half of the state are also densely populated. The western half of the state is sparsely populated.

Precipitation

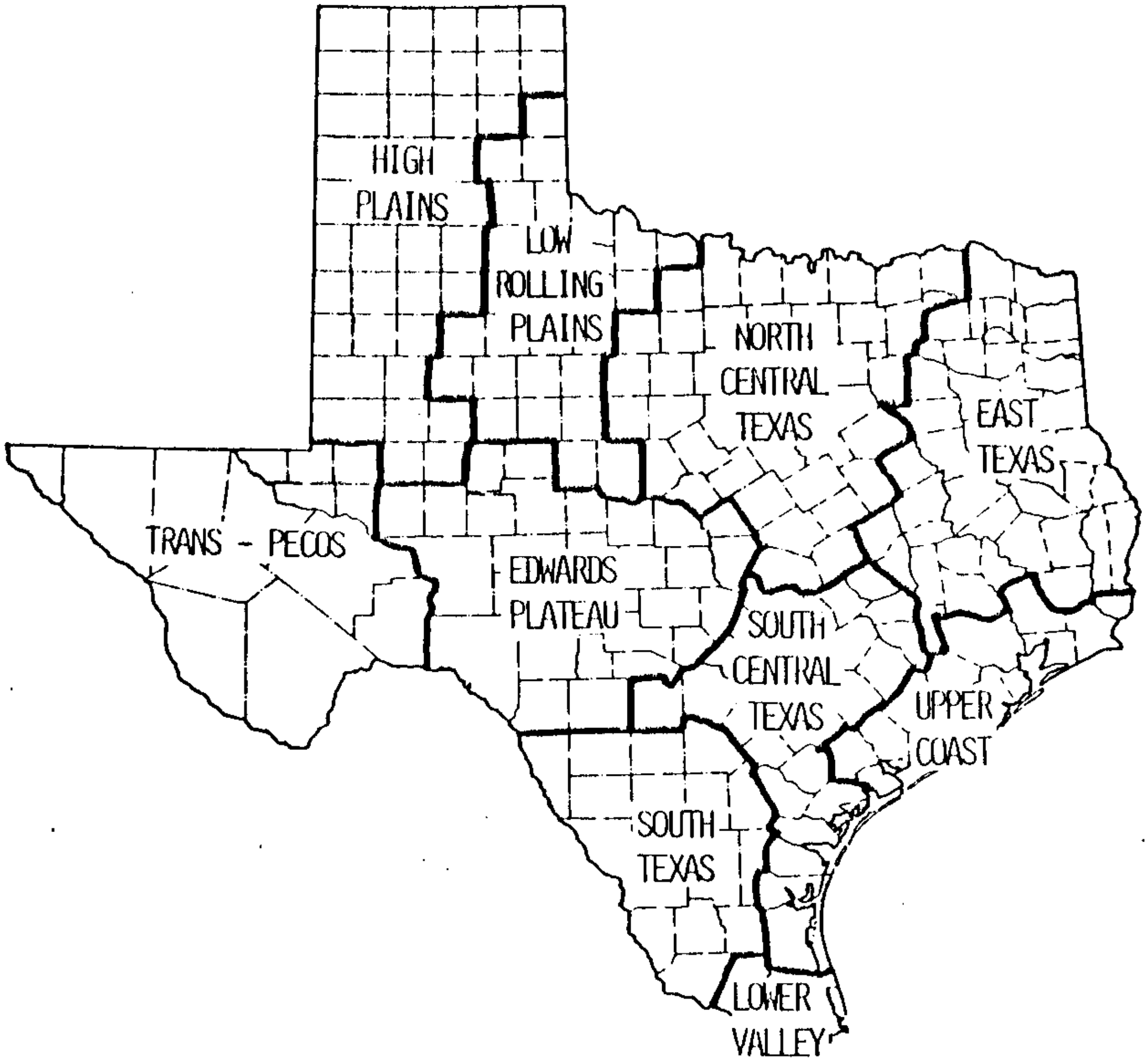
The interaction between warm, moisture-laden air from the Gulf of Mexico and drier, relatively cooler, continental surges of air from the north and west is responsible for most of the climatic patterns of the various parts of Texas. The western half of the state has a semi-arid, continental type climate, characterized by rapid and drastic fluctuations in temperature. The remainder of the state is influenced by a humid, sub-tropical climate, having moderate temperatures. Data on Texas climate and weather is available from the Office of the State Climatologist. This includes a summary of 100 years of Texas weather by Griffiths and Ainsworth (1981) which was the primary source for the precipitation data cited below. The Texas Almanac and Industrial Guide (A.H. Belo Corp., 1984) also includes a summary of weather data.

Although floods are associated with overflowing streams and water supplies are normally developed from streams, reservoirs, and aquifers, the ultimate source of the water is precipitation. Practically all the water which is used by Texans for beneficial purposes and/or causes flooding and drainage problems enters the state as precipitation from moisture-laden clouds from the Gulf of Mexico. Precipitation, like other aspects of the weather in Texas, is characterized by extreme variations, both geographically across the state, and over time seasonally and annually. As indicated by Figure 1, mean annual precipitation varies from eight inches in the extreme western part of the state to 56 inches at the eastern border. Generally, mean annual precipitation increases from west to east across the state on the average of about one inch every 15 miles, with little variation from north to south. For purposes of identifying



Source: Griffiths and Ainsworth (1981)

Figure 1
Mean Annual Precipitation
(in inches)



Source: Griffiths and Ainsworth (1981)

Figure 2
Climatological Divisions

climatic types, the state is divided into the ten climatological divisions shown in Figure 2. Table 2 shows the mean annual precipitation and the average precipitation for the wettest and driest month of the year for each climatological division. Significant seasonal variation of rainfall does occur. Mean annual precipitation statewide is about 28 inches. The wettest year of this century was 1941 with a statewide average rainfall of 42.6 inches. The driest year was 1917 with only 14.3 inches of rainfall. Table 3 shows record extreme annual means for each climatological division. The greatest recorded annual rainfall at one location was 109.4 inches at Clarksville in 1873. The least annual rainfall was 1.8 inches at Wink in 1956. The greatest 24-hour rainfall was 43 inches near Alvin in July 1979 (Griffiths and Ainsworth, 1981).

Although most precipitation in Texas is in the form of rain, snowfall also occurs. Mean annual snowfall varies from essentially zero in south Texas to 15 inches or more in the northern panhandle. Like rainfall, snowfall varies considerably from year to year. Snow melts relatively quickly. Consequently, reservoir operation in the intrastate basins of Texas are not dependent upon snow pack conditions like in others parts of the country. Snow is significant in the Red and Rio Grande Basins which have large watershed areas outside the state.

Surface Runoff

Precipitation supplies an average of about 413 million acre-feet of water to Texas annually. About 13 million acre-feet of ground water is pumped annually, of which about 8 million acre-feet are net withdrawals from storage. Of the 426 million acre-feet available annually to Texas, an estimated 176 million acre-feet evaporate from soil and water surfaces, 196 million acre-feet are transpired by evaporation, five million acre-feet are recharged to aquifers, and 49 million acre-feet are surface runoff into streams (Texas Department of Water Resources, 1984).

Runoff averaged 52 million acre-feet per year in Texas over the 1941 through 1980 historical period, but was only 23 million acre-feet annually during the 1950 through 1956 critical drought. About 50 percent of the state's total runoff originates in the eastern quarter of the state where the average runoff is about 650 acre-feet per square mile. Runoff rates decrease from about 1,100 acre-feet per square mile in parts of the Sabine River Basin to practically zero in parts of West Texas. About 16 percent of the total runoff is in the coastal areas, where the possibilities for capture and use are limited because reservoir sites are generally not available in this topographically flat region. Figure 3 shows the variation of mean annual runoff over the state. Runoff is expressed in units of inches in Figure 3, where 1.0 inch equals 53.3 acre-feet per square mile.

Streamflow depends upon numerous factors including precipitation, watershed area, infiltration and other losses, and reservoir regulation and withdrawals for beneficial use. Located in East Texas with high runoff rates, the Sabine River has the largest average discharge at its mouth of any Texas River. The adjacent Neches and Trinity Rivers also have high discharges. The Lavaca River has the lowest discharge of the 15 major

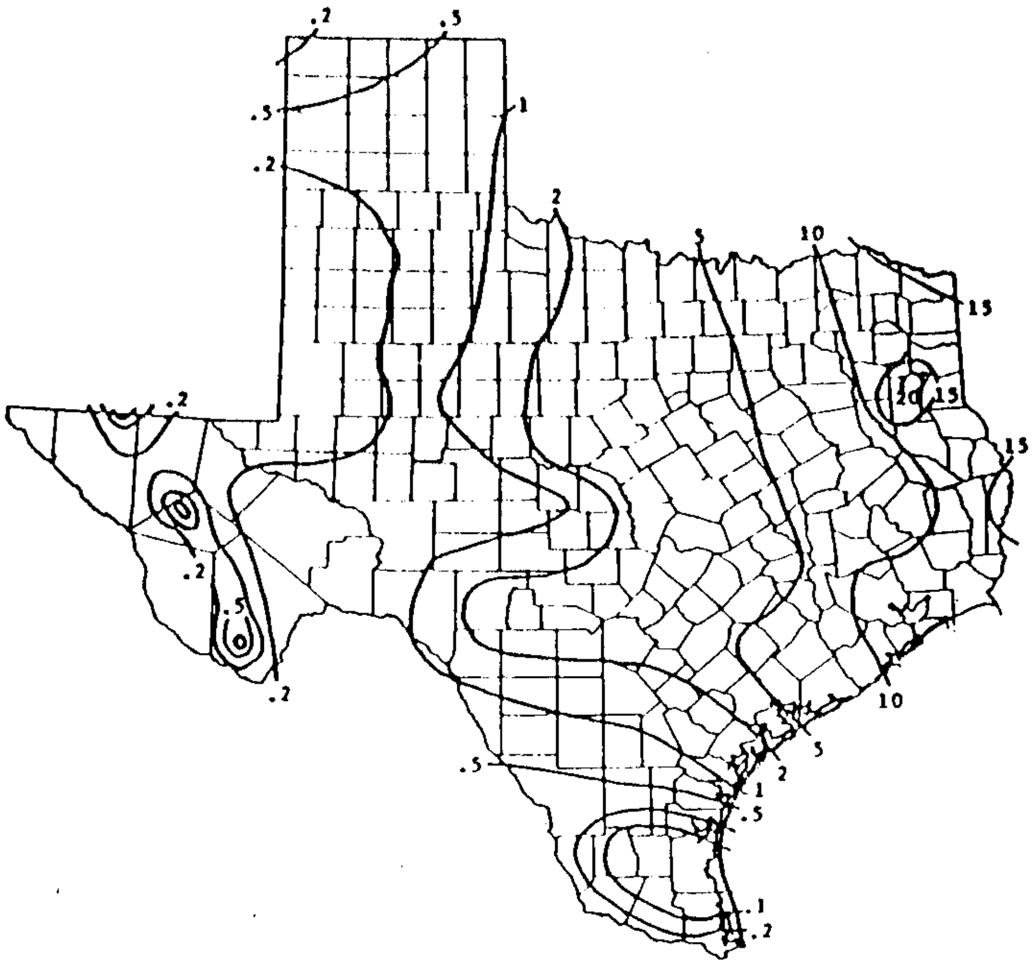
TABLE 2
AVERAGE PRECIPITATION BY CLIMATOLOGICAL DIVISION
(Period 1941-1970)

CLIMATOLOGICAL DIVISION	ANNUAL AVERAGE PRECIPITATION	WETTEST MONTH		DRIEST MONTH	
High Plains	18.59	May	2.83	January	0.56
Low Rolling Plains	23.18	May	3.82	January	0.93
North Central	32.94	May	4.65	January	1.93
East	45.37	May	5.34	August	2.81
Trans-Pecos	11.57	July	1.76	February	0.38
Edwards Plateau	23.94	September	3.22	December	1.18
South Central	33.03	September	4.32	March	1.84
Upper Coast	46.43	September	5.17	March	2.58
Southern	21.95	September	3.56	March	0.80
Lower Valley	23.44	September	4.41	March	0.82

TABLE 3
RECORD EXTREME ANNUAL PRECIPITATION MEANS
(Period 1931-1979)

CLIMATOLOGICAL DIVISION	RECORD ANNUAL MEANS			
	WETTEST		DRIEST	
High Plains	37.59	1941	9.48	1956
Low Rolling Plains	44.28	1941	13.02	1956
North Central	47.87	1957	20.03	1956
East	68.19	1973	31.29	1956
Trans-Pecos	27.15	1941	5.27	1956
Edwards Plateau	41.91	1935	11.22	1956
South Central	49.88	1973	16.75	1954
Upper Coast	70.70	1946	26.20	1954
Southern	35.93	1976	11.82	1956
Lower Valley	41.16	1941	12.88	1956

Source: Griffiths and Ainsworth (1981)



Source: Texas Society of Professional Engineers and Texas Section of the American Society of Civil Engineers (1974)

Figure 3
Mean Annual Runoff
(in inches)

rivers. The Guadalupe, San Antonio, and Nueces Rivers and their tributaries are spring fed and thus have relatively steady flow rates. The other rivers derive their flow largely from surface runoff from rainfall with some base flow from ground water.

Evaporation

Evaporation losses are an important consideration in the design and operation of conservation storage reservoirs. As shown in Figure 4, reservoir evaporation in Texas is significant, ranging from 50 inches per year in East Texas to 80 inches per year in the Trans-Pecos region. In East Texas rainfall rates are high enough such that the net evaporation minus rainfall is near zero. In the western part of the state where evaporation rates are extremely high and rainfall rates low, evaporation is a serious detriment to reservoir development.

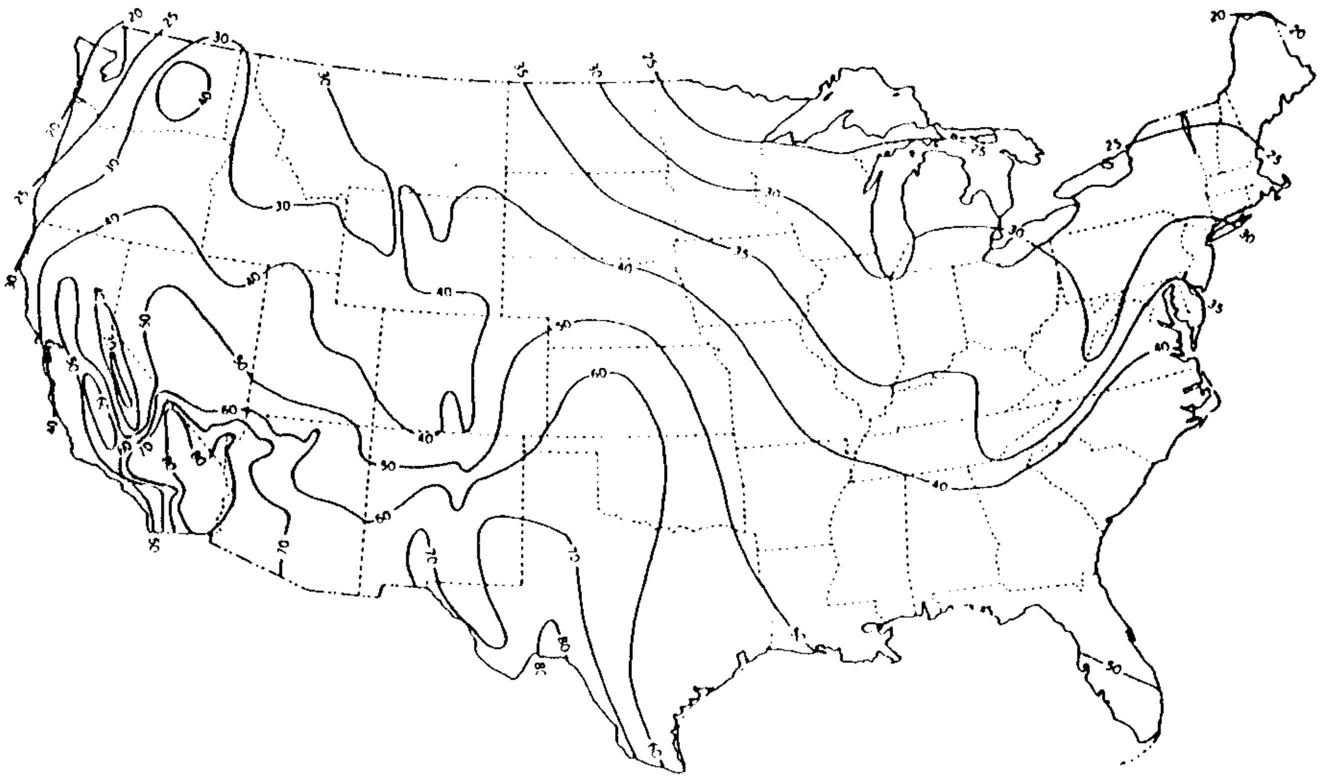
Floods

In most of Texas, a large portion of the annual rainfall occurs within short periods of time, resulting in excessive runoff. Flooding is a serious problem in the state, resulting in millions of dollars in damage annually in both urban and rural areas. All of the 254 counties have been designated by the Federal Emergency Management Agency as having some flood prone areas.

Due to the variety in climate and physiography, flood characteristics vary between different areas of the state. In the east, where the annual rainfall is highest, broad flat valleys are densely covered with timber and brush. Streams have gentle slopes, limited capacity, and follow meandering courses. Intense general rainfalls in this area produce slow-moving floods which inundate floodplains for prolonged periods of time. In central and western regions of the state, steep slopes, sparse vegetation, and relatively impervious ground result in flash floods. These high-peak, short-duration floods can be devastating in terms of property damage and loss of life. Floods in the flat coastal areas are caused by hurricanes, inland rains, and insufficient natural drainage. Rapid urbanization in the watersheds of many streams throughout the state is significantly increasing runoff rates.

The Texas Almanac and Industrial Guide (A.H. Belo Corp., 1984) contains a list of exceptionally destructive storms in Texas since 1766 which was compiled from data available from the Environmental Data and Information Service of the National Oceanic and Atmospheric Administration. The list includes floods, hurricanes, tornadoes, blizzards, and icestorms. Griffiths and Ainsworth (1981) also provide descriptions of past severe storm events in the state. Information from the Texas Almanac is summarized in the abbreviated descriptions of major floods occurring this century presented below. Dollar damages are as estimated at the time of the storm, without price level adjustments for inflation.

June 27-July 1, 1899 - A storm centered over the Brazos River Watershed resulted in an average of 17 inches of rain over an area of 7,000 square miles. At Turnersville, 33 inches of rain was recorded in three days.



Source: National Weather Service

Figure 4
Reservoir Evaporation
(in inches)

Between 30 and 35 lives were lost. Property damage was estimated at $9,000,000.

April 5-8, 1900 - A storm began in two centers, over Val Verde County on the Rio Grande River and over Swisher County in the High Plains, and converged in the vicinity of Travis County, causing disastrous floods on the Colorado, Brazos, and Guadalupe Rivers. McDonald Dam on the Colorado River at Austin was destroyed. A wall of water swept through Austin killing at least 23 people. Property damage was etimated at $1,250,000.

May 22-25, 1908 - This rainstorm was unique because it originated on the Pacific coast. It moved first into North Texas and thence to Central Texas, precipitating as much as ten inches. Heaviest floods were in the upper Trinity Basin, but flooding was general as far south as the Nueces Basin. Property damage exceeded $5,000,000 and 11 lives were lost in the Dallas vicinity.

December 1-5, 1913 - A rainstorm formed over Central Texas and spread both southwest and northeast with precipitation of 15 inches at San Marcos and 11 inches at Kaufman. Floods caused loss of 177 lives and $8,541,000 damage.

April 20-26, 1915 - A rainstorm originated over Central Texas and spread into North and East Texas with precipitation up to 17 inches, causing flood on the Trinity, Brazos, Colorado, and Guadalupe Rivers. More than 40 lives were lost and property damage was $2,330,000.

September 8-10, 1921 - Probably the most severe rainstorm in Texas history entered Mexico as a hurricane from the Gulf and moved northeasterly across Texas. Torrential rains caused record floods in Bexar, Travis, Williamson, Bell, and Milam Counties, killing 215 persons and causing property losses of over $19,000,000. Five to nine feet of water stood in downtown San Antonio. A total of 24 inches of rain was measured in Taylor in 35 hours. The greatest 18-hour rainfall recorded in United States history, 36.4 inches, fell in Thrall in Williamson County.

April 23-28, 1922 - A rainstorm entered Texas from the west and moved from the Panhandle to North Central and East Texas. Rains up to 12.6 inches over Parker, Tarrant, and Dallas Counties caused severe floods on the upper Trinity River at Fort Worth. Eleven lives were lost. Damage was estimated at $11,000,000.

May 24-31, 1929 - A rainstorm began over Caldwell County and spread over much of central and coastal Texas with a maximum rainfall of 12.9 inches, causing floods in the Colorado, Guadalupe, Brazos, Trinity, Neches, Sabine Rivers. Much damage occurred in Houston from overflow of bayous. Damage was estimated at $6,000,000.

June 30-July 2, 1932 - Torrential rains fell over the upper watersheds of the Nueces and Guadalupe River, causing destructive floods. Seven persons drowned. Property losses exceeded $500,000.

July 22-25, 1933 - A tropical storm moved very slowly from Freeport across eastern Texas and into Louisiana. Rainfall averaged 12.50 inches over an area of about 25,000 square miles. Twenty inches or more fell in a small area of eastern Texas and western Louisiana surrounding Logansport. Property damage was estimated at $1,147,790.

September 15-18, 1936 - Excessive rains over the North Concho and Middle Concho Rivers caused a sharp rise in the Concho River which overflowed San Angelo. Much of the business district and 500 homes were flooded. Four people drowned and property losses were estimated at $5,000,000. Four-day storm rainfall at San Angelo measured 25.2 inches of which 11.8 inches fell in one day.

September 8-10, 1952 - Heavy rains over the Colorado and Guadalupe River watersheds caused loss of 5 lives and several million dollars of property damages including 17 homes destroyed and 454 damaged.

June 26-28, 1954 - Hurricane Alice moved in from the Gulf south of Brownsville up the Rio Grande River. Heaviest rains were in the Langtry-Sheffield-Ozona area, where as much as 27.1 inches of rain fell in 48 hours near Pandale. This resulted in the greatest flood on the middle Rio Grande since June 1865. Rises of 50 to 60 feet, or 30 to 40 feet above flood stage, within 48 hours, occurred at Eagle Pass and at Laredo. An 86-foot wall of water in the Pecos River canyon washed out the highway bridge constructed 50 feet above the river. The international bridge at Laredo was washed out. Most of the deaths and severe property damage were in Mexico.

April-May 1957 - Torrential rains caused flooding throughout the area east of the Pecos River to the Sabine River during the last 10 days of April causing 17 deaths and destroying several hundred homes. During May more than 4,000 people were evacuated from unprotected lowlands on the West Fork of the Trinity River above Fort Worth and along creeks in Fort Worth. Twenty-nine houses at Christoval and 83 houses at San Angelo were damaged. Five persons were drowned in floods in South Central Texas.

October 28, 1960 - Rains of 7-10 inches fell in South Central Texas. Eleven people drowned in flash floods. About 300 families in Austin were driven from their homes. Damage in Austin was estimated at $2,500,000.

September 7, 1962 - Rainfall of up to 11 inches in three hours fell over the Big Fossil and Denton Creek watersheds in the vicinity of Fort Worth. Extensive damage from flash flooding occurred in Richland Hills and Haltom City.

September 16-20, 1963 - Hurricane Cindy caused rains of 15 to 23.5 inches to fall in portions of Jefferson, Newton, and Orange Counties resulting in $11,600,000 of property damage.

September 21-23, 1964 - Flash flooding on the Trinity River and its tributaries in Collin, Dallas, and Tarrant Counties resulted in two drownings and an estimated $3,000,000 property damage.

June 11, 1965 - Torrential rains of up to 8 inches in two hours near Sanderson caused a major flash flood that swept through the town. Twenty-six people drowned and property losses were estimated at $2,715,000.

April 22-29, 1966 - Twenty to 26 inches of rain fell in portions of Wood, Smith, Morris, Upshur, Gregg, Marion, and Harrison Counties. Nineteen people drowned in the rampaging rivers and creeks that swept away bridges, roads, and dams, and caused an estimated $12,000,000 damage.

September 18-23, 1967 - Hurricane Beulah moved inland near the mouth of the Rio Grande River. Rains of 10 to 20 inches over much of the area south of San Antonio resulted in record-breaking floods. An unofficial gaging station at Falfurrias registered 36 inches of rainfall. 1.4 million acres were inundated.

September 9-13, 1971 - Hurricane Fern caused 10 to 26 inches of rain in the Coastal Bend region. The resulting flooding killed two people and caused $30,231,000 of damages.

May 11-12, 1972 - A rainstorm in South Central Texas resulted in 17 drownings at New Braunfels and one drowning at McQueeney. Property damage was $17,500,000.

June 12-13, 1973 - From 10 to 15 inches of rain fell in southeastern Texas. Ten people drowned. Over $50,000,000 in property and crop damage occurred.

November 23-24, 1974 - Flash flooding in Central Texas killed 13 people and caused $1,000,000 in property damage.

January 31-February 1, 1975 - Flash flooding in Nacogdoches County resulted in 3 deaths and over $5,500,000 in damage.

May 23, 1975 - Heavy rains, high winds, and hail in the Austin area resulted in over $5,000,000 in property damage and 40 people injured. Four deaths were caused by drowning.

June 15, 1976 - Rains in excess of 13 inches in Harris County caused damage estimated at near $25,000,000. Eight deaths were storm-related including three drownings.

March 27, 1977 - Heavy rains were responsible for five drownings and over $1,000,000 damage in Tarrant, Somervell, and Dallas Counties.

March 26, 1978 - Four people drowned and 15 others were injured as 10 inches of rain fell in less than two hours west of Canyon, sending a wall of water through Palo Duro Canyon.

August 1-4, 1978 - Remnants of tropical storm Amelia caused some of the worst flooding of this century. As much as 30 inches of rain fell near Albany in Shackelford County, where six drownings were reported. Bandera, Kerr, Kendall, and Gillespie Counties were hit hard with 27 people drowned and damages of at least $50,000,000.

July 24-25, 1979 - Tropical storm Claudette caused over $750,000,000 in property and crop damages but few injuries. Near Alvin, 43 inches of rain fell setting a new state record for 24 hours.

September 18-20, 1979 - Coastal flooding occurred as 18 inches of rain fell in 24 hours at Aransas Pass and 13 inches fell at Rockport.

August 9-11, 1980 - Hurricane Allen hit south Texas. Over 20 inches of rain fell in extreme south Texas.

September 5-8, 1980 - Hurricane Danielle brought rain and flooding to Southeast and Central Texas. Seventeen inches fell at Port Arthur and 25 inches near Junction.

May 24-25, 1981 - Severe flooding in Austin claimed 13 lives, injured about 100 and caused $40,000,000 in damages. Up to 5.5 inches of rain fell in one hour just west of Austin.

May 10-13, 1982 - Heavy rains from a slow-moving cool front caused flash floods throughout North Central and northern East Texas. Rainfall of 5-8 inches within a 10-hour period resulted in raging floodwater entering more than 2,100 homes in and near Wichita Falls, forcing more than 5,000 residents to flee and property damage of about $25,000,000. General rains of 10 to 12 inches caused widespread urban flooding north and northeast of the Dallas-Fort Worth area.

December 24, 1982 - Rains of up to 15 inches occurred in Southeast Texas.

Droughts

Development and management of conservation storage reservoirs in Texas is based primarily on providing dependable quantities of acceptable quality water during extended drought periods. During droughts, reservoir inflows are decreased simultaneously with increased demands on the water in storage. Droughts in Texas apparently occur at random with no predictable cycle. From the early days of Texas history recorded by Spaniards exploring the Southwest, drought has been a reoccurring problem. A drought in Central Texas dried up the San Gabriel River in 1756, forcing the abandonment of a settlement of missionaries and Indians (Orlob, 1969). By agricultural, economic, hydrologic, or meteorological standards, the worst drought on record began in 1950 in the western part of the state and spread until 244 of the 254 counties in the state were classified as disaster areas by the end of 1956. Other severe droughts occurred in 1909-1910, 1916-1917, and 1933-1934. In most years, some sections of the state receive less than normal rainfall, while other sections receive a greater than normal supply. Severe drought or excessively wet conditions rarely exist over the entire state at the same time. While the Great Plains drought of the early 1930's received considerable publicity as the "dust bowl days", its presence in Texas was confined largely to the western one-third of the state and to the years 1933-1934 (Orlob, 1969).

The duration and extent of Texas droughts during the period 1892-1984 is shown in Table 4 by climatological division. For this purpose, a

TABLE 4
DROUGHT PERIODS BY CLIMATOLOGICAL DIVISION (1892-1984)

Year	High Plains	Low Rolling Plains	North Central	East Texas	Trans Pecos	Edwards Plateau	South Central	Upper Coast	Southern	Lower Valley
1892	--	--	--	--	68	--	--	73	--	--
1893	--	--	67	70	--	49	56	64	53	59
1894	--	--	--	--	--	68	--	--	--	--
1897	--	--	--	--	--	--	73	--	72	--
1898	--	--	--	--	--	--	--	--	69	51
1901	--	71	70	--	--	60	62	70	44	--
1902	--	--	--	--	--	--	--	--	65	73
1907	--	--	--	--	--	--	--	--	--	65
1909	--	--	72	68	67	74	70	--	--	--
1910	59	59	64	69	43	65	69	74	59	--
1911	--	--	--	--	--	--	--	--	--	70
1916	--	73	--	74	70	--	73	69	--	--
1917	58	50	63	59	44	46	42	50	32	48
1920	--	--	--	--	--	--	--	--	--	71
1921	--	--	--	--	72	--	--	--	--	73
1922	--	--	--	--	68	--	--	--	--	--
1924	--	--	73	73	--	71	--	72	--	--
1925	--	--	72	--	--	--	72	--	--	--
1927	--	--	--	--	--	--	--	74	--	74
1933	72	--	--	--	62	68	--	--	--	--
1934	66	--	--	--	46	69	--	--	--	--
1937	--	--	--	--	--	--	--	--	72	--
1939	--	--	--	--	--	--	69	--	--	72
1943	--	--	72	--	--	--	--	--	--	--
1948	--	--	73	74	62	--	73	67	--	--
1950	--	--	--	--	--	--	68	--	74	64
1951	--	--	--	--	61	53	--	--	--	--
1952	68	66	--	--	73	--	--	56	70	
1953	69	--	--	--	49	73	--	--	--	--
1954	70	71	68	73	--	50	50	57	71	--
1956	51	57	61	68	44	43	55	62	53	53
1962	--	--	--	--	--	68	--	--	67	65
1963	--	--	63	68	--	65	61	73	--	--
1964	74	--	--	--	69	--	--	--	--	63
1970	65	63	--	--	--	72	--	--	--	--

The numbers represent the percentage of the 1931-1960 normal precipitation. Only percentages of 75 percent or less are shown. The 1931-1960 normal precipitation for the ten climatological divisions are 18.51, 22.99, 32.93, 45.96, 12.03, 25.91, 33.24, 46.19, 22.33, and 24.27 inches.
Source: Texas Almanac and State Industrial Guide (A.H. Belo Corp., 1984).

meteorological drought was arbitrarily defined as when a division has less than 75 percent of the 1931-1960 normal precipitation. The numbers in the table are the percentages of the 1931-1960 normal annual preciptation. Only the percentages which were less than 75 are shown. The 1931-1960 normal annual precipitation is also provided. The 1941-1970 normal annual precipitation is included in Table 2. The Texas Almanac (A.H. Belo Corp., 1984) tabulated the data for the years 1892 through 1982. Data published by the National Oceanic and Atmospheric Administration indicate that precipitation in 1983 and 1984 was above 75 percent of normal for all ten climatological divisions.

Water Quality

The quality of the state's surface waters has improved significantly during the past decade due to water quality management efforts including advances in wastewater treatment by industries and municipalities. However, discharges from municipal sewage-treatment and industrial plants and runoff from urban areas are important concerns. Eutrophication and turbidity are problems in several water supply reservoirs, including those in the Houston and Dallas-Fort Worth areas. Natural concentations of salts and minerals preclude the use of some water in the upper reaches of the Red, Brazos, Canadian, Colorado, Pecos, and Rio Grande Rivers. Chloride control projects have been proposed in the Red and Brazos River Basins to prevent surface water with high salinity concentrations from contaminating better quality water. The recently completed Truscott Reservoir in the Red River Basin is the only chloride control project actually constructed in Texas todate.

Water Use and Availability

The Texas Department of Water Resources (TDWR) recently conducted a comprehensive analysis of the water-related problems and needs of the state. The primary purpose of the planning studies was to update and revise the Texas Water Plan which was adopted by the Texas Water Development Board in 1969. The studies were documented by several publications including draft reports dated May 1977, February 1983 and June 1984, and a final report dated November 1984. The water use and availability data presented in the following paragraphs are taken from Texas Department of Water Resources documents.

Table 5 shows the amount of water used in 1980 for various purposes in each of the major river basins and coastal basins. The table also indicates the proportion of each type of use supplied by groundwater versus surface water. A total of 17.9 million acre-feet of water was used in Texas in 1980 for the following purposes: agriculture (72.5% of total), municipal (15.8%), manufacturing (8.5%), steam-electric power generation (1.9%), and mining (1.3%). Of the 17.9 million acre-feet total water used, 10.9 million acre-feet (61%) was from groundwater and 7.0 million acre-feet (39%) was from surface water. The 7.0 million acre-feet of surface water, which was essentially all from reservoirs, was divided between uses as follows: agriculture (55.4%), municipal (21.7%), manufacturing (18.1%), steam-electric power generation (3.9%), and mining (0.9%). This data is for withdrawals except steam-electric power data includes only

TABLE 5

1980 WATER USE IN 1,000 ACRE-FEET

BASIN	MUNICIPAL		MANUFACTURING		STEAM ELECTRIC		IRRIGATION		MINING		LIVESTOCK		TOTAL		TOTAL
	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	GROUND	SURFACE	
Major Basins															
Canadian	22.0	11.4	31.5	3.5	2.7	11.6	1,748.5	1.1	5.7	1.1	12.4	3.3	1,822.8	32.0	1,854.8
Red	48.9	49.5	11.6	5.6	0.1	9.1	1,264.3	94.7	1.7	0.9	18.8	14.6	1,345.4	174.4	1,519.8
Sulphur	7.1	21.0	0.1	45.0	0.2	1.7	0.0	1.8	1.2	0.1	2.6	3.9	11.2	73.5	84.7
Cypress	10.7	4.9	0.9	197.5	0.1	29.6	0.0	0.5	1.4	0.5	1.6	1.8	14.7	234.8	249.5
Sabine	33.0	28.8	9.7	74.6	1.6	22.9	0.1	8.9	4.9	1.9	4.0	4.7	53.3	141.8	195.1
Neches	55.3	24.7	76.5	103.9	4.9	7.3	7.5	24.9	2.2	2.7	3.9	4.4	150.3	167.9	318.2
Trinity	82.4	593.1	5.7	92.0	1.2	46.2	16.8	63.1	2.9	14.9	7.9	14.5	116.9	823.8	940.7
San Jacinto	309.8	167.0	51.1	176.5	15.9	7.0	82.9	3.8	2.1	3.4	1.3	1.1	463.1	358.8	821.9
Brazos	122.4	168.0	11.5	198.0	7.7	51.9	3,260.0	123.7	16.9	9.7	23.3	28.7	3,441.8	580.0	4,021.8
Colorado	61.5	162.9	6.9	17.9	1.0	30.1	1,166.2	211.0	63.9	7.5	15.5	12.4	1,315.0	441.8	1,756.8
Lavaca	7.7	0.0	0.6	0.0	0.0	0.0	208.8	106.9	2.4	0.6	1.0	2.3	220.5	109.8	330.3
Guadalupe	35.8	8.5	4.4	37.1	2.2	18.4	4.3	6.4	0.9	0.2	4.2	4.8	51.8	75.4	127.2
San Antonio	231.9	1.0	14.0	0.3	1.4	27.9	36.3	24.6	1.0	0.0	1.2	3.9	285.8	57.7	343.5
Nueces	26.7	3.7	2.4	0.1	0.7	3.0	397.5	74.3	5.4	0.0	4.6	8.6	437.3	89.7	527.0
Rio Grande	111.8	64.1	8.7	1.5	13.0	1.7	470.6	451.1	51.0	0.4	12.1	4.1	667.2	522.9	1,190.1
Coastal Basins															
Neches-Trinity	6.6	24.4	2.0	76.1	0.0	0.0	0.0	544.9	0.7	0.7	0.5	0.3	9.8	646.4	656.2
Trinity-San Jacinto	11.7	0.0	0.6	55.4	0.1	0.9	14.4	30.6	0.1	13.6	0.1	0.1	27.0	100.6	127.6
San Jacinto-Brazos	58.3	28.5	4.5	109.7	1.8	0.2	9.6	316.1	0.3	0.5	0.7	0.4	75.2	455.4	530.6
Brazos-Colorado	11.2	0.2	3.6	16.4	0.0	0.0	79.5	225.3	6.0	5.5	0.9	0.8	101.2	248.2	349.4
Colorado-Lavaca	4.3	0.0	2.0	0.0	0.1	0.0	118.0	127.0	0.4	0.0	0.5	0.4	125.3	127.4	252.7
Lavaca-Guadalupe	3.3	2.1	0.1	14.1	0.0	0.0	53.8	44.3	0.3	0.4	0.7	0.5	58.2	61.4	119.6
San Antonio-Nueces	8.0	6.2	0.1	14.4	0.0	0.0	3.2	0.1	0.8	0.1	0.4	1.8	12.5	22.6	35.1
Nueces-Rio Grande	19.2	153.7	0.8	31.4	0.0	5.6	14.8	1,264.5	2.9	0.2	1.5	6.9	39.2	1,462.3	1,501.5
Total	1,289.6	1,523.7	249.3	1,271.0	54.7	275.1	8,957.1	3,749.6	175.1	64.9	119.7	124.3	10,845.5	7,008.6	17,854.1

Source: Texas Department of Water Resources (1984) consumptive use. The actual withdrawals for cooling water are many times greater than consumptive use. A significant portion of agricultural, municipal, and manufacturing withdrawals become return flows.

The State of Texas is experiencing exceptionally rapid population and economic growth compared to the nation as a whole. The population of the state has grown from 3.0 million in 1930 to more than 15 million in 1983. The Texas Department of Water Resources projections shown in Figure 5 indicate that the population will increase to between 19.6 and 21.2 million in the year 2000 and between 28.3 and 34.3 million in 2030. The TDWR also has available projections at the city, county, and river basin level. Texas has a broad-based industrial, service, trades, energy, and agricultural economy which is growing along with the population.

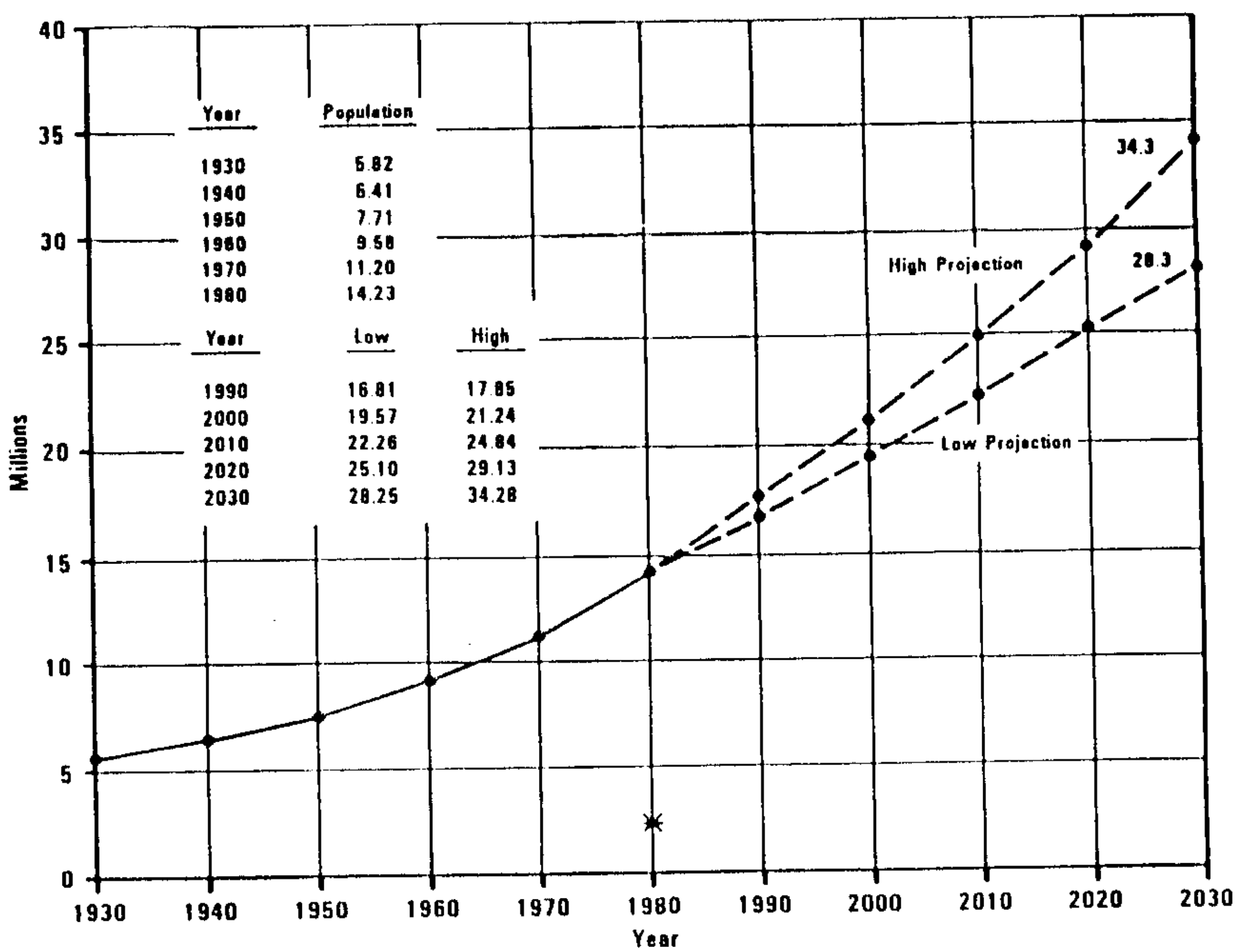
Dependable supplies of suitable quality water are necessary to support the economic and population growth of the state. Present and projected future requirements for each type of use are presented in Table 6. Past and projected future water use and source of supply are shown in Figure 6.

More than 50 percent of Texas is underlain by seven major aquifers and sixteen minor aquifers. Collectively, these aquifers receive an average annual natural recharge of about 5.3 million acre-feet and contain about 431 million acre-feet of water in storage that is recoverable using conventional water well technology. About 89 percent of the recoverable groundwater is in the Ogallala Aquifer in the High Plains. For most of the aquifers, water withdrawal is occurring at a greater rate than recharge. Of the 10.8 million acre-feet withdrawn from groundwater in 1980, 5.5 million acre feet was from storage. Groundwater mining is causing water-level declines, decreased well yields, land subsidence, and saline water encroachment. By the year 2000, if current water use trends continue, the state's aquifers are projected to be capable of supplying about 6.8 million acre-feet annually, or about 63 percent of the present level. Consequently, greatly increased demands will be placed upon surface water reservoirs.

Both ground and surface water sources supply the full range of uses throughout the state. However, the bulk of the total groundwater use in the state is for irrigation in the High Plains from the Ogallala Aquifer. Few major surface water reservoirs or good reservoir sites exist in this area. About half of the irrigation from surface water occurs in the lower Rio Grande Valley using water regulated by International Falcon Reservoir. Much of the remaining surface water irrigation is concentated in the coastal areas of the eastern half of the state. Both ground water and surface water presently provide significant supplies for municipal and industrial use, but a significant shift toward a greater reliance on surface water is underway.

From 1980 to 2000, water requirements under drought conditions for nonagricultural uses are projected to increase from about 5.0 million acre-feet to 8.8 million acre-feet annually. Of the 8.8 million acre-feet, approximately 6.5 million acre-feet per year or 73 percent will be required in the 26 Standard Metropolitan Statistical Areas (SMSAs). About

62 percent of the current water use in the SMSAs are from developed surface water sources. By the year 2000, because of physical and economic problems related to overdraft or mining of ground water, about 80 percent of the 6.5 million acre-feet water requirement for the SMSAs will have to be supplied from developed surface-water resources, some of which are located in neighboring river basins.



Source: Texas Department of Water Resources (1984)

Figure 5
Population Projections

TABLE 6
TEXAS DEPARTMENT OF WATER RESOURCES
WATER USE PROJECTIONS

1980 Reported Water Use in Texas in acre-feet/year

municipal and domestic	2,813,000
manufacturing	1,520,000
mining	239,000
steam-electric	330,000
agricultural	12,851,000
total	17,853,000

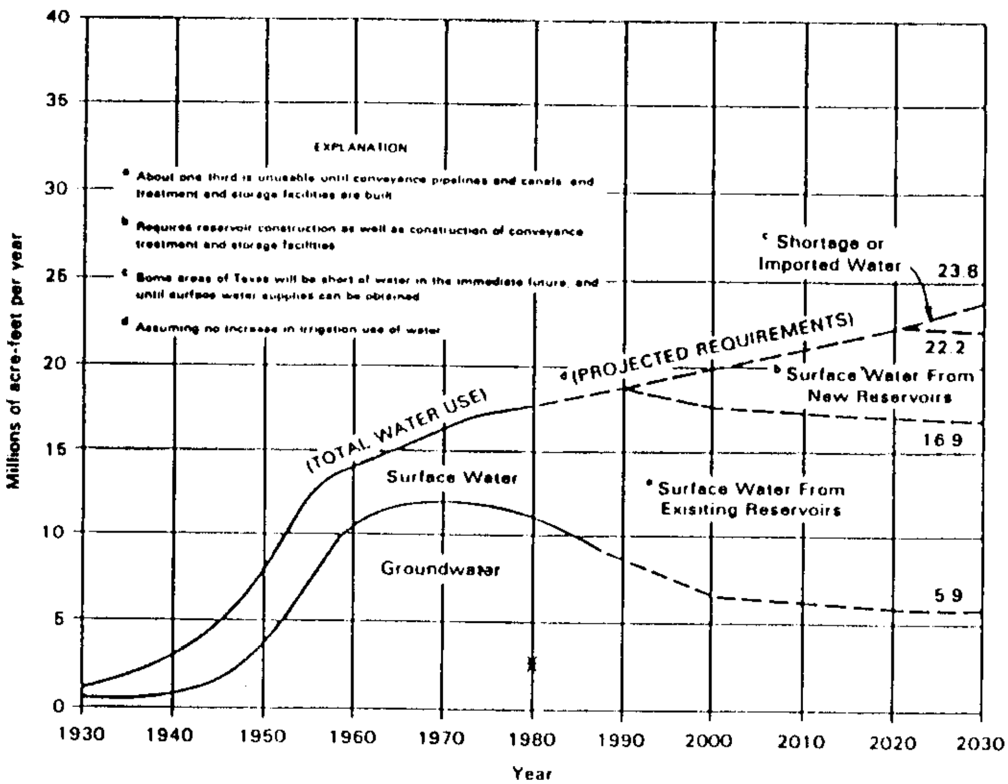
Projected Water Use in acre-feet/year

Year 2000	Low	High
municipal and domestic	3,512,000	5,081,000
manufacturing	2,407,000	2,718,000
mining	268,000	268,000
steam-electric	717,000	817,000
agricultural	10,427,000	16,543,000
total	17,331,000	25,425,000

Year 2030	Low	High
municipal and domestic	5,059,000	8,178,000
manufacturing	4,231,000	5,014,000
mining	387,000	387,000
steam-electric	1,119,000	1,417,000
agriculture	11,385,000	15,351,000
total	22,181,000	30,347,000

Note: In addition, estimated freshwater inflow requirements for Texas bays and estuaries range from a low (survival limit) of 4.7 million acre-feet annually to a high (enhancement) of 13.6 million acre-feet annually.

Source: Texas Department of Water Resources (1984).



Source: Texas Department of Water Resources (1984)

Figure 6
Water Use and Source of Supply Projections

CHAPTER 3
RESERVOIR DEVELOPMENT IN TEXAS

Inventory of Major Reservoirs

Texas contains 187 reservoirs with controlled storage capacities equalling or exceeding 5,000 acre-feet. This includes 182 existing and five projects under construction. Conservation, flood control, and total capacities of 40.0 million acre-feet, 18.5 million acre-feet, and 58.5 million acre-feet, respectively, are contained in the 187 reservoirs. Texas has about 5,700 reservoirs with surface areas greater than ten acres. However, the 187 major reservoirs represent over 95 percent of the total storage capacity in all Texas reservoirs. The term "major reservoir" is used herein to refer to a reservoir with a controlled storage capacity equal to or larger than 5,000 acre-feet. The major reservoirs are listed by river basin with descriptive data in Appendix A. Sources of information regarding the reservoirs are also discussed in Appendix A. The number and capacities of the major reservoirs located in each basin are tabulated in Table 7. The number of reservoirs ranges from one in the Lavaca River Basin to 40 in the Brazos River Basin. Three of the eight coastal basins contain one or more major reservoirs.

The storage capacity in several reservoirs on the international and interstate rivers are shared between Texas and neighboring states or Mexico. International Amistad, International Falcon, Texoma, Toledo Bend, and Caddo Reservoirs are on state borders. Several other reservoirs located entirely in Texas are on border streams or streams which cross state borders. Although few in number, the border reservoirs include the largest three reservoirs in the state. The United States and Mexico have divided the storage capacity in the international reservoirs by treaty. Texas has entered into interstate compacts with neighboring states which divide the storage capacity in the interstate reservoirs. Of the 40.0 million acre-feet of conservation capacity in the 187 major reservoirs lying wholly or partially in Texas, roughly 33.6 million acre-feet is owned or used by Texas with the remaining 6.4 million acre-feet controlled by neighboring states and Mexico.

Reservoirs in Texas vary tremendously in size. Several hundred thousand natural lakes, farm and stock ponds, flood retarding and stormwater detention structures, recreation lakes, and small water supply reservoirs range in size from less than an acre-foot to 5,000 acre-feet. The 187 major reservoirs described in Appendix A range in size from 5,000 acre-feet to over 5,000,000 acre-feet. Table 8 shows the distribution of reservoirs between various capacity ranges. The number of reservoirs decrease rapidly with increasing capacity level.

The Largest Reservoirs

The 28 reservoirs in Texas with total storage capacities exceeding 500,000 acre-feet are listed in Table 9. These 28 reservoirs contain 46.2 million acre-feet total capacity, which is 79 percent of the total capacity of the 187 major reservoirs in the state. The 28 largest reservoirs contain 29.9 million acre-feet of conservation and 16.2 million

TABLE 7
NUMBER AND CAPACITY OF MAJOR RESERVOIRS BY RIVER BASIN

BASIN	NUMBER OF RESERVOIRS	CONTROLLED STORAGE CAPACITY (ACRE-FEET)				
		CONSERVATION			FLOOD CONTROL	TOTAL
		ACTIVE	INACTIVE	TOTAL		
Trinity	31	7,075,180	271,910	7,347,090	1,820,200	9,167,290
Rio Grande	7	6,120,320	13,400	6,133,720	2.654,000	8,787,720
Brazos	40	3,343,850	564,100	3,907,950	3,940,600	7,848,550
Red	23	3,959,250	9,180	3,968,430	2,972,900	6,941,330
Sabine	12	6,289,790	---	6,289,790	---	6,289,790
Colorado	24	3,690,730	103,110	3,793,840	1,529,620	5,323,460
Neches	10	2,180,270	1,452,000	3,632,270	1,099,400	4,731,670
Sulphur	4	438,820	37,000	475,820	2,640,400	3,116,220
Canadian	2	833,400	43,100	876,500	543,200	1,419,700
Cypress	8	757,490	---	757,490	587,200	1,344,690
San Jacinto	6	592,230	---	592,230	411,500	1,003,730
Nueces	3	977,490	---	977,490	---	977,490
Guadalupe	5	417,580	23,900	441,480	346,400	787,880
San Antonio	4	342,300	---	342,300	12,600	354,900
Lavaca	1	157,900	---	157,900	---	157,900
Coastal Basins	7	280,250	---	280,250	---	280,250
Total	187	37,446,850	2,517,700	39,974,550	18,558,020	58,532,570

TABLE 8
RESERVOIR CAPACITY RANGES

TOTAL CONTROLLED CAPACITY (ACRE-FEET)	NUMBER OF RESERVOIRS
5,000 - 50,000	109
50,000 - 100,000	12
100,000 - 500,000	38
500,000 - 1,000,000	15
1,000,000 - 2,000,000	7
2,000,000 - 5,000,000	4
over 5,000,000	2

TABLE 9
RESERVOIRS WITH STORAGE CAPACITIES GREATER THAN 500,000 ACRE-FEET

RESERVOIR	RIVER BASIN	PRIMARY OWNER-OPERATOR	DATE IMPOUNDMENT BEGAN	SURFACE AREA (ACRES)		STORAGE CAPACITY (ACRE-FEET)		TOTAL
				CONSERVATION	FLOOD CONTROL	CONSERVATION	FLOOD CONTROL	
Texoma	Red	Corps of Engineers	1943	89,000	143,300	2,722,000	2,660,000	5,382,000
Amistad	Rio Grande	International Boundary & Water Commission	1968	64,900	34,400	3,505,000	1,744,000	5,249,000
Toledo Bend	Sabine	Sabine River Authority	1966	181,600	-	4,477,000	-	4,477,000
Sam Rayburn	Neches	Corps of Engineers	1965	114,500	142,700	2,898,200	1,099,400	3,997,600
Falcon	Rio Grande	International Boundary & Water Commission	1953	87,210	98,960	2,267,600	910,000	3,177,600
Wright Patman	Sulphur	Corps of Engineers	1956	20,300	119,700	145,300	2,509,000	2,654,300
Whitney	Brazos	Corps of Engineers	1951	23,560	49,320	627,100	1,372,400	1,999,500
Travis	Colorado	Lower Colorado River Authority	1940	18,930	44,450	1,172,600	781,400	1,954,000
Livingston	Trinity	City of Houston, Trinity River Authority	1968	82,600	-	1,750,000	-	1,750,000
Meredith	Canadian	Canadian River MWA	1965	16,500	21,540	864,400	543,200	1,407,600
Richland*	Trinity	Tarrant County WCID 1	1986	38,850	-	1,135,000	-	1,135,000
Belton	Brazos	Corps of Engineers	1954	12,300	23,600	442,000	640,000	1,082,000
Ray Roberts*	Trinity	Corps of Engineers	1986	29,350	36,900	803,800	260,800	1,064,600
Lewisville	Trinity	Corps of Engineers	1954	23,280	39,080	456,600	525,200	981,800
Buchanan	Colorado	Lower Colorado River Authority	1937	23,060	-	955,200	-	955,200
Tawakoni	Sabine	Sabine River Authority	1960	36,700	-	936,200	-	936,200
Lake O' the Pines	Cypress	Corps of Engineers	1957	1,060	38,200	254,900	587,200	842,100
Lavon	Trinity	Corps of Engineers	1953	21,400	29,450	472,600	275,600	748,200
Canyon	Guadalupe	Corps of Engineers	1964	8,240	12,390	390,300	346,400	736,700
Waco	Brazos	Corps of Engineers	1965	7,270	19,440	169,200	553,300	722,500
Choke Canyon	Nueces	City of Corpus Christi	1982	26,000	-	700,000	-	700,000
Cedar Creek	Trinity	Tarrant County WCID 1	1965	33,750	-	679,000	-	679,200
Twin Buttes	Colorado	City of San Angelo	1962	9,080	32,560	186,200	454,400	640,600
Lake Fork	Sabine	Sabine River Authority	1982	27,690	-	635,200	-	635,200
Stillhouse Hollow	Brazos	Corps of Engineers	1968	6,430	11,830	239,800	390,600	630,400
Possum Kingdom	Brazos	Brazos River Authority	1941	14,440	-	569,380	-	569,380
Kemp	Red	City of Wichita Falls Wichita County WID 2	1922	16,540	24,720	319,600	248,300	567,900
Somerville	Brazos	Corps of Engineers	1967	11,460	24,400	169,800	337,700	507,500
TOTAL				1,046,000	998,140	29,944,180	16,238,900	46,183,080

* Currently under construction.

acre-feet of flood control capacity which represents 75 percent and 88 percent, respectively, of the total conservation and flood control capacities contained in the 187 major reservoirs. Two reservoirs contain storage capacities in the over 5.0 million acre-feet range. These largest two projects contain conservation, flood control, and total storage capacities totalling 6.2 million acre-feet, 4.4 million acre-feet, and 10.6 million acre-feet, respectively, or 15.6 percent, 23.7 percent, and 18.2 percent, respectively, of the corresponding totals for the 187 major reservoirs. More than 17 percent of the total storage capacity in the several hundred thousand reservoirs in Texas is contained in the two largest reservoirs. In terms of total storage capacity, Lake Texoma is the largest reservoir in Texas and tenth largest in the nation. Toledo Bend Reservoir has the largest conservation capacity of any reservoir in Texas. In terms of water surface area at top of conservation pool, Toledo Bend Reservoir is the largest reservoir in the South and fifth largest in the nation.

Reservoirs Under Construction

Table 10 lists the five major reservoirs currently under construction. These projects have conservation, flood control, and total capacities totalling 2,483,700 acre-feet, 519,300 acre-feet, and 3,003,000 acre-feet, respectively. Two of the projects under construction, Richland Reservoir and Ray Roberts Reservoir, will be the tenth and thirteenth largest projects in the state. Richland, Ray Roberts, and Joe Pool are physically under construction at this time and should be completed within the next two years. Both Wallisville Reservoir and Cooper Reservoir were partially completed when construction was suspended by court action due to insufficient environmental impact statements. Both projects are currently being restudied.

Storage Capacity Nomenclature

Reservoir storage capacity can be divided between controlled and uncontrolled capacity. The data quoted in this report is limited to controlled storage capacity. This is the capacity below the elevation of an ungated spillway crest or the uncontrolled overflow section of a gated spillway. The release or withdrawal of water from controlled storage capacity is regulated by gates, valves, or pumps. Uncontrolled spillways provide a safety valve to allow excessive inflows to pass through a reservoir when the controlled storage capacity is full. During major flood events inflows may greatly exceed outflow through an uncontrolled spillway. Consequently, a relatively large storage capacity above the uncontrolled spillway crest elevation is typically included in a reservoir to insure that the dam is not overtopped. Also, ungated spillways with limited flow capacity are often designed to retard flood flows and thus provide downstream flood protection. Surcharge flood control storage behind uncontrolled spillways is not included in the capacity figures provided in this report.

Controlled reservoir storage capacity is divided between flood control and conservation storage. Flood control storage capacity is empty except during and immediately following a flood event. Outlet works and spillway gates are opened as necessary to keep the flood control space

TABLE 10
MAJOR RESERVOIRS UNDER CONSTRUCTION AS OF APRIL 1985

Reservoir	Basin	Owner	Projected Completion	Storage Capacity (acre-feet) Conservation	Flood Control	Total
Richland	Trinity	Tarrant County WCID	1986	1,135,000	---	1,135,000
Ray Roberts	Trinity	Corps of Engineers	1986	803,800	260,800	1,064,600
Joe Pool	Trinity	Corps of Engineers	1985	176,900	127,100	304,000
Wallisville	Trinity	Corps of Engineers	?	58,000	---	58,000
Cooper	Sulphur	Corps of Engineers	1991	310,000	131,400	441,400
Total				2,483,700	519,300	3,003,000

empty, subject to the constraint of not causing downstream flooding. Most of the major flood control reservoirs in Texas were sized to contain a design flood with a recurrence interval in the range of 50 to 100 years. Conservation capacity is used to store water until it is needed. Flood control and conservation capacity in a multiple purpose reservoir is divided by a set top of conservation (bottom of flood control) pool elevation.

The term "conservation storage capacity" is used herein to include all controlled storage capacity which is not specifically allocated to flood control. Conservation capacity is further divided into active and inactive capacity. The inactive conservation storage includes dead storage and sediment reserve. Dead storage is reservoir capacity below the lowest outlet level. Water cannot be released from dead storage by gravity flow. Although not normally available for water supply, dead storage may be useful for providing head for hydropower or additional water surface for recreation. The loss of reservoir capacity due to sedimentation is significant in Texas. Rates of sediment deposition vary greatly between reservoirs and over time. A sediment reserve is often allocated to allow for anticipated loss of capacity during the life of the project due to sediment deposition. Capacity designated as sediment reserve has been included in the capacity data presented herein as inactive storage. Active conservation storage, or usable storage, is the capacity allocated to store water for withdrawal or release for beneficial purposes under normal operating procedures.

Dependable Yield

The amount of water supplied by a reservoir for beneficial use depends upon inflows and evaporation and other losses, which are highly stochastic, as well as storage capacity. The concept of dependable (firm) yield is commonly used to quantify water availability. Dependable yield is the maximum quantity of water which can be supplied from a reservoir annually through an extended drought period, which is typically taken to be the historical period of lowest natural flow on record for the stream. The dependable yield of a reservoir changes over time with changing conditions such as watershed development and construction of other reservoirs.

An extremely important aspect of designing and operating conservation storage reservoirs is the analysis of the relationship between dependable yield and storage capacity. This relationship varies greatly with geographical location in Texas. McDaniels (1964) illustrated this variation with the following comparison. In humid East Texas, a reservoir may provide a firm annual yield larger than its conservation storage capacity. In subhumid Central Texas, a reservoir may provide a firm yield equal to only one-fifth or less of its conservation storage capacity. In semiarid and arid West Texas, a reservoir may provide a firm annual yield varying within a range of one-tenth to one-thirtieth or less of its conservation storage capacity.

The Texas Department of Water Resources (1984) has estimated the dependable yield from all the major reservoirs in the state to be about 11 million acre-feet annually.

Project Purposes

Project purposes can be associated with either flood control or conservation storage capacity. Flood control capacity is kept empty to capture inflows during major flood events to reduce downstream flows and consequently reduce flood damages. Conservation capacity is used to store water whenever possible so it will be available when needed. Conservation capacity provides some incidental flood protection whenever the flood event coincides with a partially drawn-down pool. Surcharge storage in conservation only reservoirs may also provide some incidental flood protection. Likewise, temporary storage of flood waters in flood control pools may provide some incidental contribution to conservation purposes. However, flood control and conservation capacities are generally treated as distinctly separate pools serving different purposes.

Thirty-five of the major reservoirs in Texas contain controlled flood control storage capacities totalling 18.6 million acre-feet. This includes three flood control only and 32 multipurpose projects. Flood control capacity represents about 32 percent of the total controlled capacity of the major reservoirs. This data does not include the numerous smaller flood retarding dams with uncontrolled flood control storage capacity.

The conservation purposes for each reservoir are categorized in Table A-1 as follows: municipal, industrial, agricultural (irrigation), steam-electric power, hydroelectric power, mining, brine control, and recreation. A total of 163 of the 184 conservation reservoirs provide municipal and/or industrial water supply. Irrigation is a designated purpose of 20 of the major reservoirs. Medina Reservoir with 254,000 acre-feet capacity and three other small (less than 8,000 acre-feet) reservoirs are used primarily or solely for irrigation. The other irrigation projects also supply other uses, primarily municipal and industrial. Municipal, industrial and irrigation uses require that water be withdrawn through an intake structure located at the reservoir or at a downstream location on the river. Essentially all the surface water withdrawn from Texas streams for beneficial use is regulated by reservoirs even though the actual point of withdrawal may be as far as several hundred miles downstream of the regulating reservoirs. Agricultural use is highly consumptive. Municipal and industrial use involve significant return flows to the stream system.

Ten of the multiple purpose reservoirs include storage designated for mining. Most of the mining water is for secondary recovery of petroleum. Minor amounts are used for sand and gravel operations and recovery of other minerals.

A number of reservoirs supply water for steam-electric power plants which is used primarily for condenser cooling. Consumptive (evaporation) use is relatively small compared to withdrawals. Depending on the cooling system used by the plant, a significant amount of heat may be tansferred to the reservoir as the water is recirculated and cooled.

During the past decade, concern over depleting reserves of fossil fuels has focused attention on increasing hydroelectric power generation at existing reservoir projects, both nationwide and in Texas. Texas has more than twenty hydroelectric power plants. Several plants have been added or reactivated during the past several years. Hydroelectric power accounted for about one-half of one percent of the electricity generated in the state in 1980. Hydroelectric power is used primarily for peak loads. Water is not consumed in the generation of hydroelectric power and is usually used for other purposes after passing through the turbines.

Water oriented recreation is popular in Texas. Recreation facilities are provided at reservoir projects by federal and state agencies, municipalities, and private developers, with the Corps of Engineers being the single largest reservoir recreation manager. Nearly 65 million visitors utilized recreational facilities at reservoirs managed by the Corps of Engineers in Texas in 1982 (A.H. Belo Corp., 1984). Lake Texoma, with 10.7 million visitors, led in attendance in Texas and ranked second in the United States for visitation at Corps of Engineers lakes. Lewisville Reservoir and Lake O' the Pines with 6.6 million and 5.1 million visitors, respectively, ranked second and third in Texas. Fishing is the most popular of the various reservoir recreation activities included in this data.

The recently completed Truscott Reservoir in the Red River Basin is the only existing brine control project in Texas. Several similar brine control projects have been proposed for the Red and Brazos River Basins but have not yet been constructed. The Truscott project consists of a dam across a box canyon with no means for release of water other than evaporation. Natural salt brine which would otherwise flow downstream into Lake Kemp is collected and pumped into Truscott Reservoir for permanent disposal.

Navigation facilities in Texas are located primarily along the coast. Inland navigation occurs on the downstream reaches of the Sabine, Neches, Trinity, Brazos, and Colorado Rivers. However, normal streamflows plus reservoirs releases for other purposes normally provide adequate flow depths for navigation. Reservoirs have not been operated in Texas specifically for navigational purposes.

Historical Perspective of Reservoir Development

Although a few small reservoirs were developed in Texas for irrigation and power purposes prior to 1900, Eagle Lake with impoundment beginning in 1900 is the oldest of the major reservoirs still in existence. Eagle Lake is a 9,600 acre-foot irrigation reservoir in the Colorado River Basin.

Caddo Lake is the only natural lake in Texas with a storage capacity greater than 5,000 acre-feet. All of the major reservoirs, including Caddo Lake now, are impounded by man-made dams. Caddo Lake is located on Cypress Creek in northeast Texas and northwest Louisiana. The stateline runs through the lake. Although originally a natural lake, the Corps of Engineers completed construction of a dam in 1914 to preserve the lake because removal of logs and debris from the river downstream for navigation purposes had resulted in erosion threatening to drain the lake. Construction of a new dam was completed in 1971 because the 1914 dam was found to be no longer safe.

McDaniels (1964) points out that Austin Dam and Lake McDonald on the Colorado River was perhaps the most ill-fated reservoir development in Texas. A 49,300 acre-foot project was completed in 1893 by the City of Austin for municipal water supply and hydroelectric power generation. The dam was reportedly the largest masonry overflow-type dam in the world at that time. The dam was breached by a flood in April 1900. By that time, about half the storage capacity had already been lost to sedimentation. Reconstruction of a 32,000 acre-foot project was initiated in 1911 and completed in 1915. Subsequently, the dam became inoperative for hydroelectric power because floods in September 1915 and April 1918 carried away some of the spillway gates and the flood of June 1935 destroyed the remaining gates and gate piers. By 1924, sedimentation had reduced the storage capacity of the second reservoir to a small fraction of its original capacity. The large depletions of storage capacity by sediment occurred largely because the capacity provided was inadequate with respect to a large drainage area. Construction of Tom Miller Dam and Lake Austin, with a capacity of 21,000 acre-feet, at the site was completed by the Lower Colorado River Authority in 1939. Lake Buchanan and Lake Travis, completed in 1937 and 1940, trap sediment and reduce flood flows to Lake Austin (McDaniels, 1964).

Mansfield Dam and Lake Travis on the Colorado River was the first of the large multiple purpose projects constructed in Texas by the federal government. The Bureau of Reclamation constructed the project in 1937 to 1942. Denison Dam and Lake Texoma on the Red River was the first Corps of Engineers reservoir project in the state. Construction was initiated and completed in 1939 and 1943, respectively. At that time, Denison Dam was the largest rolled earthfill dam in the United States (Corps of Engineers, 1981). Lake Texoma is still the largest reservoir in Texas.

Dowell and Breeding (1967) provide a brief history of each of the major reservoirs in existence as of 1966. McDaniels (1964) shows the growth in number and storage capacity of the major reservoirs in Texas between 1910 and 1963. This information is extended to 1985 and presented as Table 11 and Figure 7. A number of early reservoirs have been completely inundated by construction of larger dams downstream. Also, several reservoirs have been enlarged sometime after initial construction by raising the dam height. Consequently, the data in Table 11 and Figure 7 reflect enlargements of existing reservoirs and inundation of old reservoirs as well as addition of new projects.

The 35 major reservoirs in operation in 1935 were relatively small projects constructed by various local entities primarily for either irrigation or municipal and industrial water supply. Several of these early projects were also used for generating hydroelectric power. Most of the present reservoir capacity in the state was developed during the period from 1935 to 1970. Lake Texoma accounted for over 50 percent and Lake Travis almost 20 percent of the total capacity added during the period 1935 to 1950. Numerous projects including most of the larger projects became operational between 1950 and 1970. Reservoir development has progressed at a much slower rate since 1970.

TABLE 11
HISTORICAL GROWTH IN NUMBER AND CAPACITY OF RESERVOIRS

YEAR	NUMBER OF RESERVOIRS: Added During 5-Year Period	NUMBER OF RESERVOIRS: At End of Year	TOTAL CONTROLLED CAPACITY (1,000 acre-feet): Added During 5-Year Period	TOTAL CONTROLLED CAPACITY (1,000 acre-feet): At End of Year
1910		3		29
1915	6	9	506	535
1920	1	10	7	542
1925	8	18	570	1,112
1930	13	31	274	1,386
1935	4	35	630	2,016
1940	11	46	3,455	5,471
1945	5	51	6,291	11,762
1950	12	63	319	12,617
1955	23	86	9,536	21,617
1960	16	102	4,945	26,562
1965	27	129	10,038	36,600
1970	22	151	14,703	51,303
1975	11	162	745	52,048
1980	11	173	2,089	54,137
1985	10	183*	1,697	55,834

*Includes 182 major reservoirs in operation as of April 1985 and Joe Pool Reservoir which is currently under construction with initial impoundment scheduled for December 1985.

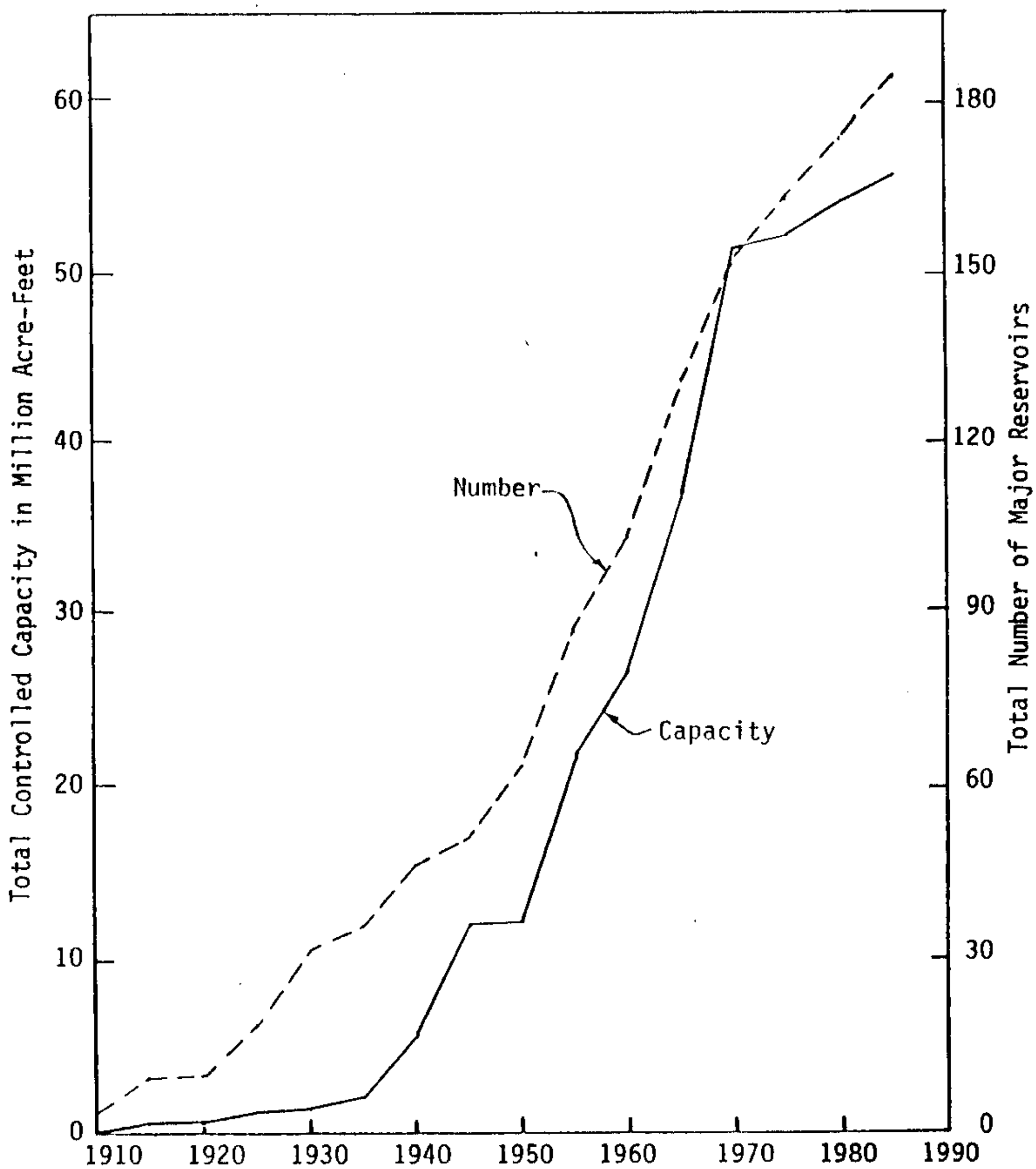


Figure 7
Historical Growth in Number and Capacity of Major Reservoirs

Langbein (1982) developed a plot similar to Figure 7 which shows the growth in reservoir storage capacity in the conterminous United States since 1920. A rapid increase in storage capacity during the 1930's through the 1960's is followed by a markedly slower growth rate in the 1970's. Thus, the general trend in Texas has been consistent with that of the nation.

Future Reservoir Development

Numerous reservoir projects have been proposed in the original Texas Water Plan adopted by the Texas Water Development Board in 1969 and various comprehensive basinwide and statewide water resources planning reports prepared by the Corps of Engineers, Bureau of Reclamation, and other federal and state water agencies. The various proposed but yet unconstructed projects have been studied in various degrees of detail. Several of the proposed projects have been authorized by the U.S. Congress for federal construction but are currently unfunded or in an inactive status.

The Texas Department of Water Resources (1984) estimates that 65 remaining reservoir sites could provide an additional dependable yield of 5.3 million acre-feet annually. This includes 4.3 million acre-feet from capturing additional runoff and 1.0 million acre-feet of recapturable treated wastewater return flow. A number of the proposed reservoir sites are shown on Plate 1. New reservoir projects are needed to meet increasing water demands and to replace declining groundwater supplies. Also, several chloride control reservoirs are needed in the upper Red and Brazos Basins to stop contamination of downstream surface water supplies by natural salt deposits. The Texas Department of Water Resources developed a schedule of when the proposed projects should be constructed and the estimated costs. A number of projects are indicated to be needed immediately or in the near future.

Although depleting groundwater reserves and increasing water demands associated with economic and population growth require greater control and utilization of the state's surface water resources, a number of factors will likely limit future reservoir construction. These factors include: a decreasing availability of federal funds; prior development of the most advantageous reservoir sites; project economics; environmental considerations; and the related policy thrust toward a greater reliance on nonstructural measures such as flood plain management and water demand management.

The 1930's through 1960's are generally considered to be the nationwide "construction era" of water resources development. A transition to a "management era" involving a much greater reliance on flood plain management, water demand management, and more effective utilization of existing facilities is occurring during the 1970's and 1980's. The data provided in Table 11 and Figure 7 indicates that reservoir development in Texas has followed this nationwide trend. The shift from primarily "construction" solutions to a much greater reliance on "management" strategies is also evident in the Texas Water Plan. Whereas the 1969 plan focused on large scale storage and conveyance facilities, the 1984 updated plan is built largely upon demand management and achieving more efficient use of limited water resources.

The federal government has played a major role in reservoir development in Texas and the nation in the past. However, water policy changes in recent years are greatly reducing federal investments in water projects. New studies and construction projects have traditionally been authorized by the Congress through omnibus bills enacted every two years. As of April 1985, the last omnibus authorization act was the Water Resources Development Act of 1976. Few federal studies or construction projects have been initiated in recent years. In 1984, for the first time in the history of the Corps of Engineers, the nationwide budget for operation and maintenance of existing projects exceeded that for design and construction of new projects. Also, recent proposals regarding changing cost sharing policies have emphasized shifting of responsibilities for financing new water projects from the federal to state and local governments.

Planning and authorization procedures for federal water projects have traditionally required that economic benefits exceed costs for a project to be justified. Economic feasibility is also an important consideration in nonfederal water resources development. Economic justification of reservoir projects is much more difficult now than in the past. Increasing real estate and relocations costs, increasing discount rate, and greater reliance on nonstructural measures are three of the several major reasons for decreasing economic feasibility (Wurbs, 1983).

Costs for lands and improvements have escalated drastically at proposed reservoir sites. The Texas Department of Water Resources (1984) has proposed that the state create a reservoir site development easement system to protect sites from commercial development and inordinate price increases.

In an economic analysis, the time value of captial is reflected by a discount rate. The discount rate used for planning federal water projects has steadily increased from 3.25 percent in 1968 to 7.875 percent in 1984. Since reservoir development requires large initial investments with benefits spread out over a lengthy project life, increasing the discount rate results in decreasing the likelihood of economic feasibility. Assuming benefits accuring uniformly over a 50-year period of analysis and price levels and all other factors held constant, more than twice the annual benefits are required to justify each dollar of investment cost at the 1984 discount rate of 7.875 percent than at the 1969 rate of 3.25 percent. Several proposed federal multiple purpose reservoirs in Texas were recommended as economically feasible projects ten or more years ago but are infeasible at the current discount rate even if the other factors discussed herein are not considered.

The increased reliance on nonstructural measures makes structural measures more difficult to economically justify. For example, the economic analyses which supported authorization of most of the existing reservoirs in the state containing flood control storage included a significant level of benefits attributable to reducing flood damages associated with future flood plain development. Current procedures are based on the assumption that flood plain management will prevent future development in 100-year flood plains. Justification for construction of new water supply reservoirs must now consider implementation of demand management strategies.

The best reservoir sites have already been developed. Also, since each river basin has a limited amount of streamflow, construction of new reservoirs decreases the yield of existing reservoirs. The economic and environmental cost of each incremental unit of additional firm yield grows progressively greater.

The era of intensive reservoir development in Texas is probably over. New reservoirs will continue to be constructed, but not as frequently. The intensifying needs for controlling and utilizing the state's surface water resources combined with difficulties in developing new reservoir projects should result in a continually increasing focus on optimizing the operation of existing reservoirs.

CHAPTER 4
THE INSTITUTIONAL FRAMEWORK FOR RESERVOIR MANAGEMENT

Reservoir development and management is accomplished within a complex system of organizations, laws, and traditions. The water management community consists of water users, flood plain occupants, tax payers, concerned citizens, public officials, environmental organizations, special interest groups, universities, consulting firms, professional organizations, businesses, industries, utilities, and municipal, county, state, federal, and international agencies. Water policy is formulated and management decisions made within a framework of legal and political systems. Water is a publicly-owned resource, and its allocation and use is governed by law.

Within this complex institutional framework, a number of entities are primarily responsible for the actual operation of the major reservoirs in Texas. These principal reservoir development and management organizations are identified and described in this chapter. Legal rights to the use of water and project funding are major institutional factors in determining reservoir operating policies. Funding considerations are discussed in conjunction with the water resources development and management organizations. Water rights considerations are addressed as a separate subsection.

Federal and Nonfederal Roles

The reservoir management agencies can be categorized as federal agencies, state and local governmental entities, and private companies. Most of the major reservoirs in Texas were constructed by state and local governmental agencies or private industry for conservation purposes. However, two-thirds of the total storage capacity is contained in reservoirs constructed by federal agencies. Most of the federal reservoirs are large multiple purpose projects.

Federal agencies have constructed 38 major reservoirs and significantly modified two others. Four additional projects are presently under construction. The federal government is responsible for construction of eight of the ten largest and 21 of the 28 reservoirs with capacities exceeding 500,000 acre-feet. Eight federally-constructed projects have been turned over to nonfederal entities for operation and maintenance. The others are operated by federal agencies. The 43 projects with federal involvement contain 52 percent, 99.9 percent, and 67 percent of the conservation, flood control, and total capacities, respectively, of the 187 major reservoirs. Federal involvement in reservoir construction and operation in Texas is summarized in Table 12.

The five projects constructed by the Bureau of Reclamation were turned over to local sponsors for maintenance and operation. The Bureau of Reclamation continues to own the projects until the local sponsor has completed payments to the federal government for reimburseable costs. The Soil Conservation Service has also constructed two major water supply reservoirs which are owned, operated, and maintained by nonfederal sponsors. The Corps of Engineers operates and maintains its projects upon

TABLE 12
FEDERAL INVOLVEMENT IN RESERVOIR DEVELOPMENT AND MANAGEMENT

FEDERAL INVOLVEMENT	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL
Constructed, Owned, and Operated by International Boundary and Water Commission	2	5,772,600	2,654,000	8,426,600
Constructed, Owned, and Operated by Corps of Engineers	27	10,081,790	13,344,820	23,426,610
Presently Under Construction by Corps of Engineers	4	1,348,700	519,300	1,868,000
Major Modification by Corps of Engineers	2	448,600	248,300	696,900
Constructed by Bureau of Reclamation and Maintained and Operated by Nonfederal Sponsors	5	3,081,100	1,779,000	4,860,100
Constructed by Soil Conservation Service and Maintained and Operated by Nonfederal Sponsors	2	17,850	---	17,850
Constructed by Soil Conservation Service and Owned and Operated by U.S. Fish and Wildlife Service	1	18,150	---	18,150
Constructed, Owned, and Operated by Forest Service	1	8,000	---	8,000
Total	44	20,776,790	18,545,420	39,322,210

This data does not include federal grants and loans, such as those provided by the early Works Progress Administration (WPA) Program, which helped finance several of the nonfederal projects.

completion of construction. Withdrawals or releases from conservation storage are made at the discretion of the nonfederal sponsors.

State and local governmental entities have constructed 108 major reservoirs and one other is presently under construction. These reservoirs contain 45 percent, 0.1 percent, and 31 percent, respectively, of the conservation, flood control, and total storage capacities of the 187 major reservoirs. This does not include the several federally-constructed projects which are maintained and operated by nonfederal sponsors or the conservation storage in federally-maintained and operated reservoirs for which nonfederal sponsors have contracted.

Private companies constructed, own, and operate 36 major reservoirs containing no flood control storage and less than three percent of the total conservation storage of the major reservoirs.

Project Purposes

Institutional arrangements for developing and managing reservoirs are based on project purposes. With the exception of Olmos Reservoir, all reservoirs in Texas containing controlled flood control storage were constructed and are operated by the federal agencies. The federal government has borne all costs associated with flood control. The Corps of Engineers is responsible for flood control operations of its own reservoirs and those constructed by the Bureau of Reclamation. The International Boundary and Water Commission handles the total flood control operations of its projects.

About three-fourths of the conservation storage capacity in the major reservoirs is designated for municipal and industrial uses. Municipal and industrial water supply has traditionally been a local responsibility. The federal government confines itself to a secondary role in this area. However, municipal and industrial storage is included in all but two (Addicks and Barker) federal reservoirs, subject to nonfederal cost sharing. Although municipal and industrial water supply was already being included in federal reservoirs, the Water Supply Act of 1958 established a uniform policy. Under the provisions of this law, the federal water agencies may provide additional capacity for municipal and industrial water supply in reservoirs to be constructed primarily for federal purposes such as flood control, irrigation, or navigation. Cost allocated to water supply must be repaid, with interest, by nonfederal sponsors over a period of time not to exceed 50 years. The interest rate has steadily increased from 3.342 percent in 1970 to 10.403 percent in 1984. The interest rate in effect when a contract is executed remains fixed throughout the repayment period. Repayment of costs for future water use can be delayed until the water is first used up to the limit of ten years after completion of construction. No interest is charged during this period. However, no more than 30 percent of the costs of the project may be allocated to storage for future supply. Inclusion of municipal and industrial storage in a federal reservoir requires a contractual agreement with one or more nonfederal sponsors prior to construction. All costs, including construction, operation and maintenance, and major replacement, are allocated to project purposes by a formal cost allocation method. The incremental cost method was used for earlier projects and the separable costs - remaining benefits method was used for most of the later projects in Texas.

The conservation storage in several of the federal reservoirs is used for irrigation as well as municipal and industrial water supply. However, the Bureau of Reclamation has not constructed large federally-subsidized reservoirs devoted primarily to irrigation in Texas like it has in several other western states. In general, nonfederal sponsorship of conservation storage in federal reservoirs has been handled similarly for irrigation and municipal and industrial uses.

Three of the Corps of Engineers reservoirs and the two International Boundary and Water Commission reservoirs have hydroelectric power plants. Lake Travis constructed by the Bureau of Reclamation also has hydropower, but it was added by the Lower Colorado River Authority. The Western Area Power Administration (WAPA) is responsible for marketing the power generated at the two International Boundary and Water Commission projects. The Southwestern Power Administration (SWPA) markets the power from the Corps of Engineers projects. These are two of several agencies of the Department of Energy which market hydroelectric power from federal projects in various geographical regions of the nation. The SWPA and WAPA sell the power to electric cooperatives, municipalities, and utility companies. A plan for construction of a power plant at Town Bluff Dam was recently developed, in which the Sam Rayburn Power Agency would bear the cost for construction of the plant at the Corps of Engineers project and would buy the power from SWPA at rates which would cover operation, maintenance, and marketing cost. When constructed, this will be the first project in SWPA's seven-state marketing region to be built by the Corps of Engineers with nonfederal funds (SWPA, 1984). The proposed Town Bluff project is in accordance with recent federal policy requirements for funding for future federal hydropower projects to come at least in part from nonfederal sources. A majority of hydroelectric power projects in Texas are owned and operated by river authorities which are state agencies.

Federal and nonfederal entities have been involved to various extents in providing recreation at the major reservoir projects. A few small reservoirs are used only for recreational purposes. However, most recreation occurs at larger multiple purpose projects. The federal water resources development program has strongly emphasized multiple purpose development. Consequently, the federal projects all include public access and recreational facilities. Prior to 1965, recreation was included in federal projects as a fully federal expense. The Federal Water Recreation Act of 1965 established development of the full recreational potential at Federal projects as a full project purpose subject to nonfederal cost sharing. Under the provisions of the act, the federal government is authorized to bear 50 percent of the separable costs of providing recreational facilities and to make federal lands available for the use of nonfederal entities agreeing to operate and maintain these facilities. The joint costs allocated to recreation are borne entirely by the federal government. This authority includes providing additional lands and facilities at existing projects as well as proposed new projects. If nonfederal interests do not accept responsibility for recreational development, the responsible federal agency must bear the cost of developing minimum facilities required for public health and safety and are accessible by roads previously in existence or otherwise necessary for project construction (Corps of Engineers, 1979). Very little recreational development has taken place to date in Texas under the provisions of this act. Recreation contracts have been executed for the Ray Roberts and Joe Pool Reservoirs which are currently under construction.

The federal reservoirs include a significant amount of project-owned publicly accessible land around the shoreline. Many of the nonfederal reservoirs have privately-owned land adjacent to the shoreline essentially all the way around the lake.

Cities and water districts often include recreational facilities as an incidental use of their water supply reservoirs. Before 1971, most river authorities were not authorized to supply recreation, but were directed not to prevent free public use of their lands. They generally served the public by making land available to other agencies for recreational development or leasing their land for commercial recreation enterprises. However, the River Authority Recreation Act passed by the legislature in 1971 gave the river authorities the authority and responsibility to develop water resources for public recreation purposes and to acquire and improve parkland near public waters (Ruesink, 1979).

Reservoir Managers in Texas

The 187 major reservoirs in Texas are owned, maintained, and operated by 4 federal agencies, 43 water districts and river authorities, 39 cities, 2 counties, a state agency, and 22 private companies. A number of other entities contract with the reservoir owners for use of the conservation storage capacity. The reservoir owners are listed in Table A-2 along with the number of reservoirs and total storage capacities in their reservoirs. Table 13 summarizes the totals from Table A-2 for each category of reservoir owner.

Corps of Engineers

The U.S. Army Corps of Engineers is the largest reservoir manager in Texas. The agency has constructed and now owns, maintains, and operates 26 multiple purpose and two single purpose flood control reservoirs. Four other multiple purpose projects are currently under construction. These 32 reservoirs contain 29 percent, 75 percent, and 43 percent, respectively, of the conservation, flood control, and total capacity of the 187 major reservoirs. In addition to these "traditional" Corps of Engineers projects, the agency has undertaken specific responsibilities in regard to several other reservoirs. The agency constructed, reconstructed, and recently assumed maintenance responsibilities for Caddo Dam. The Corps of Engineers reconstructed and raised Kemp Dam to correct structural deficiencies and add flood control capacity and continues to be responsible for flood control operations. Lake Kemp is owned by the City of Wichita Falls and Wichita County Water Improvement District No. 2. The Corps of Engineers is also responsible for flood control operations of projects constructed by the Bureau of Reclamation, for which flood control capacity was included at federal expense. Travis, Twin Buttes, and Meredith

TABLE 13
TYPES OF RESERVOIR OWNERS

TYPE OF OWNER	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET)		
		CONSERVATION	FLOOD CONTROL	TOTAL
Federal Agencies	36	17,358,240	16,518,120	33,876,360
International Boundary and Water Commission	(2)	(5,772,600)	(2,654,000)	(8,426,600)
Corps of Engineers	(32)	(11,559,490)	(13,864,120)	(25,423,610)
Other	(2)	(26,150)	---	(26,150)
Water Districts and River Authorities	57	16,080,060	1,324,600	17,404,660
Jointly Owned by Cities and Water Districts or River Authorities	4	2,539,490	248,300	2,787,790
Cities	48	2,843,470	467,000	3,310,470
Counties	5	54,810	---	54,810
Other State Agencies	1	5,420	---	5,420
Private Companies	36	1,093,060	---	1,093,060
Totals	187	39,974,550	18,558,020	58,532,570

Reservoirs are in this category. The Corps of Engineers also provided engineering services for construction of International Amistad Dam.

The Corps of Engineers has major nationwide responsibility for flood protection, navigation, and the planning and development of water resources projects to meet multipurpose objectives. Water resources development activities in Texas by this agency date back to the 1870's, with early efforts concentrating on navigation improvements along the Gulf coast. Denison Dam and Lake Texoma on the Red River, constructed in 1939-1943, was the first Corps of Engineers reservoir project in the state. The agency has constructed a number of hurricane protection and local flood protection projects, primarily levees and channel improvements, in Texas. Other Corps activities include flood plain management information services; inventory and inspection of nonfederal dams; and regulatory functions in regard to issuing permits for discharging dredge and fill materials and constructing facilities in navigable waters. The scope of the Corps of Engineers water resources development and management program is broad and constantly changing.

Most Corps of Engineers water resources projects are developed under specific congressional authorization. The process generally consists of the following major steps.

- City, state, or other local interests petition their representative in Congress for federal assistance in addressing water related problems and needs.

- The senator or congressman requests the appropriate congressional committee to direct the Corps of Engineers to conduct a feasibility study (called a survey study) and develop recommendations. Authority for the planning study is either a resolution adopted by the appropriate senate or house committee or a congressional act.

- Congress appropriates funds annually to conduct the survey study.

- The Corps of Engineers conducts a survey study to determine the feasibility of plans of improvement. The study is closely coordinated with state and local agencies and the public. The study is documented by a report which is forwarded through review channels to the Congress. The report may recommend no further federal action, a plan for construction of one or more projects, or some other plan of action.

- Based on the recommendations of the survey report, the Congress authorizes advanced engineering and design and construction of specific projects.

- Congress appropriates funds annually for advanced engineering and design and construction.

- The Corps of Engineers performs advanced engineering and design, awards and administers construction contracts, and supervises construction.

- In the case of navigation improvements, flood control reservoirs, and multiple purpose reservoirs, the Corps of Engineers operates and maintains the completed project. Local flood protection projects are turned over to local sponsors for operation and maintenance.

Construction of most of the Corps of Engineers reservoirs in Texas were authorized under this process by omnibus authorizaton acts passed in the 1940's and 1950's based on comprehensive basinwide survey reports. Ray Roberts and Joe Pool Reservoirs, currently under construction, were authorized by the Flood Control Act of 1965 as part of the comprehensive plan of improvement for the Trinity River Basin. The recently completed Aquilla Reservoir, authorized by the Flood Control Act of 1968, is the most recently authorized of the existing and under construction Corps of Engineers reservoirs. Corps of Engineers planning, design, construction, and operation and maintenance funds are appropriated annually by the Congress.

The Corps of Engineers Southwestern Division encompasses Texas and four other states. The division office is in Dallas. The coastal area of the state is the jurisdiction of the Galveston District. The Red and Canadian River Basins are in the Tulsa District. The remainder of the state which includes 26 of the 30 reservoirs is the responsibility of the Fort Worth District.

Bureau of Reclamation

The Bureau of Reclamation was created by the Reclamation Act of 1902 "to provide for the reclamation of arid and semiarid lands in the West." The program has grown over the years to include a broad range of multiple purpose water resources development and management activities. The Southwest Region of the Bureau of Reclamation covers all of Texas and Oklahoma and parts of Kansas, Colorado, and New Mexico. The regional office is in Amarillo.

The Bureau of Reclamation has constructed five reservoirs in Texas, Travis, Twin Buttes, Texana, Choke Canyon, and Meredith. Lake Travis completed in 1940 was the first project and Texana completed in 1981 the most recent. These five reservoirs contain 7.7 percent, 9.6 percent, and 8.3 percent of the conservation, flood control, and total capacities, respectively, of the major reservoirs. All five projects contain water supply storage and three contain flood control.

The Bureau of Reclamation maintains and operates a number of reservoirs in the other western states. However, the reservoirs in Texas have been turned over to local sponsors. The federal government retains ownership of the reservoirs until all reimburseable costs have been repaid by the nonfederal sponsor.

The Bureau of Reclamation has also constructed several water conveyance and distribution systems for irrigation and municipal and industrial use in the Texas portion of the Rio Grande, Colorado, and Canadian River Basins.

International Boundary and Water Commission

The International Falcon and International Amistad Reservoirs contain 14 percent of both the conservation and flood control capacities of the major reservoirs in Texas. The two reservoirs were constructed and are owned and operated by the International Boundary and Water Commission (IBWC).

The boundary between the United States and Mexico was established by treaties in 1848 and 1853. As the settlements grew along the boundary rivers and the adjoining lands began to be developed for agriculture in the late nineteenth century, questions arose as to the location of the boundary when the rivers changed their course and transferred tracts of land from one side of the river to the other. The two governments adopted certain rules to deal with such questions by a convention in 1884. By a convention in 1889, the two governments created the International Boundary Commission charged with application of the rules of the 1884 convention. A convention in 1906 provided for the distribution between the United States and Mexico of the waters of the Rio Grande for the 89-mile boundary reach of the Rio Grande through the El Paso-Juarez Valley. Mexico was allotted 60,000 acre-feet annually to be delivered in accordance with a monthly schedule at the headgate to Mexico's Acequia Madre just above Juarez. A provision was included for the Mexican and United States share of the water to be diminished in the same proportion in the case of extraordinary drought or serious accident to the irrigation system. Water deliveries are facilitated by Elephant Butte Reservoir in New Mexico which the United States constructed at its own expense (IBWC, 1981).

A treaty in 1944 for "Utilization of Water of the Colorado and Tijuana Rivers and of the Rio Grande" distributed the waters of the Rio Grande from Fort Quitman to the Gulf of Mexico between the two countries. The name of the International Boundary Commission was changed to International Boundary and Water Commission. The 1944 Treaty also provided for the two governments to jointly construct, operate, and maintain on the main channel of the Rio Grande River the dams required for the conservation, storage, and regulation of the greatest quantity of the annual flow of the river to enable each country to make optimum use of its allotted waters. The International Falcon and Amistad Reservoirs were constructed in response to this treaty (IBWC, 1981).

The IWBC consists of a Mexican section and a United States section. The two sections maintain their respective headquarters in the adjoining cities of El Paso, Texas and Ciudad Juarez, Chicuahua. Each section maintains its own engineering, legal, and administrative staff. Each government funds the cost of the operation of its section of the IBWC. The United States performance of its part of the cooperative projects is subject to authorization and appropriation of funds by the Congress.

In addition to the two reservoirs, the IBWC has undertaken a number of water conveyance and distribution, flood control channelization and levees, water quality improvement, boundary preservation, data collection, and mapping projects.

Soil Conservation Service

The Soil Conservation Service (SCS) has constructed about 1900 flood control dams in Texas under the provisions of the Watershed Protection and Flood Prevention Act of 1954. The SCS program is limited to watersheds of less than 400 square miles and dams of less than 12,500 acre-feet of flood control capacity and 12,500 acre-feet of conservation capacity. A combined flood control and conservation reservoir can have up to 25,000 acre-feet capacity. For SCS flood control projects, design and construction costs are borne by the federal government. Nonfederal sponsors pay for real estate acquisition and relocation of highways and utilities. Upon completion of construction, nonfederal interests maintain and operate a project. All costs allocated to water supply must be reimbursed by nonfederal sponsors.

Rita Blanca Lake and Lake Clyde were constructed by the SCS and are now owned and operated by the Cities of Dalhart and Clyde, respectively. The numerous flood control reservoirs are not included in the listing of major reservoirs because most of the storage capacity is uncontrolled. Controlled storage capacities are less than 5,000 acre-feet for each dam.

Water Districts and River Authorities

Water districts are units of local government organized to fulfill specific water resource functions. Water districts have operational autonomy. They are not dependent on cities or counties for establishing policy or providing controls. These districts are governed by elected officers, and they may levy taxes and issue bonds. Districts may be created two ways: (1) under general law procedure or (2) by a special act of the legislature. Under general law, water districts may be created by a county commissioners court (usually initiated by citizens' petition); the Texas Water Rights Commission; and, in a few cases, by municipalities. Special act districts are individually created by the state legislature, usually subject to district confirmation elections.

Water districts in Texas vary greatly in purpose. They undertake all types of water development and management programs including municipal, industrial, and agricultural water supply, sewage treatment, flood control and drainage, navigation, electric power generation, soil conservation, and recreation. This may involve the construction of levees, channel improvements, power facilities, and reservoir projects.

The 880 active registered water districts in Texas are divided into the following types of districts: 323 water control and improvement districts, 25 water improvement districts; 314 municipal utility districts, 41 fresh water supply districts, 37 levee and flood control districts, 51 drainage districts, 8 underground water districts, 25 navigation districts, 19 river authorities, and 37 other miscellaneous types of districts (Texas Advisory Commission on Intergovernmental Relations, 1983).

River authorities are a special type of water district which were created to develop and manage water resources from a basinwide perspective. Some river basins in Texas are served by a single river authority while other basins are served by several authorities. The Conservation Amendment of the Texas Constitution, passed in 1917, enabled the creation of districts such as river authorities as governmental agencies and vested them with all the same authority as other agencies under the constitution and law of the state. The state constitution uses the term "conservation and reclamation district" instead of "river authority". The Texas Department of Water Resources classifies 19 water districts as being river authorities as of 1983 (Texas Advisory Commission on Intergovernmental Relations, 1983).

The Brazos River Authority, created in 1929, was the first authority ever set up in the United States to administer the waters of a major river. Thus, Texas created its first river authority four years before the creation of the Tennessee Valley Authority by the federal government. The most active period for the organization of river authorities was 1929 through 1941. During the severe drought of the 1950's, several cities created water districts that provided the same services as river authorities to secure fresh water supplies for their residents and to accommodate future, anticipated growth. The most recent river authority reorganization occurred in 1977 with the formation of the Angelina and Neches River Authority.

Each river authority has been created by a separate legislative act, and each has its own primary functions within its general responsibility for the development, control, and management of water resources. River authority activities generally focus on one or more of the following areas: water supply and distribution, flood control, water quality control, navigation, and generation of hydroelectric and/or thermal power. River authorities also provide parks and recreational facilities.

River authorities are governed by boards of directors ranging in size from 3 to 24 members. Directors may be apointed by the governor with state senate confirmation, appointed by the Texas Water Commission, elected from the districts, or appointed by the governing bodies of member cities and/or counties.

River authorities primarily finance their activities through operational and service fees. In addition, they are eligible for state and federal grants similar to other political subdivisions. Nine authorities may levy ad valorem taxes and issue bonds suppported by taxes subject to voter approval. All river authorities may issue revenue bonds backed by fees from particular enterprises. River authorities generally do not have to seek voter approval to issue revenue bonds. No river authority receives a line-item appropriation from state or federal tax revenues. River authorities enter into contracts with local interests to sell water or power from authority projects. Under Texas law, a river authority obtains a permit for the right to a specified amount of water annually. The river authority may then sell the right to use the water. Because of larger jurisdictions and specific legislative authority, river authorities can often more effectively finance, construct, and operate dams and reservoirs than cities or local districts.

Forty-three water districts and river authorities own and operate 59 major reservoirs containing 41 percent, 7 percent, and 30 percent of the conservation, flood control, and total storage capacity, respectively of the 187 major reservoirs. Four additional reservoirs are jointly owned with cities. The water districts and river authorities also control all or portions of the conservation storage of 21 Corps of Engineers projects. About 60 percent of the total conservation storage of the state's major reservoirs is managed by water districts and river authorities. The Sabine River Authority and Lower Colorado River Authority account for more than half the reservoir storage capacity controlled by river authorities and water districts. The Brazos River Authority has been particularly active in contracting for conservation storage in Corps of Engineers reservoirs as well as constructing several projects itself. Most of the water districts which own and operate reservoirs have a single relatively small reservoir.

Cities

Thirty-nine cities own and operate 48 of the major reservoirs in the state. Four other major reservoirs are jointly owned by cities and water districts or river authorities. Cities have also contracted for conservation capacity in nine Corps of Engineers reservoirs. About 15 percent of the total conservation storage in the state is directly controlled by cities. The numerous municipalities across the state are also customers for the water provided by water district and river authority reservoirs. Thus, a large portion of the state's conservation storage capacity is for municipal and related industrial use. Municipalities are concerned primarily with supplying water for domestic, public, and industrial use. Several cities own reservoirs used by hydroelectric and steam-electric generating plants. Recreation also occurs at city-owned reservoirs.

Private Companies

Reservoir operation is primarily a public sector responsibility. Most private enterprises purchase their water from cities, water districts, or river authorities. However, several private companies do own and operate their own reservoirs. Reservoirs owned and operated by private companies contain 2.7 percent of the conservation storage of the major reservoirs in the state and no flood control. Electric utility companies own and operate 24 reservoirs which contain 82 percent of the total capacity of the 36 privately owned major reservoirs. The electric utility reservoirs provide cooling water and other uses for steam-electric generating plants. The eleven electric utility companies as well as the eleven other private entities owning and operating major reservoirs are listed in Table A-2.

Texas Department of Water Resources

Although it does not own and physically operate and maintain reservoir projects, the Texas Department of Water Resources (TDWR) plays a major role in reservoir management in the state. The TDWR has a broad range of responsibilities related to developing and managing the water resources of the state, including: maintaining a comprehensive state water plan and a state water quality management plan; collecting basic data on the occurrence, quantity, and quality of surface and ground water resources; adjudication of water rights; performing regulatory functions in regard to issuing permits for various water related activities; and creation and supervision of water districts. The TDWR coordinates water quality control programs of various state agencies and local governments and coordinates state programs with those of the federal government. It assists and coordinates efforts of local government in applying for flood insurance coverage under the national flood insurance laws. The TDWR is the designated state agency to cooperate with the Corps of Engineers and Bureau of Reclamation in planning water resource development projects and may act as the cooperating local sponsor for federal projects in lieu of, or in cooperation with, local governmental entities. The TDWR administers the Water Development Fund which is used to purchase bonds of eligible governmental entities, such as cities and water districts, which are unable to sell their bonds through commercial channels at a reasonable interest rate. The bond financing assistance is used for construction of reservoirs, wells, pipelines, or wastewater treatment facilities or purchase of storage space in reservoirs.

The TDWR is also responsible for operating the United States share of the conservation storage capacity in the International Falcon and Amistad Reservoirs and administering the allocation of the water to users. A Water Master, who is on the staff of the TDWR, works directly with irrigation districts, individual farmers, and municipalities in Texas who hold permits for use of water from the Rio Grande River. The Water Master administers the water allocation system and determines the required releases to be made from Falcon and Amistad Reservoirs. The International Boundary and Water Commission makes the releases as requested by the Water Master. Although water master operations are common in other western states, the Rio Grande is presently the only river basin in Texas for which a water master has been designated. However, similar operations will likely be established in the other basins in the future.

The Texas Department of Water Resources was created in 1977 by combining three water agencies: the Texas Water Development Board, Water Quality Board, and Water Rights Commission. The former six-member Water Development Board continued to be the Board for the new agency. The Water Quality Board was dissolved and the Water Rights Commission was abolished to be replaced by the Texas Water Commission structured to carry out the judicial functions for the agency.

Water Rights

Streamflow is public property in Texas subject to administration by the state. Texas water law recognizes claims to surface water rights granted under Spanish, Mexican, English, Republic of Texas, and United States as well as Texas state laws. Both the appropriation and riparian doctrines are recognized.

The basic concept of the riparian doctrine is that water rights are incidental to the ownership of land adjacent to a stream. The riparian doctrine was introduced into Texas by the Spanish and Mexican governments and later in a somewhat different form by the Republic of Texas. For many years, Texas courts and water agencies ruled that Spanish and Mexican land grants carried extensive riparian water rights, including the right to use water for irrigation. Following more thorough investigations of Spanish and Mexican water law, the courts determined in the Valmont Plantations v. Texas case in 1962 that riparian rights to use water for irrigation did not attach to these land grants, unless specifically included. Few specific grants of irrigation were made except in the vicinities of San Antonio and El Paso. Extensive amounts of land, mostly in South and Central Texas, can be traced to Spanish and Mexican grants. Land grants made between 1836 and 1840 by the Republic of Texas also were controlled by Mexican law and have the same water rights. In 1940, the State of Texas adopted the common law of England in which riparian water rights include the right to make reasonable use of water for irrigation or for other extensive and consumptive purposes.

The appropriation doctrine was adopted by the state with the Appropriation Acts of 1889 and 1895. Since 1895, public lands which transferred into private ownership no longer carried riparian water rights. Water rights are claimed through statutory procedures. At first, appropriation was accomplished through an informal procedure in which a water user simply filed a sworn statement with his county clerk describing his water diversion. Later, certified copies of these claims were recognized by the state, and came to be called "certified filings". Since 1913, more strictly administered procedures have been followed based on administration of a statewide appropriation system by a single state agency, which was established as the Board of Water Engineers in 1913, renamed the Texas Water Commission in 1962, renamed the Texas Water Rights Commission in 1965, and renamed the Texas Water Commission and incorporated into the Texas Department of Water Reources in 1977. All appropriation statutes recognize the superior position of riparian water rights. Riparian landowners can also acquire appropriative water rights and may claim both types of rights, each without prejudice to the other.

The complications of having various forms of riparian and appropriative water rights existing on the same stream has been a significant difficulty in managing the surface water resources of the state. As late as 1968, no single state agency had a record of the number of riparian water users in any major river basin, the extent of their claims, or the amount of water they were using. Prior to 1967, several unsuccessful legislative attempts were made to more accurately measure riparian rights. A 1917 water rights adjudication attempt was held unconstitutional. In 1955, the legislature adopted a statute requiring all water users, including riparians, to file a statement each March with the Water Commission stating the amount of water used during the preceding calendar year. However, most riparian water users ignored the law and failed to file reports, and penalty provisions were inadequate and were not enforced (McNeeley and Lacewell, 1977).

In 1926, the courts divided streamflow into "ordinary normal flow" and "flood flows". Riparian rights are limited to normal flow and therefore not applicable to flood waters impounded by reservoirs. The ordinary or normal flow of a watercourse is judicially defined as the flow below the line "which the stream reaches and maintains for a sufficient length of time to become characteristic when its waters are in their ordinary, normal and usual conditions, uninfluenced by recent rainfall or surface runoff". Although the courts and water agencies have found this definition to be extremely difficult to apply in actual practice, it has been the basis for correlating riparian and appropriative rights since 1926.

The Water Rights Adjudication Act was passed in 1967 to remedy the confused surface water rights situation. The stated purpose of the act was to require a recording of all claims for water rights which were not already recorded, to limit the exercise of those claims to actual use, and to provide for the adjudication and administration of water rights. Pursuant to the act, all unrecorded claims were required to be filed with the Texas Water Commission. Minor exceptions were made for those using only small quantities of water for domestic and livestock purposes. Claims were to be recognized only if valid under existing law and only to the extent of the maximum actual beneficial use of water without waste during any calendar year from 1963 to 1967, inclusive. The deadline for filing was September 1, 1969, but numerous late claims were received and accepted by the Commission. The base period and filing date were extended to 1970 and 1971, respectively, for some riparians, and the filing deadline was extended to September 1974 for those who failed to file because of extenuating circumstances or for good cause (McNeeley and Lacewell, 1977).

Statewide 11,600 unrecorded claims were filed claiming more than 7 million acre-feet of water. About 95 percent of the claims were for riparian rights, and the remainder were certified filings which had not been properly recorded previously. More than half the claims were rejected because they showed no water use during the base period. Shortly after receiving the claims, the Texas Water Rights Commission (now the Texas Water Commission of the Texas Department of Water Resources) initiated a series of administrative adjudications of water rights on a river segment by river segment basis. As of 1985, the adjudication process is essentially complete.

The Rules of the Texas Department of Water Resources prescribe the procedures for applying for a water permit at the present time. The appropriator must submit a formal application. A water use application is approved by the Commission only if unappropriated water is available, a beneficial use of the water is contemplated, existing water rights are not impaired, and it is not detrimental to the public welfare. After approval of an application, the Commission issues a permit giving the applicant the right to use a stated amount of water in a prescribed manner. Permits may be regular, seasonal or temporary, or emergency in nature. Permits may also be granted for the impoundment and storage of water with the use of the impounded water to be determined at a later date by the Commission. Once the right to the use of water has been perfected by the issuance of a permit from the Texas Water Commission and the subsequent beneficial use of the water by the permittee, the water authorized to be appropriated under the terms of the particular permit is not subject to further appropriation until the permit is cancelled. A permit may be cancelled if water is not used during a ten-year period. Cancellation of unused permits, certified filings, or certificates of adjudication is done through administrative action by the Commission (Texas Department of Water Resources, 1984).

The Wagstaff Act, enacted in 1931, provides that "any appropriation made after May 17, 1931, for any purpose other than domestic and municipal use, is subject to the right of any city or town to make appropriations of water for domestic or municipal use without paying for the water." The Rio Grande River was specifically excluded. A city has not actually acquired water rights under the Wagstaff Act to date but could in the future as competition for water intensifies.

State water law prioritizes the beneficial uses of water. The Texas Water Code specifies that preference for appropriation be given in the following order: (1) domestic and municipal, (2) industrial, (3) irrigation, (4) mining and recovery of minerals, (5) hydroelectric power, (6) navigation, (7) recreation and pleasure, and (8) other beneficial uses.

A landowner may construct a dam or a non-navigable stream on his property to impound or diffuse surface water without a permit as long as the water impounded does not exceed 200 acre-feet. This provision is pertinent to the management of major reservoirs because construction of numerous small dams in a watershed collectively can significantly reduce the amount of runoff that reaches the main river.

In regard to ground water, Texas courts have followed unequivocally the common law rule that the landowner has a right to take for use or sale all the water he can capture from beneath his land. The state has little control over the use of ground water. Consequently, conjunctive management of ground and surface waters is extremely difficult.

Interstate Compacts

Texas participates in five interstate river compacts which have been ratified by the states involved and the U.S. Congress. The compacts are administered by commissions representing the member states. The compacts and the dates they became effective are Rio Grande (1939), Pecos (1948), Canadian (1952), Sabine (1954), and Red (1980). The purposes of the interstate compacts are generally to provide for an equitable apportionment between the states of the water available from the river and to facilitate cooperative planning, implementation, and management of projects for the conservation and utilization of the water resource.

CHAPTER 5
RESERVOIR OPERATION BY RIVER BASIN

The major reservoirs are listed by river basin in Table A-1 along with descriptive data. The river basins are delineated and reservoir locations shown on the map provided as Plate 1. Table 6 is a summary of the number and capacity of major reservoirs by river basin. Reservoir purposes and uses, owners and operators, and water customers are discussed in this section. System operation or interactions between reservoirs are also addressed. This section was developed from information available in Texas Department of Water Resources and Corps of Engineers documents, supplemented by publications of other agencies and informal contacts with various reservoir management personnel.

Canadian River Basin

Rita Blanca Lake and Meredith Lake are the two major reservoirs in the Texas portion of the Canadian River Basin. Rita Blanca Lake was constructed by the Soil Conservation Service and is maintained by the City of Dalhart for recreation. Lake Meredith, along with 322 miles of pipeline, 10 pumping plants, and 3 regulating reservoirs, was constructed by the Bureau of Reclamation and is operated by the Canadian River Municipal Water Authority. By contractual agreement the eleven member cities of the Municipal Water Authority are allocated specific annual quantities of water from the reservoir for municipal and manufacturing uses. Allocations are adjusted proportionally in times of water shortage. The Tulsa District of the Corps of Engineers regulates the flood control storage in Lake Meredith.

Red River Basin

Twenty-two major reservoirs are located in the Texas portion of the Red River Basin. Lake Texoma contains 78 percent of the total storage capacity in the basin. Lake Texoma was constructed by the Corps of Engineers for flood control, hydroelectric power, water supply, and recreation purposes. The Tulsa District of the Corps of Engineers operates the project. The Red River Authority, City of Denison, Texas Power and Light Company, Atlantic Richfield Company, and Texaco Company have contracted for the conservation storage capacity. Lake Randall, owned by the City of Denison for a municipal water supply, is also used for regulating diversions from Lake Texoma. Valley Lake, owned and operated by Texas Power and Light Company, is also supplemented by diversions from Lake Texoma to maintain a constant operating level for steam-electric power plant operation.

The City of Wichita Falls owns and operates Wichita, Kickapoo, and Arrowhead Lakes and is co-owner with the Wichita County Water Improvement District No. 2 of Lake Diversion and Lake Kemp. Lake Wichita is not currently being used because of the inadequacy of the dam structure. Lakes Kickapoo and Arrowhead are the principal sources of surface-water supply for the Wichita Falls area. Lake Diversion supplies irrigation as well as municipal uses. In 1974 the Corps of Engineers completed reconstruction of the Lake Kemp Dam to make it safe and to provide a specific allocation of storage for flood control. The city and water improvement district are reimbursing the federal government for the reconstruction cost allocated to conservation storage. The federal government in turn reimburses the local interests annually for operation and maintenance cost they incur allocated to flood control.

Bivins Lake, owned by the City of Amarillo, is used for aquifer recharge. Electra, Baylor Creek, and Crook Reservoirs are owned by and provide water for the Cities of Electra, Childress, and Paris, respectively. Santa Rosa Reservoir is owned by the W.T. Waggoner Estate and is used for livestock watering and oil and gas secondary recovery operations. Lake Bonham, owned by the Bonham Municipal Water Authority, supplies municipal and industrial water to the City of Bonham. North Fork Buffalo Creek Reservoir is owned by the Wichita County Water Control and Improvement District No. 3 and supplies most of the water used by the City of Iowa Park. Hubert H. Moss Lake is owned by the City of Gainesville in the Trinity River Basin. Although no water has been used from the project to date, it will provide municipal and industrial supply for Gainesville in the future. Farmers Creek Reservoir, owned and operated by the North Montague County Water Supply District, supplies the City of Nocona and other areas of Montague County. MacKenzie Reservoir is owned by the MacKenzie Municipal Water Authority and serves several member cities. Likewise, Greenbelt Reservoir is owned by the Greenbelt Municipal and Industrial Water Authority and serves several member cities.

Pat Mayse Reservoir was constructed and is operated by the Corps of Engineers for flood control, municipal and industrial water supply, and recreation. The City of Paris has contracted for the conservation storage. Coffee Mill Creek Lake is owned and operated by the U.S. Forest Service for recreation. Buffalo Lake, owned by the U.S. Fish and Wildlife Service, is not currently in use because of inadequacy of the dam structure.

Several natural salt pollution areas are located in the Red River Basin. Truscott Reservoir was recently constructed by the Red River Authority as an element in a chloride control plan for the basin. Truscott Reservoir will collect and store natural salt brine which otherwise flows downstream into Lake Kemp.

Sulphur River Basin

Wright Patman Lake is a Corps of Engineers project operated by the Fort Worth District for flood control, municipal and industrial water supply, and recreation. Most of the storage capacity is allocated to flood control, but the Cities of Texarkana, Texas and Texarkana, Arkansas contracted with the Corps of Engineers to provide a conservation pool for water supply purposes. The Corps of Engineers also modifies the operating rules to make an additional supply of water available on a seasonal basis. When the authorized Cooper Lake is completed, the plan is to reallocate 120,000 acre-feet of flood control storage in Wright Patman Lake to municipal and industrial water supply. The City of Texarkana, Texas signed an agreement with the Corps of Engineers in 1968 for this future reallocated conservation storage. Several other small cities and industries purchase water from Wright Patman Lake from Texarkana.

Cooper Lake is an authorized Corps of Engineers multiple purpose project for which construction has been initiated but halted due to environmental litigation.

Lake Sulphur Springs is owned and operated by the City of Sulphur Springs and provides municipal and industrial water for the city and surrounding area. River Crest Reservoir, owned by Texas Power and Light Company, is an off-channel storage facility which provides water for steam-electric power plant cooling.

Cypress Creek Basin

Of the eight major reservoirs in the Cypress Creek Basin, Lake O' the Pines if the only federal project and thus the only reservoir with flood control storage. Lake O' the Pines is a Corps of Engineers reservoir operated by the Fort Worth District for flood control, municipal and industrial water supply, and recreation. The Northeast Texas Municipal Water District has contracted for the conservation capacity and supplies the water to the Cities of Daingerfield, Lone Star, and Hughes Springs and several industries.

Johnson Creek Reservoir and Welsh Reservoir, owned by Southwestern Electric Power Company, provide cooling water for operation of the company's steam-electric power plants located at the reservoirs and are maintained at constant operating levels by diversions from Lake O' the Pines. Ellison Creek Reservoir is owned by Lone Star Steel Company and supplies water for its steel mill. Monticello Lake is owned and operated by Texas Utilities Generating Company to supply cooling water for steam-electric power plants located near the reservoir and is maintained at a constant operating level by diversions from Lake Bob Sandlin. The Titus County Fresh Water Supply District No. 1 owns and operates Lake Bob Sandlin which supplies the water needs of the City of Mount Pleasant and provides water to Texas Utilities Generating Company for steam-electric power plant cooling. Lake Cypress Springs, owned by the Franklin County Water District, supplies water to the City of Mount Vernon, rural areas in Franklin County, and the Texas Utilities Generating Company.

The Northeast Texas Municipal Water District, Franklin County Water District, Titus County Fresh Water Supply District No. 1, Texas Water Development Board, and Lone Star Steel entered into an operating agreement in 1972 which was approved by the Texas Water Rights Commission in 1973. The operating agreement includes rules for the operation of the reservoirs owned by the various entities and provision for accounting for the waters held in storage. The agreement provides that Lake Cypress Springs and Lake Bob Sandlin can store water previously appropriated to the downstream Lake O' the Pines and Ellison Creek Resevoir subject to releases from upstream storage to satisfy downstream requirements upon demand. Storage accounts were established such that the basin waters are divided through exchange of storage in accordance with the existing water rights.

Caddo Lake is the only natural lake in Texas with a capacity greater than 5,000 acre-feet. However, in 1914 a man-made dam was constructed to prevent erosion of the downstream channel from draining the lake. In 1971, for safety reasons, the Corps of Engineers completed construction of a replacement dam. The Texas-Louisiana stateline runs through the lake. Prior to 1976, the dam was owned and maintained by the Caddo Lake Levee District. The Water Resources Development Act of 1976 transferred maintenance responsibility to the Corps of Engineers. The Cities of Marshall, Texas and Oil City and Mooringsport, Louisiana withdraw municipal supplies from the lake. Cooling water is also withdrawn from the lake by a steam-electric power plant located near Mooringsport. The City of Shreveport recently completed a pumping and conveyance system to deliver water from Caddo Lake to Cross Lake which supplies the city.

The Caddo Lake Compact augments and amplifies the Red River Compact approved by the Red River Compact Commission in 1979. The stated purpose of the Caddo Lake Compact is to preserve and protect Caddo Lake while allowing its utilization for water needs of adjacent portions of Louisiana and Texas. Raising the crest elevation of the uncontrolled spillway is stated to be a primary means of accomplishing this purpose. Rules are established for apportioning water withdrawals between Texas and Louisiana, both before and after the spillway level is raised.

Sabine River Basin

Toledo Bend Reservoir contains 65 percent of the total storage capacity of the basin. Toledo Bend Reservoir is owned and operated jointly by the Sabine River Authorities of Texas and Louisiana for municipal and manufacturing use, irrigation, hydroelectric power generation, and recreation. The Cities of Hemphill and Huxley and several private water companies have contracted with the Sabine River Authority of Texas for the use of water. Several utilities have a contract with the two river authorities for the hydroelectric power generated.

Lake Tawakoni and Lake Fork are owned and operated by the Sabine River Authority of Texas for municipal and industrial water supply and recreation purposes. The City of Dallas, located in the upper Trinity River Basin has contracted with the river authority for 80 percent of the water supply in Lake Tawakoni. Water is delivered from the lake to Dallas by an existing 72-inch diameter pipeline. The City of Dallas is presently constructing an additional 84-inch pipeline. The Cities of Terrell in the Trinity River Basin and Commerce in the Sulphur River Basin have also contracted with the river authority for supplemental supplies from Lake Tawakoni. The project also supplies water to several small cities in the Sabine River Basin. Lake Fork Reservoir was completed by the Sabine River Authority in 1981. The City of Dallas and Texas Utilities Generating Company are contracting for a major portion of the water in this project.

Lake Gladewater is owned and operated by the city of Gladewater for municipal and industrial water supply. Lakes Quitman, Holbrook, Winnsboro, and Hawkins are owned and operated by the Wood County Fresh Water Supply District for recreation and flood control. Although there is no controlled flood control storage capacity, the limited capacity of the service spillways provide surcharge storage. Lake Murvaul, owned by the Panola County Water Supply District, provides municipal and industrial supply for the City of Carthage and other customers in Panola County. Lake Cherokee, owned and operated by the Cherokee Water Company, provides cooling water for a Southwestern Electric Power Company Plant and municipal and industrial water for the Cities of Kilgore, Longview, and White Oak. Martin Lake is owned and operated by Texas Utilities Generating Company to provide cooling water for four steam-electric power plants planned for construction near the reservoir.

Neches River Basin

Of the 10 major reservoirs in the basin, Sam Rayburn Reservoir contains 84 percent of the storage capacity and is the only project with flood control capacity. Sam Rayburn Reservoir is owned and operated by the Corps of Engineers, Fort Worth District, for flood control, hydroelectric power, recreation, and municipal, industrial, and agricultural water supply. The Lower Neches Valley authority and City of Lufkin have contracted for releasees to be made in accordance with a specified schedule. The water is released through the hydroelectric turbines and used downstream for municipal, industrial, and irrigation use. The Sam Rayburn Power cooperative sells the electricity.

B.A. Steinhagen Lake is located immediately downstream of and acts as a reregulation reservoir for Sam Rayburn Reservoir. Surges of water released for power generation at Sam Rayburn Dam are impounded in B.A. Steinhagen Lake to be released as needed for municipal, industrial, and irrigation in Beaumont and other areas along the lower Neches River. The Corps of Engineers owns and operates the project. The Lower Neches Valley Authority is the water supply sponsor.

Lakes Pinkston, Jacksonville, Nacogdoches, and Tyler are municipal water supply reservoirs owned and operated by the Cities of Center, Jacksonville, Nacogdoches, and Tyler, respectively. Lake Kurth is operated as an off-channel storage project for industrial water diversions from the Angelina River by Southland Paper Mills. Striker Creek Reservoir, owned by the Angelina and Nacogdoches Counties Water Control and Improvement District No. 1, provides water for industrial purposes and steam-electric power plant cooling. Lake Athens, owned by the Athens Municipal Water Authority, provides municipal water to the City of Athens in the Trinity River Basin. Lake Palestine is owned and operated by the Upper Neches River Municipal Water Authority for municipal and industrial purposes. The City of Dallas has contracted with the water authority for a little over half of the storage in Lake Palestine.

Trinity River Basin

The Trinity River Basin contains 27 existing major reservoirs and four others under construction. All but four of the 31 reservoirs are located in the upper half of the basin, in or near the Dallas-Fort Worth metroplex.

The Corps of Engineers owns and operates six of the existing projects in the basin and have three other projects under construction. The Corps of Engineers projects were developed as components of a comprehensive plan for flood control and water supply. Bardwell, Navarro Mills, Benbrook, Grapevine, Lavon, and Lewisville Lakes are located in the upper basin and each provides flood control, municipal and industrial water supply and recreation. These 6 reservoirs contain 1,325,060 acre-feet or 26 percent of the total conservation capacity contained in the 27 existing major reservoirs and 1,432,300 acre-feet or 100 percent of the flood control capacity. Three other Corps of Engineers projects are now under construction, Wallisville Reservoir in the lower basin and Ray Roberts and Joe Pool Reservoirs in the upper basin. Construction of Ray Roberts and Joe Pool Lakes is nearing completion. These two projects are also for flood control, municipal and industrial water supply, and recreation. Upon completion of Ray Roberts Reservoir, a portion of the flood control capacity in Lewisville Reservoir equivalent to the flood control capacity of Ray Roberts will be reallocated to conservation storage. Thus, Ray Roberts Reservoir is actually adding to system conservation capacity without changing system flood control capacity. Construction of Wallisville Reservoir was halted in 1973 due to environmental litigation.

The Trinity River Authority has contracted for the conservation storage in Bardwell, Navarro Mills, and Joe Pool Lakes. North Texas Municipal Water District has contracted for the conservation storage in Lavon Lake. Conservation storage in Grapevine Lake is divided between Grapevine (16.3 percent), Dallas (52.7 percent), and Dallas County Park Cities (31.0 percent). The existing 436,000 acre-feet of conservation capacity in Lewisville Lake is divided between the Cities of Dallas (95.2 percent) and Denton (4.8 percent). Upon completion of Ray Roberts Lake upstream, 177,600 acre-feet of flood control capacity in Lewisville Lake will be reallocated to conservation. The additional conservation storage will be divided 74 percent for Dallas and 26 percent for Denton. Dallas and Denton have also contracted for 74 percent and 26 percent, respectively, of the conservation storage capacity in Ray Roberts Lake.

Halbert, Terrell, Weatherford, Amon G. Carter, Worth, Arlington, and Ray Hubbard are municipal and industrial water supply lakes owned and operated by the cities of Corcicana, Terrell, Weatherford, Bowie, Fort Worth, Arlington, and Dallas, respectively. The Tarrant County Municipal Water District No. 1 owns and operates Eagle Mountain and Cedar Creek Reservoirs and currently has Richland Reservoir under construction to provide water to Fort Worth and other users in Tarrant County. Waxahachie Lake is owned and operated by the Ellis County Water Control and Improvement District No. 1 for municipal and industrial water supply. Kiowa, owned by Lake Kiowa, Inc., is used solely for recreation. White Rock Lake is a recreational lake owned by the City of Dallas. Trinidad Lake, owned by Texas Power and Light, North Lake and Mountain Creek Lake, owned by Dallas Power and Light, Forest Grove Lake, owned by Texas Utilities Generating Service, and Fairfield Lake, owned by Industrial Generating Service, are used for supplying cooling water for steam-electric plants.

Houston County Reservoir, owned by Houston County Water Control and Improvement District No. 1, is located in the middle of the basin below the reservoirs cited above. It supplies water to the Cities of Crockett, Lovelady, and Grapeland.

Anahuac Lake at the lower end of the basin is owned by the Chambers-Liberty Counties Navigation District. The project supplies irrigation water for the lower Trinity River Basin and the Neches-Trinity Coastal Basin. It is also a future municipal supply for the City of Anahuac.

Lake Livingston, the largest reservoir in the basin, is jointly owned by the Trinity River Authority and the City of Houston. The Trinity River Authority controls 30 percent of the yield and Houston has the remaining 70 percent. The project provides for municipal and industrial uses and irrigation. The Coastal Industrial Water Authority has completed construction of the principal components of a major conveyance and distribution system designed to ultimately convey an average of about 1.4 million acre-feet of water annually from the Trinity River to the Houston-Galveston area in the San Jacinto River Basin and the Trinity-San Jacinto Coastal Basin. The Trinity River water delivered through this facility is provided from Houston's share of Lake Livingston and other water rights owned by Houston.

Trinity-San Jacinto Coastal Basin

Houston Power and Light Company owns and operates Cedar Bayou Reservoir as a part of the cooling water facilities for the Cedar Bayou steam-electric power plant. Saline cooling water withdrawn from Cedar Bayou is discharged into Cedar Bayou Reservoir prior to being discharged into Trinity Bay.

San Jacinto River Basin

The San Jacinto River Basin contains two major federal flood control dams and four major nonfederal conservation reservoirs. Addicks Dam and Barker Dam are flood control only projects constructed and operated by the Galveston District of the Corps of Engineers. Sheldon Reservoir is owned and operated by the Texas Parks and Wildlife Department for recreation and wildlife management and as a fish hatchery. Lewis Creek Reservoir is owned and operated by Gulf States Utilities Company for cooling water for a steam-electric power plant.

Lake Houston is owned and operated by the City of Houston. The San Jacinto River Authority has an agreement with Houston which allows diversion of raw water to industrial plants in the Baytown area and for irrigation. A number of industries in Harris County and the Galveston County Water Authority have also contracted with the City of Houston for raw water from Lake Houston. The City of Houston furnishes treated water from Lake Houston to users within the City and also to the City of Galveston, Galveston County Water Authority, and the City of Pasadena.

Lake Conroe, owned and operated by the San Jacinto River Authority, provides municipal and industrial water supplies for the City of Houston through releases to Lake Houston. Houston has rights to two-thirds of the storage in Lake Conroe. Water is also diverted from Lake Conroe to maintain a constant level in Lewis Creek Reservoir.

San Jacinto-Brazos Coastal Basin

The Galveston County Water Authority operates an off-channel reservoir which stores and regulates water diverted by canal from the Brazos River for municipal, industrial, and irrigation uses. This is the only major reservoir in the basin.

Brazos River Basin

Nine of the 40 major reservoirs in the Brazos River Basin were constructed by the Corps of Engineers as components of a comprehensive basinwide plan of development. Georgetown, Aquilla, Granger, Proctor, Somerville, Stillhouse Hollow, Waco, Belton, and Whitney Lakes are each operated by the Fort Worth District of the Corps of Engineers for flood control, water supply, and recreation. Whitney Lake serves the additional purpose of hydroelectric power generation. The nine Corps of Engineers projects have conservation capacities totalling 1,896,500 acre-feet or 49 percent of the conservation capacity of the 40 major reservoirs in the basin. All of the 2,972,900 acre-feet of flood control storage capacity in the basin is contained in the Corps of Engineers projects. Corps of Engineers personnel operate and maintain the nine federal multiple purpose projects. The Corps of Engineers is totally responsible for flood control operations. Conservation releases are made as directed by the local project sponsor. The Brazos River Authority (BRA) has contracted for all of the conservation capacity in each of the Corps of Engineers projects, except Fort Hood military base has 3.2 percent of the conservation storage in Belton Lake and the City of Waco has 12.5 percent of the conservation storage capacity in Lake Waco. The City of Waco is also the primary customer for the 87.5 percent of the Lake Waco conservation capacity controlled by the BRA.

In addition to controlling the conservation storage in the nine Corps of Engineers projects, the Brazos River Authority constructed, owns, and operates Granbury, Limestone, and Possum Kingdom Reservoirs. The twleve reservoirs are operated as a system to supply downstream municipal, industrial, and agricultural water users as well as users located in the vicinities of the reservoirs. Possum Kingdom Reservoir, completed in 1941, provides water supply and hydroelectric power. Lake Limestone, completed in 1978, will supply water to off-channel cooling lakes for two lignite-fueled power plants being built by the Texas Power and Light Company. Lake Granbury is committed for cooling a gas-fired plant on the lake and a nuclear-powered plant being built about seven miles from the lake. BRA uses Lake Belton to supply water under contracts with the Cities of Temple and McGregor, and through Bell County Water Control and Improvement District No. 1 and two water supply corporations, to several other cities and communities. Water from Lake Whitney is contracted for use by the Cities of Cleburne, Whitney, and Rio Vista. Water from Proctor Reservoir is provided to several cities under a contract between BRA and the Upper Leon River Municipal Water District. Proctor also provides water for agriculture use to individual farmers around the lake and to a corporation of farmers along the Leon River downsteam of the dam. Stillhouse Hollow Reservoir supplies water to a number of communities and rural water supply corporations. Somerville Reservoir and the recently completed Georgetown, Granger, and Aquilla reservoirs are also committed for municipal and industrial water supply.

In addition to the uses cited above, BRA operates the upstream reservoir system to regulate flows for municipal, industrial, and irrigation uses in the lower Brazos Basin and neighboring coastal basins. Downstream water customers include a large chemical plant at the mouth of the Brazos

River, a canal company with a pumping plant a short distance upstream, and several public utility plants generating electric energy for the lower Brazos Basin and Houston area. BRA owns and operates several canal systems which include pumping stations and about 200 miles of canals. Water is diverted to municipalities and industries in the coastal area south of Houston which includes one of the world's largest petrochemical complexes. Water is also supplied through BRA canal systems for irrigation of rice in Fort Bend, Brazoria, and Galveston Counties.

Eleven reservoirs with storage capacities totalling 273,720 acre-feet or 7.0 percent of the total conservation storage of all the major reservoirs are owned and operated by cities for municipal and industrial supply and recreation. The City of Abilene owns and operates Kirby, Abilene, and Fort Phantom Hill Reservoirs for municipal, industrial, and recreational use. Likewise, Mineral Wells, Cisco, Daniel, Sweetwater, Pat Cleburne, and Graham Reservoirs are owned and operated by the Cities of Mineral Wells, Cisco, Breckenridge, Sweetwater, Cleburne, and Stamford, respectively. Lake Stamford, owned by the City of Stamford, was constructed primarily for supplying cooling water for a steam-electric power plant but also serves municipal uses. Bryan Utilities Lake, owned by the City of Bryan, is used for steam-electric power plant cooling and recreation.

Five reservoirs with storage capacities totalling 430,850 acre-feet or 11 percent of the conservation storage in the major reservoirs of the basin are owned and operated by municipal water districts which supply water to member cities and other users. These reservoirs are Mexia, Millers Creek, Leon, White River, Palo Pinto and Hubbard. The corresponding water districts are Bristone Municipal Water Supply District, North Central Texas Municipal Water Supply District, Eastland County Water Supply District, White River Municipal Water District, Palo Pinto Municipal Water District No. 1, and West Central Municipal Water District.

Six reservoirs with a storage capacity totalling 270,410 acre-feet or 6.9 percent of the total conservation storage of the major reservoir in the basin are owned and operated by electric utility companies to provide cooling water for steam-electric power plants. Texas Power and Light Company owns and operates Lake Creek, Tradinghouse, and Twin Oaks Reservoirs for steam-electric power plant cooling. Smithers Reservoir is owned and operated by Houston Lighting and Power for the same purpose. Likewise, Gibbons Creek Reservoir is owned and operated by Texas Municipal Power Agency. Supplemental water is delivered to Gibbons Creek Reservoir from Lake Limestone through contractural arrangements with the Brazos River Authority. Squaw Creek Reservoir, owned and operated by Texas Utilities Generating Company, will provide cooling water for the Comanche Peak Nuclear Power Plant currently under construction. Lake Granbury will supply water as needed to Squaw Creek Reservoir.

Dow Chemical Company owns and operates Brazoria and William Harris Reservoirs to provide off-channel storage and regulation of water diverted from the Brazos River for manufacturing use at the industrial complex in southern Brazoria County. The Aluminum Company of America owns and operates Alcoa Lake for manufacturing use and steam-electric power plant cooling. Davis Lake, owned by the League Ranch, is used for irrigation. Camp

Creek Lake owned by the Camp Creek Water Company is used primarily for recreation.

Colorado River Basin

Four of the 24 reservoirs located in the Colorado River Basin contain flood control storage capacity. The Fort Worth District of the Corps of Engineers is responsible for flood control operations of two projects constructed by the Bureau of Reclamation as well as two Corps of Engineers projects. Hords Creek Lake and O.C. Fisher Lake are owned and operated by the Corps of Engineers for purposes of flood control, water supply, and recreation. Hords Creek Reservoir is by far the smallest Corps of Engineers reservoir in Texas. The Central Colorado River Authority has contracted fo the conservation capacity in Hords Creek Reservoir which provides a water supply for the City of Coleman. The Upper Colorado River Authority has contracted for the water supply storage capacity in O.C. Fisher Reservoir.

Twin Buttes Reservoir was constructed by the Bureau of Reclamation and is owned and operated by the City of San Angelo. The Corps of Engineers is responsible for flood control operations. The San Angelo Water Supply Corporates operates the conservation storage which is used to supply municipal and manufacturing water for the city and project irrigation water in Tom Green County. San Angelo also obtains water from O.C. Fisher Reservoir through the Upper Colorado River Authority and Lake Nasworthy which the city owns.

Lake Travis was also constructed by the Bureau of Reclamation under an agreement with the Lower Colorado River Authority (LCRA) which operates the project. LCRA constructed and operates a hydroelectric plant at the project. The Corps of Engineers is responsible for specifying releases to be made from the flood control pool. Lake Travis serves purposes of flood control, hydroelectric power, water supply and recreation.

The Lower Colorado River Authority operates a system of six reservoirs located upstream of or in the City of Austin for purposes of water supply, hydroelectric power, and recreation. This system is comprised of Travis, Buchanan, Lyndon B. Johnson, Inks, Marble Falls, and Austin Reservoirs. Lake Austin is owned by the City of Austin and operated by LCRA through a long-term lease agreement. Hydroelectric power plants are located at each of the six reservoirs. Lake Buchanan and Lake Travis are the principal water supply reservoirs, with the remaining reservoirs operated at or near constant level at all times.

LCRA also owns and operates Lake Bastrop and Cedar Creek Reservoir which are used for steam-electric power plant cooling water. Both projects are off-channel storage reservoirs dependent upon diversion of water from the Colorado River as needed to maintain constant levels.

Lake J.B. Thomas and Lake E.V. Spence are owned and operated by the Colorado River Municipal Water District primarily to supply water to the Cities of Snyder and San Angelo with a small amount of water being exported to Fisher County in the Brazos River Basin. Lake Brownwood is owned and operated by Brown County Water Improvement District No. 1 for municipal, manufacturing, irrigation and recreation uses. The Soil Conservation Service constructed Lake Clyde for water supply and floodwater detention. The City of Clyde owns and operates the water supply storage capacity. Winters, Brady, Walter E. Long, Coleman, and Oak Creek Reservoirs are municipal water supply reservoirs owned by the Cities of Winters, Brady, Austin, Coleman, and Sweetwater, respectively. Oak Creek Reservoir also supplies cooling wated for a steam-electric power plant owned by West Texas Utilities Company. Lake Colorado City and Champion Creek Reservoir are owned and operated by Texas Electric Service Company for steam-electric power plant cooling water. Lake Colorado City also supplies municipal water to the City of Colorado City. Eagle Lake, owned by the Lakeside Irrigation Company, is an off-channel reservoir used for storage and regulation of irrigation water pumped from the Colorado River.

Colorado-Lavaca Coastal Basin

The recently completed South Texas Project Reservoir is the only major reservoir in the Colorado-Lavaca Coastal Basin. The South Texas Project is a nuclear-fueled electric power generating complex now under construction which is owned by Houston Lighting and Power Company, Central Power and Light Company, City Public Service Board of San Antonio, and the City of Austin. The Reservoir will provide cooling water. Desired operating levels for salinity and temperature control will be maintained by recirculation of water from the Colorado River through the Reservoir.

Lavaca River Basin

Lake Texana is the only major reservoir in the Lavaca River Basin. The project was constructed by the Bureau of Reclamation and is operated by the Lavaca-Navidad River Authority to supply water for municipal, industrial, and irrigation purposes.

Guadalupe River Basin

Major reservoirs in the Guadalupe River Basin consists of a multiple purpose Corps of Engineers project, a steam-electric plant cooling water reservoir, and three hydroelectric power projects. Canyon Lake is owned and operated by the Fort Worth District of the Corps of Engineers for flood control, water supply, and recreation. The Guadalupe-Blanco River Authority (GBRA) has contracted for the conservation storage. The GBRA owns and operates Coleto Creek Reservoir as a cooling pond for a stream-electric power plant owned by Central Power and Light Company. The GBRA also owns and operates six small hydroelectric dams on the Guadalupe River between New Braunfels and the confluence with the San Marcos River. Three of the hydropower reservoirs, McQueeney, H-4, and Dunlap Reservoirs have capacities of 5,000 acre-feet or slightly more and are listed with the major reservoirs in Table A-1. The other three hydroelectric projects, Molte, H-5, and TP-4 has capacities less than 5,000 acre-feet.

San Antonio River Basin

Olmos, Victor Braunig, Calaveras, and Medina are the four major reservoirs in the San Antonio River Basin. Olmos Lake is owned and operated by the City of San Antonio flood control. During nonflooding periods when the reservoir is empty, the pool area is used as a park and playground. Victor Braunig Lake and Calaveras Creek Reservoir are owned by the City of San Antonio and operated by the City Public Service Board to supply cooling water for steam-electric power generation. Runoff into these reservoirs is supplemented by water pumped from the San Antonio River. Medina Lake is owned and operated by the Bexar-Medina-Atascosa Counties Water Improvement District No. 1 to supply water for irrigation.

Nueces River Basin

Three major reservoirs are located in the Nueces River Basin. The Upper Nueces Reservoir is owned and operated by the Zavala and Dimmit Counties Water Improvement District No. 1 to supply water for irrigation. Lake Corpus Christi is owned by the Lower Nueces River Water Supply District and operated by the City of Corpus Christi for purposes of municipal, industrial, and agricultural water supply. In addition to using the water itself, the City of Corpus Christi sells water to the San Patricio Municipal Water District, Alice Water Authority, and several cities and industries. Choke Canyon Reservoir was constructed by the Bureau of Reclamation and is jointly owned by the Nueces River Authority and the City of Corpus Christi. The recently completed Choke Canyon Reservoir is operated in conjunction with Lake Corpus Christi to provide municipal and industrial water supply for the coastal bend area. Recreation is also provided.

Nueces-Rio Grande Coastal Basin

Four major reservoirs are located in the Nueces-Rio Grande Coastal Basin. Barney M. Davis Reservoir is owned and operated by Central Power and Light Company to store cooling water for the Barney M. Davis steam-electric power plant located adjacent to the Laguna Madre near Corpus Christi. Saline water is withdrawn from Laguna Madre for cooling of the plant condensers. After retention in the Barney Davis cooling pond, the water is returned to Laguna Madre.

The three other major reservoirs are used for temporary storage and regulation of water diverted from the Rio Grande Basin. Valley Acres Reservoir is owned and operated by the Valley Acres Water District for municipal and agricultural purposes. Delta Lake is owned and operated by Hidalgo and Willacy Counties Water Control and Improvement District No. 1 for irrigation. Loma Alta Reservoir is owned and operated by the Brownsville Navigation District for municipal and irrigation uses.

Rio Grande River Basin

The Texas portion of the Rio Grande River Basin contains seven major reservoirs including two large international projects on the Rio Grande River and five smaller reservoirs located on tributaries on the United States side of the Rio Grande River.

International Falcon and Amistad Reservoirs were constructed under the terms of a 1944 treaty between the United States and Mexico. The reservoirs are owned and operated by the United States and Mexico Sections of the International Boundary and Water Commission. The Bureau of Reclamation designed and supervised construction of the Falcon project. The Corps of Engineers designed and supervised construction of Amistad. The Texas Department of Water Reources administers the United States share of the conservation storage in the two projects. The two reservoirs are operated as a system for flood control, water supply (primarily irrigation), hydroelectric power, and recreation.

International Falcon Reservoir has a total controlled storage capcity of 3,177,600 acre-feet of which 2,267,600 acre-feet is allocated to conservation storage (including 2,800 acre-feet of sediment storage) and 910,000 acre-feet is allocated to flood control. During the winter months, up to 400,000 acre-feet of flood control capacity may be reallocated for additional temporary conservation storage. The United States has 58.6 percent and Mexico 41.4 percent of the conservation storage capacity. The United States share is used within the State of Texas. Therefore, Texas share of conservation storage in Falcon Reservoir is 1,328,800 acre-feet in summer months and 1,563,200 acre-feet in winter months.

International Amistad Reservoir has a total controlled capacity of 5,249,700 acre-feet, including 3,505,400 acre-feet of conservation storage (including 8,000 acre-feet of sediment reserve) and 1,744,300 acre-feet of flood control storage. The United States has 56.2 percent and Mexico 43.8 percent of the conservation storage. Thus, Texas share of the conservation storage in Amistad Reservoir is 1,970,000 acre-feet.

Much of the water use from the Rio Grande River occurs in the 4-county Lower Rio Grande Valley region. The Texas Department of Water Resources reports that, in 1980, over seven thousand operating units used over 1.3 million acre-feet of water for irrigation of about 800,000 acres in the Lower Rio Grande Valley. Municipal and manufacturing use in 1980 accounted for an additional 103,000 acre-feet in the 4-county region. Most of this water was supplied from releases from International Falcon Reservoir. A Water Master employed by the Texas Department of Water Resources is responsible for administering the water allocation system and determining the releases to be made from the conservation pools of Falcon and Amistad.

Mexico and the United States each have a hydroelectric generating plant on its side of Falcon Dam. Each plant includes three 10,500-kilowatt generators driven by three 14,750 horsepower turbines, with a total capacity in each powerhouse of 31,500 kilowatts. The United States plant generated 78,536,000 kilowatt-hours of energy in 1983.

As a part of the construction of Amistad Dam, power penstocks were installed and sites were excavated on each side of the dam for future hydroelectric power plants. In 1983, the United States completed construction of a hydroelectric generating plant consisting of two units of 33,000 kilowatts each. The plant generated 117,318,000 kilowatt-hours of energy in 1983.

Amistad and Falcon Reservoirs are used extensively for recreation. Recreation facilities on the United States side of Falcon have been developed by the Texas Parks and Wildlife Department, Starr County and private interests. The National Park Service is responsible for recreation facilities on the United States side at Amistad. Mexican authorities supervise recreation on the Mexican side of the two projects.

Red Bluff Reservoir is located on the Pecos River and backs water into New Mexico. The reservoir is owned and operated by the Red Bluff Water Power Control District to provide water supplies for irrigation and hydroelectric power generation. Due to inflows of highly saline water, the actual use for irrigation has been much less than originally intended. The Pecos River Company provides that New Mexico not allow man's activities to reduce the flow of the Pecos River at the stateline to less than flows available to Texas under 1947 conditions in the basin. Texas and New Mexico have been in litigation before the U.S. Supreme Court for several years regarding Texas not receiving its share of the Pecos River flow.

Lake Balmorhea is owned and operated by the Reeves County Water Improvement District No. 1 for irrigation. Much of the inflow to the reservoir is from springs. San Esteban Lake is owned by a private estate. It is heavily silted and dry most of the time due to insufficient local runoff. Casa Blanco Lake is owned and operated by Webb County for recreation and irrigation of a golf course. Imperial Reservoir is owned and operated by Pecos County Water Control and Improvement District No. 2 for irrigation.

CHAPTER 6
RESERVOIR OPERATION PRACTICES AND PROCEDURES

This chapter provides an overview of procedures and practices followed in operating reservoirs, followed by a brief discussion of past, present, and possible future problems, issues, and directions in reservoir operation in the state. Operating procedures or release policies are addressed here from the perspective of the rules and practices followed in determining the quantities of water to be stored and to be released or withdrawn from a reservoir under various operating conditions.

Reservoir operation is based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing flood waters to reduce downstream damages. Each of the major reservoirs in Texas is operated for only conservation purposes or only flood control or a certain reservoir volume, or pool, is designated for conservation purposes and a separate pool for flood control. The pools are separated by a designated top of conservation pool elevation. Institutional arrangements for constructing and operating reservoirs are based on having separate pools for flood control and conservation. Planning, design, and operational problems associated with flood control are handled separately from those associated with conservation.

Construction of a conservation reservoir can actually worsen downstream flooding conditions due to loss of valley storage, decrease in flood wave attenuation, and increase in travel time. However, conservation capacity provides some incidental flood protection whenever the flood event coincides with a partially drawn-down pool. Drought periods in Texas have often been ended by major floods such that empty conservation storage space was available to store the flood waters. Surcharge storage in conservation only reservoirs may also provide some incidental flood protection. Downstream flooding is also considered in regulating releases from conservation projects. For example, Toledo Bend Reservoir, which has the largest conservation capacity in the state and is located in a basin with no flood control storage capacity, is operated to minimize deviations from the designated constant pool level to the extent practical. However, the operation procedures include monitoring of downstream streamflows in regard to damage potential and forecasting of reservoir inflows. The reservoir will be drawn down in anticipation of a flood or the pool will be maintained a foot or so high temporarily to prevent releases from contributing to downstream flooding. Likewise, temporary storage of flood water in flood control pools may provide some incidental benefits for conservation purposes, particularly hydroelectric power generation. However, reservoir operation throughout the state is based on treating flood control and conservation capacities as distinctly separate pools serving different purposes.

The following discussion is consistent with traditional reservoir planning and operation practice in that conservation and flood control operating procedures are covered in separate sections.

Operation for Conservation Purposes

The world has an adequate amount of precipitation to meet all water use needs for the foreseeable future. The problem is not the total long-term amount of precipitation worldwide, but rather temporal and spatial distribution. The precipitation does not occur at the optimal times and places to meet human needs. Excessive amounts of precipitation flow back to the ocean, and may even cause damaging floods, at some locations and times while severe shortages of water occur at other times and places. The purpose of reservoirs is to alter the temporal and spatial distribution of the runoff resulting from precipitation to better conform to the needs of society. Reservoirs are much more effective at altering temporal than spatial runoff distribution. However, combined with conveyance facilities, reservoirs also are used to transport runoff from one basin to another where it is needed. These general concepts are well illustrated in Texas. Extreme variations in series of wet years and dry years and floods and droughts characterize the Texas climate. The state is also characterized by geographical variations in water availability and water use.

In considering reservoir operation in the state, it is also important to realize that water storage is a regional or local as well as statewide problem. A small region of the state may be experiencing drought conditions while the state as a whole is having a relatively wet year. Physical and institutional constraints often prevent transport of water from a surface water system with a surplus supply to a neighboring system experiencing a temporary severe water shortage. Each local and regional water supplier must have the capability to assure its water users an adequate supply during drought conditions in its own area regardless of the statewide situation. A particular entity is in trouble if its reservoir storage capacity is depleted, even if the combined storage capacity in all the reservoirs statewide is ninety percent full of water. However, on the other hand, complex institutional and physical interactions between localities and regions of the state make surface water management a statewide as well as local and regional problem.

In general, reservoir operation can be categorized as being primarily influenced by either seasonal fluctuations in streamflow and/or water use or long-term threat of drought. In many parts of the world, a reservoir will be filled during a distinct season of high rainfall or snow melt and emptied during a dry season with high water demands. Thus, the reservoir level fluctuates greatly each year in a predictable seasonal cycle. This is not the case in Texas. Surface water management is greatly influenced by a long-term threat of drought. Water must be stored through many wet years to be available during drought conditions. Although reservoir storage may be significantly depleted within several months, severe drought conditions are characterized as a series of several dry years rather than the dry season of a single year.

Historical Conservation Storage Levels

The Texas Department of Water Resources publishes monthly conservation storage data for selected reservoirs, which presently include 71 projects containing 98 percent of the total conservation capacity of the major reservoirs. The number and capacity of reservoirs included has varied over the years as new projects were constructed. Adjustments have also been made occasionally in the capacities cited for existing projects. The storages contained in each reservoir near the end of the month are tabulated. The data is published in the TDWR monthly newsletter "Texas Water" and its predecessor "Water for Texas". The monthly storage data taken from these publications were compiled and plotted to provide the graphs presented in Appendix B. Graphs are provided for each major river basin and the state as a whole. Reservoir capacity and storage content are plotted for the 18-year period from 1966 through 1983. These plots provide a convenient visual summary of the past fluctuations in reservoir storage levels on a basinwide basis.

Reservoir storage expressed as a percentage of conservation capacity reached a record low in 1984. The actual storage in acre-feet was less during all the years 1966 through 1972 than in 1984, but the total capacity was also much less. Reservoir storage data before 1966 is not considered in this discussion because many of the major reservoirs became operational about that time and later. A record drop during a single year in statewide storage content also occurred in 1984. A drop in 1977 was comparable, but both the maximum and minimum storage levels occurring in 1977 were much higher than those in 1984. In 1984, reservoir storage dropped from a peak of 26.3 million acre-feet, or 82 percent of the conservation capacity, in late March to 21.3 million acre-feet, or 66 percent of the conservation capacity, in late September. The record highest statewide storage content occurred in 1982 with a high of 29.1 million acre-feet, or 92 percent of capacity, in late May decreasing to 25.9 million acre-feet, or 82 percent of capacity, in late November. Storage content has dropped below 26.0 million acre-feet at least a portion of each year for every year of record. Storage content has been above 26.0 million acre-feet at least a portion of each year for every year during the period 1973 through 1985, except 1978. Storage was 25.7 million acre-feet in late January 1985 and 26.4 million acre-feet in late February 1985. Prior to 1973, the total conservation capacity was below 26.0 million acre-feet.

During the period from 1966 to early 1985, for the state as a whole, the combined amount of water in storage has varied from about 66 to 93 percent of the total conservation capacity. The statewide totals reflect an averaging affect of combining data from many reservoirs located throughout the state. Individual reservoirs exhibit much greater storage fluctuations than the statewide totals. A number of reservoirs have been essentially full since initially filling after construction, while others have exhibited wide fluctuations in pool levels over time.

The range of variation in storage between projects is illustrated by Table 14 on a major river basin basis. This data also illustrates the range of seasonal variation in storage during a year. Reservoir storage expressed as a percentage of conservation capacity is tabulated for late March 1984 and late September 1984. A record depletion of statewide reservoir storage occurred in 1984, both in terms of depletion rate and the peak volume of empty storage capacity. During 1984, the statewide

TABLE 14
RESERVOIR STORAGE IN 1984

Basin	Total Storage Capacity (acre-feet)	Number of Reservoirs	Storage as a Percentage of Conservation Capacity: Late March 1984: Basin Total	Late March 1984: Most Empty Reservoir	Late March 1984: Most Full Reservoir	Late September 1984: Basin Total	Late September 1984: Most Empty Reservoir	Late September 1984: Most Full Reservoir
Canadian	500,000	1	61	61	61	54	54	54
Red	3,638,950	7	90	31	100	73	27	89
Sulphur	160,410	2	100	100	100	93	36	93
Cypress	521,100	3	98	95	100	84	82	93
Sabine	6,044,300	3	90	50	100	80	45	87
Neches	3,455,500	4	99	75	100	77	75	86
Trinity	4,794,580	11	94	72	100	80	50	95
San Jacinto	570,400	2	100	100	100	94	90	95
Brazos	3,366,270	19	85	45	100	64	23	88
Colorado	3,307,800	10	66	15	79	38	8	58
Lavaca	157,900	1	99	99	99	97	97	97
Guadalupe	420,680	2	89	88	100	82	81	93
San Antonio	254,000	1	54	54	54	27	27	27
Nueces	960,300	2	21	5	60	11	1	38
Rio Grande	3,835,700	3	59	47	75	46	29	63
State Total	31,987,890	71	82	5	100	66	1	97

The data were taken from the May and October 1984 issues of "Texas Water", the monthly newsletter of the Texas Department of Water Resources. The 71 reservoirs included in the compilation represent 98 percent of the conservation storage capacity of the major reservoirs of Texas.

monthly storage totals were highest in late March and lowest in late September. Table 14 includes the storage totals for each basin as well as the storage contained in the most empty reservoir and most full reservoir in the basin, all in terms of storage content as a percentage of capacity. The statewide totals for 1984 are also given. The Nueces River Basin is shown to have the most empty reservoir in the state which is 5 percent full in March and 1 percent full in September. This is the recently constructed Choke Canyon Reservoir for which impoundment began in 1982. Since initial filling has not yet occurred, the data for Choke Canyon Reservoir is not comparable to the other projects. With the exception of Choke Canyon, storages for individual projects in the state varied from 15 percent to 100 percent of capacity in late March and from 8 percent to 97 percent in late September 1984. Table 15 shows that in late September, 6 reservoirs were less than 25 percent full, 19 reservoirs were between 26 and 50 percent full, 21 reservoirs were between 51 and 75 percent full, 18 reservoirs were between 76 and 90 percent full, and 7 reservoirs had storage of 91 percent or more of their conservation storage capacity.

A statewide annual precipitation of 27.4 inches in 1984 following 28.4 inches in 1983 can be compared with annual precipitation of 18.0, 22.8, and 15.5 inches during the severe drought years 1954, 1955, and 1956. The driest year on record was 1917 with 14.3 inches. Annual precipitation statewide averages 27.1 inches during the period 1892 through 1979. Therefore, 1984 was not an extremely dry year. A much more severe depletion of reservoir storage would result if the weather conditions of the 1950's drought should occur with the 1984 conditions of development and water use.

Dependable Yield

Planning and operating reservoirs for water supply purposes is based on the concept of firm or dependable yield. This provides a quantitative measure of the amount of water which can be supplied from a reservoir. Firm yield is the maximum continuous rate of withdrawal which can be maintained during a critical drought period, commonly taken to be the most severe drought of record. Thus, firm yield represents the amount of water which can be supplied if historical inflows are repeated in the future. Streamflow and related hydrologic data are available for only a limited period of record. Future inflows may or may not closely reproduce the flow sequence reflected by the past record. Firm yield is a somewhat simplistic concept because probabilities or risk levels associated with providing various yield levels are not considered. However, the concept is widely used and provides meaningful information as long as its limitations are realized.

The Texas Department of Water Resources has estimated the total firm yield provided by the reservoirs in Texas to be about 11.0 million acre-feet per year (TDWR, 1984). This represents the maximum amount of surface water which could be supplied if the most severe drought conditions reflected in the period of record in each river basin are repeated. If conditions more severe than the drought of record for a river basin should occur, the firm yield indicated for that basin could not be provided. A given region of the state could be experiencing severe drought conditions

TABLE 15
NUMBER OF RESERVOIRS WITHIN VARIOUS RANGES OF STORAGE CONTENT

Storage Range (percent of capacity)	Number of Reservoirs	
	Late March 1984	Late September 1984
0% to 25%	6	6
26% to 50%	7	19
51% to 75%	17	21
76% to 90%	11	18
91% to 100%	30	7
Total	71	71

with inadequate reservoir storage while state-wide the actual total surface water use is well below the combined yield available from all the state's reservoirs. However, in most years for most reservoirs, streamflow will be adequate to provide yields significantly higher than the firm yield. The previously cited water use and reservoir yield data indicate that the present use of surface water state-wide is about 64 percent of the firm yield. Most of the remaining firm yield is committed for expanding municipal and industrial needs during the next 20 to 30 years (TDWR, 1984).

Firm yield has been estimated by various agencies for each of the reservoirs. The firm yield estimates provide a quantitative measure of the amount of water which can be committed for use from the reservoir. Contracts between reservoir operators and water users as well as water rights permits are typically based on firm yield. Exceptions occur, but generally water rights permits are limited so that the total amount of water allocated to all users does not exceed the firm yield from a particular reservoir or portion of a river basin.

Conservation Purposes

All of the major reservoirs in Texas except three contain conservation storage capacity. The three exceptions are Addicks and Barker Reservoirs which are single-purpose flood control and Truscott Reservoir used for brine disposal. The primary conservation purposes served are municipal, industrial, and agricultural (irrigation) water supply, cooling water for steam-electric plants, hydroelectric power generation, and recreation. Reservoir operation involves both complementary and conflicting or competitive interactions between these purposes. Numerous municipal, industrial, and irrigation users are dependent upon the limited resource water. Allocation between competing users is governed by the water law of the state. Hydroelectric power can often be generated with water that is released for downstream municipal, industrial and agricultural uses. In other cases, water may be released specifically and only for hydroelectric power generation. Reservoir recreation is extremely popular and a major consideration in reservoir operation in Texas. Recreation is generally complementary with the other conservation purposes. However, since operation for recreation essentially means maintaining a full pool without fluctuations in water surface level, releases and withdrawals for other purposes can be detrimental to recreation uses.

Water Supply and Associated Multiple Purpose Operation

As previously discussed, the 7.0 million acre-feet of surface water used in 1980, which was essentially all regulated by reservoirs, was divided between uses as follows: agriculture 55.4%, municipal 21.7%, manufacturing 18.1%, steam-electric power generation 3.9% and mining 0.9% (TDWR, 1984). This data is for withdrawals, except steam-electric power includes only consumptive use, primarily evaporation. The actual withdrawals for cooling water are much greater than consumptive use. However, withdrawals are returned directly to the reservoir or stream. Municipal and industrial withdrawals also have significant return flows to the stream system. About half the irrigation from surface water occurs in the lower Rio Grande Valley using water regulated by International Falcon Reservoir. Much of the remaining surface water irrigation is concentrated in the coastal areas of the eastern half of the state. Hydroelectric power and recreation are instream uses involving no withdrawals from the stream system and thus are not included in the above data.

According to the data tabulated in Appendix A, municipal and/or industrial water supply is provided by 163 of the 184 conservation reservoir. Most of the reservoirs providing water for irrigation also supply municipal and industrial uses. A much larger porportion of the conservation storage capacity is designated for municipal and industrial use than is designated for agricultural use. However, more than half the surface water presently used each year is for irrigation. Reservoirs used for supplying irrigation water also tend to be located in areas of the state with drier climate and less runoff which results in a lower yield per unit of storage capacity. The higher ratio of annual use to storage capacity associated with irrigation indicates a higher risk of water shortages during a drought than that associated with municipal and industrial use. Also, a large proportion of the storage capacity is reserved for future, rather than present, municipal and industrial use.

Although most of the surface water used in the state is used within the river basin from which it originates, significant interbasin transfers do occur. For example, Meredith Reservoir on the Canadian River supplies water to nine cities located in the upper Red, Brazos, and Colorado River Basins as well as two cities in the Canadian Basin. The City of Dallas, located in the upper Trinity River Basin, has contracted with the Sabine River Authority for a majority of the water supply from Lake Tawakoni and the recently completed Lake Fork. Dallas has been using Lake Tawakoni water for some time and plans to use Lake Fork in the future. The remaining supply from Lake Tawakoni is used by the City of Terrell in the Trinity Basin, City of Commerce in the Sulphur River Basin, and several small cities in the Sabine Basin. Livingston Reservoir on the Trinity River supplies water to the City of Houston in the San Jacinto River Basin. Large diversions from the Brazos, Colorado, Trinity, and San Jacinto Rivers are made to numerous water users in the several coastal basins. Extensive conveyance and distribution systems are operated to facilitate these diversions.

Water supply withdrawals are made at many projects through pumping plants with intake structures located in the reservoir. In many other cases, releases are made through outlet works and spillway structures to be withdrawn from the river at downstream diversion and intake facilities. The water may be actually withdrawn at locations several hundred river miles below the dam from which it was released. Travel times of a week or longer are not uncommon. For example, the most downstream water user serviced by the Brazos River Authority is about 200 miles below the most downsteam and 640 miles, or two weeks travel time, below the most upstream reservoir from which releases are made. The International Falcon Reservoir is 275 miles, or about one week travel time, above the most downstream water users in the Lower Rio Grande Valley. The most downstream user supplied by the Lower Colorado River Authority is also a week travel time downstream of the closest reservoir from which releases are made. Travel time and channel losses can be significant factors in scheduling reservoir releases.

Reservoir operation procedures for water supply purposes are based essentially on meeting water demands subject to institutional constraints related to water rights, project ownership, and contractual agreements. The complex organizational framework for water supply operations involves a multitude of water users and suppliers working under various contractual arrangements. Water suppliers may either own and operate reservoirs or contract with other reservoir owners for storage capacity or water use. A number of entities both own and operate their own reservoirs and contract with others for the use of additional capacity.

Water use permits are administered by the Texas Department of Water Resources in accordance with the water law of the state. Permits may involve a variety of arrangements. Permits may be regular, seasonal or temporary, or emergency in nature. Special provisions may be made for special circumstances. The legal right to use or sale the water from a reservoir is usually granted to the owner prior to construction of the project. Many reservoirs are owned and operated by cities to provide water to their citizens for domestic, public, and commercial use. The city holds the permit or water right and sales the water to its citizen customers. Another common case is a reservoir or system of several reservoirs owned and operated by a river authority which sales the water to a number of cities, industries, and/or farmers. The river authority holds the permit or water right. The cities, industries, and farmers purchase the water from the river authority without having to obtain a water right permit through the TDWR. The river authority operates the reservoirs to meet its contractual obligations to its customers. The federal government does not get involved with water rights. The nonfederal project sponsors which contract for the conservation storage in federal projects are responsible for obtaining the appropriate water rights permits through the TDWR.

Individual farmers, industries, and cities also hold water rights permits not associated with reservoirs. In several of the river basins, a number of reservoir operators, all holding appropriate water rights permits, operate reservoirs in the same basin. Reservoir operators are often required to make releases, typically not exceeding inflows, to allow downstream users not associated with the reservoir access to the water for which they are legally entitled.

A majority of the water supply reservoirs are operated as individual units to supply specific customers. Even in those cases where a water district or city owns several reservoirs, each reservoir will typically be assigned to specific users with a minimum of interaction between reservoirs. However, a number of reservoirs are operated as systems with some degree of interaction between the component reservoirs. System operation typically means maintaining a balance between storage depletions and water surface fluctuations in the component reservoirs. Hydroelectric power generation is also a concern in system operation. Releases are coordinated to meet water supply demands while minimizing the amount of water bypassing the turbines. System operation involves coordination between purposes and users as well as between reservoirs. Several examples of reservoir system operations which involve interactions between reservoirs, between purposes, and/or between users are cited in the following paragraphs.

The Lower Colorado River Authority (LCRA) operates a multiple purpose reservoir system composed of Buchanan, Travis, Inks, L.B. Johnson, Marble Falls, and Austin Lakes. Most of the storage capacity is contained in Lake Travis and Lake Buchanan. Practically all of the releases are made from Travis and Buchanan, with the storage levels in the other projects held essentially constant. In meeting water supply demands, an attempt is made to share the releases between the two projects so that their storages tend to be depleted in about the same proportion. Water supply releases are also closely coordinated with hydroelectric power generation to minimize the amount of water released without generating power. Hydrolectric power releases are limited essentially to water needed downstream for municipal, industrial, and agricultural use. To the extent that other purposes are not adversely affected, pool level fluctuations are minimized to enhance recreational use of the reservoirs. The Lower Colorado River Authority also owns and operates two off-channel steam-electric cooling reservoirs further downstream. Diversions from the river supplied by upstream reservoir releases maintain the off-channel reservoirs at constant levels.

The Brazos River Authority (BRA) operates three of its own reservoirs as well as controlling the conservation storage capacity of nine Corps of Engineers reservoirs (BRA, undated). The twelve reservoirs are operated as elements of a basin-wide water supply system. Each of the reservoirs provide water for a number of municipalities located in the vicinity of the reservoir. Industries, individual farmers, and groups of farmers have also contracted for water from several of the projects. Several projects provide water for steam-electric power plants, and there is one hydroelectric power plant. In addition to users served by specific projects, BRA has a number of downstream customers which can be supplied by releases from any number of the reservoirs in the system. BRA operates a canal system involving pumping plants and 200 miles of canals which supplies Brazos River water to industries and municipalities in the Gulf Coast area south of Houston. Many of the industrial customers are associated with the petrochemical industry. Additional canal systems supply water for irrigation of rice in Fort Bend, Brazoria, and Galveston Counties. Lower basin water customers supplied by releases from the upstream reservoirs also include a large chemical company at the mouth of the Brazos River, a canal company with a pumping plant a short distance upstream, and several large public utility plants generating electric energy for the lower Brazos Basin and Houston area. All of the reservoirs are used extensively for recreation. BRA also operates three regional sewage treatment systems to serve cities and other local agencies in several urban complexes within the Brazos Basin.

Operation of several reservoirs in the Cypress Creek Basin is governed by an operating agreement entered into in 1972 by the Northeast Texas Municipal Water District, Franklin County Water District, Titus County Fresh Water Supply District No. 1, Lone Star Steel Company, and the Texas

Water Development Board. The agreement provides rules for operating reservoirs owned by the participants and provisions for accounting for the waters held in storage. Basically, the agreement allows water to be stored in Cypress Springs and Bob Sandlin Reservoirs that was previously appropriated to downstream entities from Lake O' the Pines and Ellison Creek Reservoir subject to call for releases from upstream storage to satisfy downstream requirements as needed. The agreement establishes storage accounts in the reservoir such that the basin waters are appropriately divided through exchange of storage, in accordance with existing water rights.

Lake Meredith was constructed by the Bureau of Reclamation and is operated by the Canadian River Municipal Water Authority. The water authority has eleven member cities, located in four different river basins, which are supplied with water from Lake Meredith. The cities are allocated specific annual quantities of water from the reservoir for municipal and manufacturing uses. In times of water shortage, allocations are adjusted proportionally. The facilities for distributing the Meredith Reservoir water to the eleven cities include 322 miles of pipeline, 10 pumping plants, and three regulating reservoirs.

Falcon and Amistad Reservoirs are operated as a single unit. Releases from Falcon Reservoir supply users in the Lower Rio Grande Valley. The upstream Amistad Reservoir supplies users between the two projects and also provides inflows into Falcon Reservoir to maintain a balance between the depletion in the two reservoirs. The International Boundary and Water Commission coordinates United States and Mexico interests, operate and maintain the projects, and are directly responsible for flood control operations. However, the Texas Department of Water Resources is responsible for water supply operation. A water master employed by the TDWR works directly with the irrigation districts, individual farmers, and municipalities which hold permits to use the water. The water master maintains a water accounting system which depends upon water rights permits which have been issued and the current storage level in the reservoirs. Diversions to each water user are measured and recorded. Users are provided water upon request as long as their individual water accounts have not been depleted. The water master determines releases to be made from the reservoirs based upon requests from the water users, while also considering streamflow forecasts and travel time from the reservoir. International Boundary and Water Commission personnel operate the gates to make water supply releases as requested by the TDWR water master. The Rio Grande River Basin is presently the only basin in Texas for which a water master has been designated.

Sam Rayburn and B.A. Steinhagen Reservoirs are operated as a unit for purposes of flood control, hydroelectric power generation, municipal, industrial, and agricultural water supply, water quality maintenance, and recreation. The water quality maintenance consists of making releases to maintain a sufficient flow in the Neches River to prevent saltwater intrusion from the Gulf of Mexico. All of the flood control capacity and most of the conservation capacity is in Sam Rayburn Reservoir. The hydroelectric power plant is also at Sam Rayburn Dam. The downstream B.A. Steinhagen Reservoir is operated to reregulate releases from Sam Rayburn

Reservoir. Releases at Sam Rayburn are scheduled primarily for hydroelectric power users. The water is then temporarily stored in B.A. Steinhagen and released as required for downstream water users.

Steam-Electric Power

Twenty-nine cooling water reservoirs, containing about 2.7 percent of the total conservation capacity of the 187 major reservoirs, provide water for steam electric power plants. With the exception of recreation in some cases, these projects are used solely for steam-electric power plants. Most of the reservoirs are owned by electric companies with several being owned by river authorities or cities. The reservoirs are typically located adjacent to the power plant. Several are off-channel reservoirs with water levels maintained by diversions from a river. Several other multiple purpose conservation reservoirs provide water to steam-electric power reservoirs or directly to the power plants.

Most of the water used in a steam-electric power plant is for condenser cooling. Small quantities of water are also required for boiler feed makeup, and in the case of coal and lignite fueled plants, for flue gas scrubbing for air pollution control, dust control at the fuel handling facilities, and for ash removal. Lignite fueled plants generally are at the site of the mine. Water is also used in the mining operations. The most commonly used cooling systems are recirculating cooling reservoirs, evaporative cooling towers, once-through cooling systems, and multipurpose reservoirs used as cooling reservoirs. The water removing the heat from the generating plant is recirculated through evaporative cooling towers or cooling reservoirs or is discharged into a reservoir with only a small portion of the same water being recirculated through the electric plant. From 20 to 60 gallons of water are circulated through the plant condenser for each kilowatt-hour of electricity produced. Consumptive, or evaporative, water requirements for power plant cooling typically range from one-third to one-half gallon of water for each kilowatt-hour of electricity produced (TDWR, 1984).

Hydroelectric Power

Hydroelectric power has a number of advantages over thermal electric plants. Water is a renewable resource while natural gas and coal reserves are being depleted. Operation and maintenance costs associated with hydroelectric power are minimal compared with thermal electric plants. Hydropower does not have air pollution and safety problems associated with coal and nuclear plants. Hydroelectric plants can assume load rapidly and are very efficient for meeting peak demand power needs. Availability of water is generally the limiting factor in hydroelectric power generation. Hydroelectric plants are generally used to complement the other components of an overall power system. Hydroelectric power is used for peak load while thermal plants supply the base load. Hydroelectric plants provide effective backup for when emergencies or other operating problems shut down thermal plants. The rising cost of fossil fuel during the 1970's has focused attention on increasing hydroelectric power generation at existing projects, both nationwide and in Texas.

Hydroelectric power plays a relatively minor role in the overall production of electrical energy in the state. Natural gas accounted for 86.5 percent of the electricity produced in the Electrical Reliability Council of Texas in 1978, with coal accounting for 11.1 percent, and hydroelectric power providing only 0.6 percent (U.S. Army Corps of Engineers, 1981). Hydroelectric power is primarily surplus power used to provide for peak loads. Insufficient available streamflow limits the amount of energy that can be produced by hydropower in the state. Hydropower is generally limited to releases which complement other project purposes while minimizing competition with the other purposes for limited available water.

Electrical power is measured in units of megawatts (MW). Electrical energy is expressed in terms of megawatt-hours (MWH) or thousand megawatt-hours (GWH), where a megawatt-hour is defined as one megawatt of power delivered for one hour. Hydroelectric power is derived from the conversion of the mechanical energy of falling water to electricity through the use of turbines and generators. Consequently, the head differential between the upstream water surface and the downstream water surface after passage through the hydroelectric plant is important. The gross head is the difference in elevation between water surface upstream and downstream of the plant. The net or effective head is the head actually available for the generation of electricity. The effective head is the gross head reduced by hydraulic losses resulting from friction, entrance conditions, and so forth.

The plant capacity is the maximum power that can be realized under conditions of normal head and full flow. This is essentially the name plate capacity of the installed operating units. Firm or dependable power is the output that a plant can provide essentially all the time. Firm power is based on critical low streamflow or other minimum conditions of water availability. Surplus or secondary power is all power available in excess of firm power.

The amount of power required by an electric system is time variant. A load curve is a plot of power supplied versus time. The base load is the minimum power reflected on the load curve. The base load represents the minimum firm power that must be available. The peak load is the maximum amount of power supplied. This represents the minimum capacity that must be available to the utility to insure continuous service. The average load is the constant power that would provide the same total energy as the load curve over the given period of time. The plant factor is the ratio of the plant's average load during a year to the plant's installed capacity.

The 21 hydroelectric power plants in Texas are listed with pertinent data in Table 16. The information in the table is primarily from the Regional Reports of the National Hydroelectric Power Resources Study (U.S. Army Corps of Engineers, 1981). The hydroelectric plant on the United States side at Amistad Reservoir, which became operational in 1983, was not included in the referenced reports but is included in Table 16. Mexico also undertook construction of a hydroelectric plant at Amistad Reservoir in 1983 which is not included in the table. Red Bluff was also not included in the referenced reports but is listed in the table. The

TABLE 16
HYDROELECTRIC GENERATING PLANTS IN TEXAS

Dam	Reservoir	Stream	Effective Head (feet)	Capacity (MW)	Average Annual Energy (GWH)	Plant Factor
Lower Colorado River Authority Projects						
Alvin Wirtz	LBJ	Colorado	86	45.0	86	0.21
Buchanan	Buchanan	Colorado	131	22.5	67	0.33
Inks	Inks	Colorado	60	12.5	46	0.42
Mansfield	Travis	Colorado	170	67.5	200	0.34
Max Starke	Marble Falls	Colorado	56	30.0	56	0.21
Tom Miller	Austin	Colorado	61	13.5	70	0.59
Guadalupe-Blanco River Authority Projects						
Abbott TP-3	McQueeny	Guadalupe	30	2.8	9	0.37
TP-1	Dunlap	Guadalupe	46	3.6	14	0.43
TP-5	Molte	Guadalupe	26	2.5	7	0.33
Seguin	TP-4	Guadalupe	28	2.4	8	0.38
H-4	H-4	Guadalupe	26	2.4	8	0.37
H-5	H-5	Guadalupe	28	2.4	8	0.37
Brazos River Authority Project						
Sheppard	Possum Kingdom	Brazos	126	22.5	82	0.41
Sabine River Authorities of Texas and Louisiana Project						
Toledo Bend	Toledo Bend	Sabine	72	81.0	215.0	0.30
Red Bluff Water Power Control District Project						
Red Bluff	Red Bluff	Pecos		2.3		
Central Power and Light Company Projects (Rio Grande River Basin)						
Eagle Pass	None	Canal	81	9.6	50.0	0.59
International Boundary and Water Commission Projects						
Falcon	Falcon	Rio Grande	180	31.5	87.5	0.32
Amistad	Amistad	Rio Grande		66.0		
U.S. Army Corps of Engineers Projects						
Denison	Texoma	Red	92	70	244.0	0.39
Whitney	Whitney	Brazos	92	30	72.4	0.27
Sam Rayburn	Sam Rayburn	Angelina	92	52	127.6	0.28

national hydropower study reports are organized by Electric Reliability Council regions. Most of Texas is in the Electric Reliability Council of Texas region with the remainder in the Southwest Power Pool. Part of the power generated at Toledo Bend Reservoir is sold in Louisiana. The remainder of the hydroelectric power generated in Texas is used in the state.

In 1980, total flow through the turbines of the state's hydroelectric power plants exceeded 11 million acre-feet (TDWR, 1984). Although large volumes of water are used for hydroelectric power generation, the water is not consumed and is usually used downstream for other purposes after passing through the turbines. At several of the hydroelectric plants, reservoir water diverted through the turbines is strictly limited to releases being made for other water supply or flood control purposes as well. At some projects, hydropower releases may be in excess of those needed for other purposes, but the multiple purposes are still closely coordinated. Several of the hydroelectric plants are located downstream of other plants such that the same water flows through two or more turbines.

As indicated in Table A-2, several public agencies and a utility company own and operate hydroelectric power projects in the state. All of the public agencies are responsible for multiple purpose reservoir operation. Thus, the hydropower plants are operated in coordination with other project purposes. Most of the plants are components of multiple reservoir as well as multiple purpose systems.

The Lower Colorado River Authority (LCRA) operates six hydroelectric plants as components of both its multiple purpose reservoir system and its electrical generating system. LCRA sales electricity to eleven electric cooperatives serving 33 cities and 41 counties in Central Texas. The electricity is generated by two natural gas fueled plants, a lignite fueled plant, and six hydroelectric plants. In the early decades after creation of LCRA in 1934, most of its electricity was generated by hydropower. However, hydroelectric generation is now a byproduct of releases for downstream water supply uses. Hydropower now supplies 7 percent or less of the electricity produced by LCRA. Sales of electricity account for 96% of LCRA's revenues. More than 80 percent of LCRA's operations and maintenance costs is for fuel to run the thermal generating plants (LCRA, 1984).

The Guadalupe-Blanco River Authority owns and operates six small hydroelectric power plants on the Guadalupe River. These are essentially run of the river facilities with minimal water storage capacity. Flood control releases from Canyon Reservoir, runoff below Canyon Reservoir, and flows from Comal Springs provide water for operating the hydropower plants.

Toledo Bend Reservoir is operated jointly by the Sabine River Authorities of Texas and Louisiana. Several utility companies in both Texas and Louisiana have contracted with the two river authorities for the power generated by the project. The utilities pay an aggregate sum of money each year for the power. The portion of the reservoir between elevations 162.2 and 172.0 is designated as the power pool. Subject to the availability of water in this pool, releases are made through two turbines to generate the specified amount of energy during the period May to September each year. To the extent practical, releases for hydropower are scheduled to coincide with downstream municipal and industrial water demands.

Power generated at federal projects are marketed through agencies under the Department of Energy. The Rio Grande River Basin, which includes Falcon and Amistad Reservoirs, lies within the geographical jurisdiction of the Western Area Power Administration (WAPA). The three Corps of Engineers hydroelectric power projects, Texoma, Whitney and Sam Rayburn, are in the geographical area covered by the Southwestern Power Adminstration (SWPA). These agencies are required by law to market energy in such a manner as to encourage the most widespread use at the lowest possible rates to customers consistent with sound business principles. Preference is given to public bodies and cooperatives. SWPA and WAPA operate through contracts and agreements with other electric utilities. The electricity generated at the federal projects is sold to local electric cooperatives and utility companies by the SWPA or WAPA under various contractual arrangements. The reservoirs are operated in accordance with the agreements. For example, a contract between the federal government and the Sam Rayburn Dam Electric Company specifies that to the extent that water is available in the power pool at Sam Rayburn Reservoir, the Corps of Engineers will make releases sufficient to generate a specified minimum amount of power for a minimum number of hours each month for the period mid-April through mid-October of each year.

The SWPA directly operates 23 Corps of Engineers hydroelectric power plants in a seven-state region and obtains power from five other projects through contractual arrangements. All but four of the plants are included in an interconnected system. The three hydropower plants in Texas are among the four not included in the interconnected system. The electricity generated at Whitney, Sam Rayburn, and Texoma Reservoirs is used to serve specific customer loads in Texas (SWPA, 1984).

All releases at Falcon and Amistad Reservoirs are made for purposes of flood control and downstream water supply. However, to the extent practical, the releases are routed through the hydroelectric plants. Releases are normally not made specifically for hydropower.

The Denison Dam and Texoma Reservoir project was constructed primarily for flood control and hydroelectric power. The reservoir also provides municipal and industrial water supply. However, most water supply withdrawals are pumped from the reservoir, not released downstream. Thus, unlike the other hydroelectric projects in Texas, releases from the power pool are made solely to generate power. Downstream water rights require certain releases, but these are almost always significantly exceeded by water being released anyway for hydropower. Releases from the flood control pool are also used to generate power to the extent practical. For many years, the power generated at Denison Dam was sold in both Oklahoma and Texas. Recently, the transmission facilities and contractual arrangements have been changed so that all the power is sold in Texas (SWPA, 1984).

Instream Flow Maintenance

Instream flow needs include maintenance of sufficient streamflow for water quality, fish and wildlife habitat, livestock water, river recreation, and aesthetics. Water law and reservoir operation practices have traditionally favored offstream needs over instream needs. Releases for hydroelectric power and also water supply releases which are withdrawn from the river for municipal, industrial, or agricultural use at significant distances below the dam contribute to instream environmental needs as well. Operating procedures for some reservoirs include providing minimum instream flow levels for maintenance of fish and wildlife habitats. Some reservoirs have multi-level outlet works which allow selective blending of discharge waters for optimal downstream water quality. Reservoir release schedules have also been studied for maintenance of freshwater inflows to bays and estuaries.

Flood Control Operations

Whereas conservation operations throughout the state are the responsibility of a multitude of entities, the responsibility for flood control operations is highly centralized. The International Boundary and Water Commission is responsible for flood control operations of Falcon and Amistad Reservoirs on the Rio Grande River. These two multiple purpose projects contain 2.7 million acre-feet of flood control storage. The 12,600 acre-foot Olmos Reservoir is a flood control only project owned and operated by the City of San Antonio. It is the smallest, oldest, and only nonfederal project of the major reservoirs containing flood control storage. The U.S. Army Corps of Engineers is responsible for the 15.9 million acre-feet of flood control capacity in the remaining 32 flood control reservoirs.

The discussion here is limited to controlled storage. Releases are controlled by the operator through the use of spillway and outlet works gates. All of the large flood control reservoirs have gated spillways and/or outlet works. Numerous other small uncontrolled flood retarding and detention basin structures are in use throughout the state. The ungated outlet structures are designed with limited discharge capacities which result in outflow rates being less than inflow and storage occurring during a flood event. Streamflows are automatically reduced without requiring release decisions to be made by an operator. These small uncontrolled flood control reservoirs are not addressed in this report.

Corps of Engineers Reservoirs and Organizational Structure

The Corps of Engineers is organized with geographical divisions which are further subdivided into districts. District offices report to division offices which in turn report to the Office of the Chief of Engineers in Washington. Texas is located in the five-state Southwestern Division. The division office is in Dallas. The Galveston District is responsible for Corps of Engineers activities in the coastal area of the state. Tulsa District includes the Canadian and Red River Basins. The remainder of the state is in the geographical jurisdiction of the Fort Worth District. The Corps of Engineers operates and maintains the reservoir projects which it has constructed. The Corps of Engineers is also responsible for flood control operations at projects constructed by the Bureau of Reclamation. These projects are actually operated and maintained by local sponsors in association with the Bureau of Reclamation. However, whenever water is in the flood control pool, releases are made as directed by the Corps of Engineers.

The Corps of Engineers reservoir projects can be categorized as follows. The Galveston District owns and operates Addicks and Barker Reservoirs, which are flood control only projects with a combined capacity of 411,500 acre-feet. Texoma and Pat Mayse are multiple purpose reservoirs with 2.7 million acre-feet of flood control capacity which are owned and operated by the Tulsa District. Lake Kemp was originally constructed and continues to be owned and operated by the City of Wichita Falls. In 1974, the Tulsa District completed reconstruction of the dam to insure its safety and to provide a specific allocation of 284,300 acre-feet for flood control. The City makes releases from the flood control pool of Lake Kemp as directed by the Tulsa District. Lake Meredith was constructed by the Bureau of Reclamation and is operated by the Canadian River Municipal Water Authority. Releases from the 543,200 acre-foot flood control pool are made as directed by the Tulsa District. Travis and Twin Buttes likewise were constructed by the Bureau of Reclamation and are operated by the Lower Colorado River Authority and City of San Angelo, respectively. The Fort Worth District is responsible for releases from the flood control pools which have a combined capacity of 1.2 million acre-feet. The Fort Worth District owns and operates the following 21 multiple purpose reservoirs which contain a total of 10.2 million acre-feet of flood control capacity: Wright Patman, Whitney, Rayburn, Belton, Waco, Lewisville, Stillhouse Hollow, Canyon, Somerville, Lake O' the Pines, Proctor, Fischer, Lavon, Grapevine, Benbrook, Granger, Navarro Mills, Georgetown, Aquilla, Bardwell, and Hords Creek. Lake O' the Pines and Wright Patman Reservoirs were operated by the New Orleans District until 1979 when jurisdiction for the Texas portions of the Cypress Creek and Sulphur River Basins were transferred to the Fort Worth District. Ray Roberts, Joe Pool, and Cooper Reservoirs are multipurpose projects with 519,300 acre-feet of flood control capacity which are presently under construction by the Fort Worth District.

The Fort Worth District is responsible for about 58 percent of the flood control storage capacity of the major reservoirs in the state. Fort Worth, Tulsa, and Galveston Districts operate a total of about 86 percent of the flood control storage capacity.

A reservoir control center in the Southwestern Division office in Dallas provides overall management and coordination of reservoir operation activities in the several districts of the division. The district offices are responsible for the actual operation of the reservoirs. Each district organization includes an operations division responsible for operation and maintenance of completed projects. However, real-time reservoir regulation and associated water control activities are the responsibility of a reservoir control unit which is a part of the hydraulics and hydrology branch of the engineering division. Thus, a central reservoir control organization within the district office is responsible for determining the releases to be made at all of the reservoirs within the district. Reservoir managers and supporting personnel at the individual reservoir projects operate the spillway and outlet works gates as instructed by the district office. Telecommunications between the reservoir control unit and the reservoir project offices occur at least daily and can be essentially continuous during major flood events. Emergency operating procedures are established for each project as a contingency in case communications should be disrupted during a flood.

The reservoir control unit in a Corps of Engineers district office works closely with the appropriate National Weather Service (NWS) river forecast center. In the Fort Worth District, the reservoir control unit and NWS river forecast center are housed on the same floor of the federal office building. The reservoir control unit is also supported by other technical and administration elements within the district office.

The projects have two general types of outlet structure configurations. A number of the projects have an uncontrolled broadcrested or ogee spillway, with the crest elevation at the top of flood control pool, combined with an outlet works structure consisting of a gated intake structure, conduit through the dam, and downstream stilling basin. The gates are located at various depths below the top of conservation pool. Other projects have a controlled spillway with a set of several tainter gates. Tainter gates (also called radial gates) rest upon the spillway crest when fully closed. A gate is opened by lifting, with the water flowing under the gate and over the spillway crest. Controlled releases from the flood control pool are made by raising the tainter gates. Sluices with gates at lower elevations are also provided for relatively small releases. An uncontrolled overflow section is provided at the top of the flood control pool at some projects having a controlled principal spillway.

Flood control and conservation pools in a multiple purpose reservoir are designated by set pool elevations. The top of conservation (bottom of flood control) pool, top of flood control pool, and maximum design water surface are key pool levels or elevations in flood regulation schedules. Releases are made from the conservation pool for water supply purposes at the request of the local sponsors which have contracted for the storage. The flood control pool is the space between the top of conservation pool and the top of flood control pool. Releases from the flood control pool are regulated by opening and closing spillway and/or outlet works gates. For a project with an uncontrolled spillway, the crest elevation is set at the top of flood control pool. For a controlled spillway, an uncontrolled spillway section with the crest at the top of flood control pool may be provided for overflows. Flood waters above the top of flood control pool cannot be controlled but rather must be discharged through the spillway. Discharges are proportional to the head or depth of the water above the spillway crest and are physically limited to the capacity provided by the particular spillway configuration. Surcharge storage occurs whenever the flood control pool is full and inflows exceed discharges through the spillway. The maximum design water surface is the critical condition for which the dam and appurtenant structures were designed. The structural integrity of the dam could be threatened if flood waters rose above the maximum design water surface. Consequently, release policies are predicated on never under any circumstances allowing surcharge storage to exceed the design water surface.

Reservoirs designed and constructed by the Corps of Engineers are normally sized to contain a flood with an associated recurrence interval in the range of 50 to 100 years, or in some cases greater, without exceeding the capacity of the flood control pool. Consequently, filling to the top of flood control pool is an infrequent event. Many of the projects have never had the flood control pool completely full. This is not necessarily the case for multipurpose projects constructed by others for which the Corps of Engineers is responsible for flood control operations.

<u>Corps of Engineers Operating Procedures</u>

Each project has operating procedures which are documented in a reservoir regulation manual. A regulation schedule specifies the releases to be made under various conditions. Formulation or modification of a plan of operation requires extensive hydrologic, hydraulic, economic, and environmental studies. The plan of operation is established during project planning and design. Modifications in the operating procedures for operational projects are made as required to reflect experience gained in actual operation or changed conditions such as construction of additional projects in the basin. However, operation procedures tend to remain fairly constant over time.

Flood control regulation schedules are developed to address the particular conditions associated with each individual reservoir and river basin. Peculiarities and exceptions to standard operating procedures occur at various projects. However, the regulation schedules for all the projects were developed following essentially the same guidelines, as outlined in the Corps of Engineers manual on reservoir regulation, EM 1110-2-3600 dated May 1959, and have the same general strategy. An overview of flood control operating procedures is provided below.

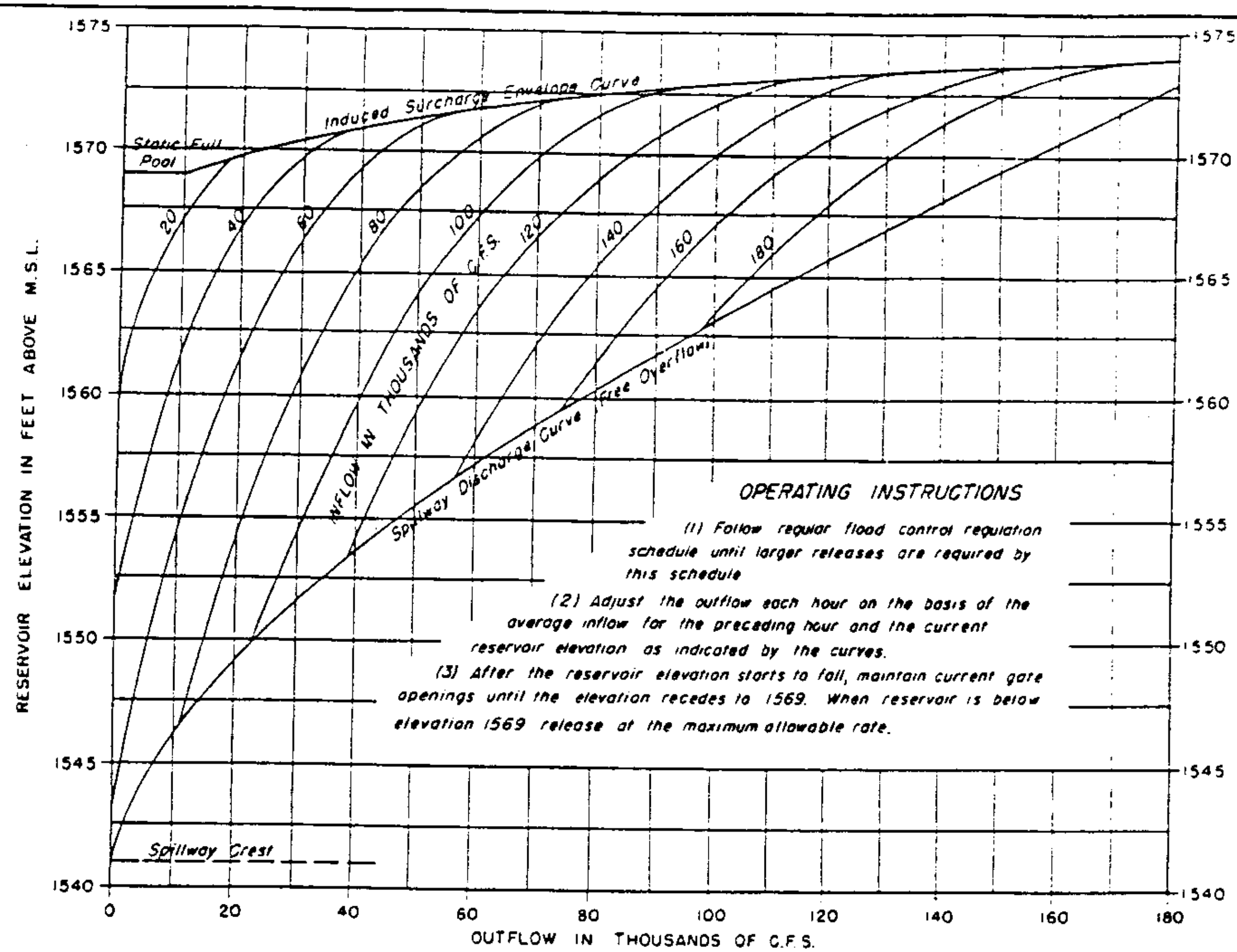
The flood control regulation schedule for a reservoir actually consists of two schedules. Both schedules are followed, and the one requiring the largest release rate controls for a given set of conditions. The regular schedule, which usually controls, is based on the assumption that ample storage capacity is available to handle the flood without special precautions being necessary to prevent the water surface from rising above the top of flood control pool. Operation is switched over to an alternative schedule during extreme flooding conditions when the anticipated runoff from a storm is predicted to exceed the controlled capacity remaining in the reservoir. If the water surface level significantly exceeds the top of flood control pool, downstream damages will necessarily occur. The objective is to assure that reservoir releases do not contribute to downstream damages as long as the storage capacity is not exceeded. However, for extreme flood events which would exceed the reservoir storage capacity, moderately high damaging discharge rates beginning before the flood control pool is full are considered preferable to waiting until a full reservoir necessitates much higher release rates.

An example regulation schedule taken from EM 1110-2-3600 is reproduced in Figure 8 to illustrate the general procedure. This type of schedule has been developed for each flood control reservoir to guide real-time flood operations whenever the storage capacity is predicted to be exceeded. In this case, release decisions are based on a current reservoir water surface elevation and inflow. The required outflow for a given reservoir elevation and inflow is read from the graph. If this outflow is less than that specified by the regular schedule, the regular schedule is followed. Otherwise, the gates are operated to release the outflow indicated by the graph.

The schedule shown in Figure 8a is formulated in terms of reservoir surface elevation, inflow, and outflow. The alternative schedule reproduced in Figure 8b reflects the same concepts but rate of rise is substituted for inflow. Rate of rise in reservoir elevation is computed directly from inflow, outflow, and change in storage. The inflow (Figure 8a) form of the schedule is normally used. Reservoir inflows are readily available to the personnel of the reservoir control unit. The rate of rise (Figure 8b) form of the schedule is provided primarily for emergency use by project personnel if communication with the reservoir control unit is interrupted. Reservoir inflow data may not be available at the project, but water surface elevations from which rate of rise is determined are readily measured and always available.

The family of curves presented in the figure represent a compromise between two conflicting considerations in regard to handling extreme flood events which would significantly exceed the flood control storage capacity of the reservoir. The regular schedule discussed below is based on not making releases unless downstream streamflows are below damaging levels. This regular schedule conceivably could be followed until the flood control pool fills. However, after the flood control pool is full, tremendously high discharge rates may be required to prevent the surcharge storage from exceeding the design water surface. The much higher peak release rate necessitated by this hypothetical operation policy can be expected to be much more damaging than a lower release rate with a longer duration beginning before the flood control pool is full. On the other hand, an operator would not want to make damaging releases early in a storm and later find that a portion of the flood control pool remained empty during the storm. Although streamflows that will occur several hours or days in the future are typically forecast during real-time operations, future flows are still highly uncertain.

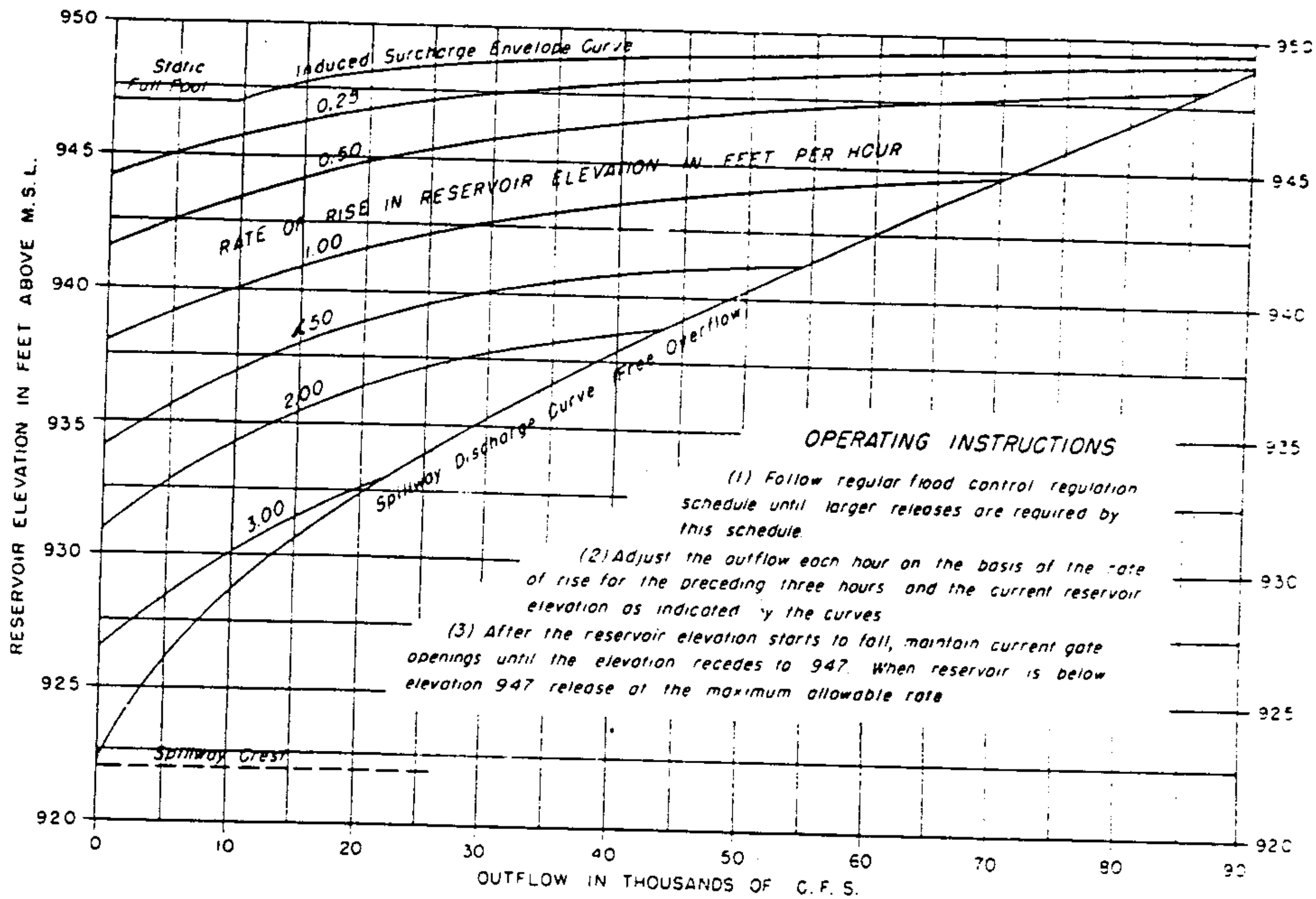
The regulation schedule curves are developed based on estimating the minimum volume of inflow that can be expected in a flood, given the current inflow rate and reservoir elevation. Having estimated the minimum inflow volume to be expected during the remainder of the flood, the outflow required to limit storage to the available capacity is determined by mass balance computations. For a given current inflow rate, the minimum inflow volume for the remainder of the storm is obtained by assuming the inflow hydrograph has just crested and computing the volume under the recession side of the hydrograph. For conservatively low inflow volume estimates, the assumed recessive curve is made somewhat steeper than the average observed recession. The complete regulation schedule which allows



SPILLWAY GATE REGULATION, SCHEDULE A

Source: U.S. Army Corps of Engineers (1959)

Figure 8a
Example Reservoir Regulation Schedule



SPILLWAY GATE REGULATION, SCHEDULE B

Source: U.S. Army Corps of Engineers (1959)

Figure 8b
Example Reservoir Regulation Schedule

the outflow to be adjusted on the basis of the current inflow and empty storage space remaining in the reservoir is developed by making a series of computations with various assumed values of inflows and amounts of remaining storage available.

As previously indicated, the flood control regulation schedule for a reservoir actually consists of two schedules. The regular schedule is followed as long as the indicated releases are greater than the outflow values read from the graph discussed above. The regular schedule is based on downstream flooding conditions. Nondamaging flow rates and stages are specified at selected index locations, called control points, which are representative of the damage potential in the associated reach of channel and flood plain. Nondamaging flow rates are equal to or closely related to bankful stream capacities. U.S. Geological Survey stream gaging stations are located at the control points. Releases are made to empty the flood control pool as quickly as possible without exceeding the allowable flow rates at each downstream control point. The regulation schedule consists of specified flow rates to be maintained at the designated control points.

When a flood occurs, the spillway and outlet works gates are closed. The gates remain closed until a determination is made that the flood has crested and flows are below the nondamaging levels specified for each of the control points. The gates are then operated to empty the flood control pool as quickly as possible without exceeding the allowable flows at the control points. Normally, no flood control releases are made if the reservoir level is at or below the top of conservation pool. However, if flood forecasts indicate that the inflow volume will exceed the available conservation storage, flood control releases from the conservation storage may be made if downstream conditions permit. The idea is to release some water before the stream rises downstream, if practical, for a forecasted flood.

For many reservoirs, the allowable flow rate associated with a given control point is constant regardless of the reservoir surface elevation, assuming the outflow still exceeds the value specified by the previously discussed graph illustrated by Figure 8. At other projects, the flood control pool is subdivided into two or three zones with the allowable flow rates at one or more of the control points varying depending upon the level of the reservoir surface with respect to the discrete alternative zones. This allows stringently low flow levels to be maintained at certain locations as long as only a relatively small portion of the flood control pool is occupied, with the flows increased to a higher level, at which minor damages could occur, as the reservoir fills. The variation in allowable flow rates at a control point may also be related to whether the reservoir level is rising or falling.

A reservoir is operated based on maintaining flow rates at several control points located various distances below the dam. The most downstream control points for a number of projects are well over a hundred miles below the dam. Lateral inflows from uncontrolled watershed areas below the dam increase with distance downstream. Thus, the impact of the reservoir on flood flows decreases with distance downstream. Operating to downstream control points requires streamflow forecasts. Flood attenuation and travel time from the dam to the control point and inflows from watershed areas below the dam must be estimated as an integral part of the reservoir operating procedure.

Most of the flood control reservoirs are components of basinwide multireservoir systems. Two or more reservoirs located in the same river basin will have common control points. A reservoir may have one or more control points which are influenced only by that reservoir and several other control points which are influenced by other reservoirs as well. Reservoirs in a system are operated, to the extent practical, to maintain approximately the same percentage of flood-control storage utilized in each reservoir. Releases from all reservoirs, as well as runoff from uncontrolled watershed areas, must be considered in forecasting flows at control points.

Maximum allowable rate of change of reservoir release rates are also usually specified. Abrupt gate openings causing a flood wave with rapid changes in stage are undesirable.

The top of conservation and flood control pool elevations are established during project planning and design and normally remain constant thereafter. A multipurpose reservoir operating policy in which conservation and flood control operations are differentiated by a designated top of conservation (bottom of flood control) pool elevation is sometimes referred to as a rule curve. The rule curve essentially specifies the top of conservation pool elevation, which in general may vary monthly or seasonally. However, all the multiple purpose flood control reservoirs operated by the Corps of Engineers in Texas, except two, have constant top of conservation pool elevations with no seasonal variation. Lake O' the Pines and Wright Patman Lake, in the northeast corner of the state, are the two projects with seasonal rule curves. The operating rule curve for Lake O' the Pines provides for raising the top of conservation pool 1.5 feet from mid-May through mid-September for recreation purposes. The operating rule curve for Wright Patman varies significantly during the year in response to an interim operating agreement with the conservation storage sponsor to provide additional municipal and industrial water supply. The top of conservation pool is constant from November through March and varies with date from April through October. The top of conservation pool peaks on June 1 at a level 6.9 feet above the winter pool level.

Other Projects

The International Boundary and Water Commission operates Falcon and Amistad reservoirs with designated flood control pools similar to the Corps of Engineers. Top of conservation and flood control pool elevations are set and normally used in operating the reservoirs. The top of conservation pool elevations can be, at the discretion of the Commission, temporarily raised for seasonal rule curve type operation. However, the optional encroachment into the flood control pool does not necessarily occur routinely each year and the magnitude of encroachment can be varied within a fixed maximum limit. Flood control operations are based on storing as much flood water as possible without endangering the integrity of the dam.

Olmos Reservoir, located on Olmos Creek, is owned and operated by the City of San Antonio. Impounded flood waters are stored until releases can be made without damaging downstream property. During nonflood periods when the reservoir is empty, the pool area serves as a park and playground.

Problems, Issues, and Directions

Determining the amount of water to store and to release or withdraw from a reservoir or system of several reservoirs is a complex decision-making process involving numerous physical, hydrologic, environmental, economic, legal, institutional, political, and public relations considerations. Each reservoir project or system has its particular operating complexities and difficulties. Several major issues and problem areas pertinent to reservoir operation in general in the state are cited in this subsection. Present and potential future directions in reservoir operations are also discussed.

Reservoir Operating Problems

An unmanageable water rights system has been a major complicating factor in operating reservoirs in Texas. As previously discussed, the complications of having various forms of riparian and appropriative rights on the same stream has been a significant difficulty in managing the surface water resources of the state. As late as 1968, no single state agency had a record of the number of riparian water users in any major river basin, the extent of their claims, or the amount of water they were using. The Water Rights Adjudication Act was passed in 1967 to remedy the confused surface water rights situation. The adjudication process was essentially completed in 1984. A number of appeals are still undecided. For example, the Lower Colorado River Authority (LCRA) maintains the position that based on the Texas water law tradition of "first in time, first in right", the agency holds rights to water now in the Colorado not held by other claims in 1934 when the agency was created (LCRA, 1984). A preliminary decision by the Texas Water Commission in 1982 confirmed LCRA's claimed rights to use water for hydroelectric power generation but limited its rights for municipal, industrial, and agricultural uses. The water rights granted were adequate to serve present commitments but limited potential future additional sale of water. LCRA appealed the decision, and a final determination of water rights has not been made.

The new permit system should greatly enhance surface water management. Many conflicts over water rights have been resolved. The quantities of water for which various entities hold permits are known. Estimates of the amount of water still available for future water rights appropriations are also known. In some river basins, such as the Rio Grande, essentially all of the firm yield has been committed to users through the permit system. In portions of the other basins, such as the Sabine, significant amounts of water remain for future appropriation.

A major problem at the present time is assuring that water is actually used as allocated on paper. The Rio Grande is presently the only river basin with a water master system. Other basins will likely have water masters in the future. Without a strict enforcement and accounting system, the water may not necessarily be actually used in accordance with the adjudicated water rights or permits issued. Currently, unauthorized withdrawals are likely to not be detected until someone complains to the Texas Department of Water Resources.

Evaporation and sedimentation are natural processes which adversely affect reservoir operation. Nature collects a tax on stored water in the form of evaporation. Over four million acre-feet of water per year is evaporated from the major reservoirs of Texas. This is a very significant water loss when compared to the seven million acre-feet per year of surface water used for beneficial municipal, industrial, and agricultural purposes.

Rivers in Texas transport large volumes of sediment produced by erosion in the contributing watersheds, particularly during major rainfall and flood events. Streambank erosion and aggradation also occurs. Reservoirs in Texas are efficient sediment traps. Accumulation of sediment deposits significantly reduces reservoir storage capacity over time. Reservoir design typically includes providing additional capacity to accommodate 100 years of sedimentation.

Hydroelectric power operations typically involve frequent relatively rapid fluctuations in reservoir pool levels and release rates. Erosion of the reservoir shoreline and downstream channel banks sometimes accompany hydropower releases. Complaints are not uncommon from downstream riparian property owners concerned about losing their land to streambank erosion. Due to the reservoir acting as a sediment trap, reservoir releases have a lower suspended sediment load and correspondingly greater erosion capacity than unregulated streamflow. This adds to the problem of hydropower releases causing downstream erosion.

Downstream channel encroachments and other limitations on channel capacities are a major problem for flood control operations. An inhouse study conducted by the Corps of Engineers several years ago revealed that practically all the flood control projects have constraints affecting water contol operations. The most common type of constraint was inadequate downstream channel capacity. Flood control release schedules are developed based on establishing nondamaging discharges at representative downstream control points. Subsequent to a flood event, the flood control pool is emptied as rapidly as possible without exceeding those allowable discharges. Retaining water in the flood control pool reduces the capability to control subsequent flood inflows. The problem is that the reservoir managers often receive complaints that someone is being damaged or inconvenienced and wants the release rates to be lowered. The problems could be caused by an incorrect initial estimate of nondamaging discharge levels, decrease in channel capacity due to natural erosion and aggradation processes, or encroachments as people locate activities near or in the river. In some situations, someone will be adversely affected to some extent by almost any discharge level.

Flood control operations are based on reducing peak flows which means that reservoirs result in longer flow durations at lower flow rates. In some cases, people would prefer an uncontrolled high magnitude but short duration flood. For example, a low water crossing for a road might be inundated much longer with than without a flood control reservoir. People are concerned about how many days the road is closed rather than the peak depth of inundation. Streambank caving is also sometimes attributed to maintaining bankful flows for long periods of time. Extended duration flows can also delay drainage of water ponded behind levees.

Changing Conditions

Rapid population and economic growth and depleting groundwater reserves are resulting in continually increasing demands being placed upon the surface water resources of the state. However, economic, financial, political, and environmental feasibility of constructing new reservoirs is much more difficult to achieve now than in the past. The past construction era of water resources development has transitioned into the present management era. Consequently, an increased focus on optimizing the operation of existing projects to meet increasing demands can be expected.

Reservoir storage capacities and operating policies are generally established prior to construction and tend to remain constant thereafter. However, public needs and objectives and numerous factors affecting reservoir effectiveness significantly change over the years. The increasing pressure to use existing limited storage capacity as efficiently and beneficially as possible should encourage periodic reevaluations followed, whenever warranted, by changes in reservoir operating policies.

As illustrated graphically in Figure 6, water supply needs are increasing with population and economic growth, and depleting groundwater supplies are resulting in an increasing reliance on surface water. Other factors affecting the effectiveness of reservoir operating policies change over time as well. The economics of alternative sources of electrical energy has focused attention during the past decade on increasing hydroelectric power generation at existing reservoirs through improved operating procedures and/or additional generating units. Watershed and flood plain conditions change over time. Construction of numerous small flood retarding dams by the Soil Conservation Service and other entities in the watersheds of major reservoirs have reduced flood inflows to the reservoirs. Construction of numerous small ponds for recreation or watering livestock have also decreased reservoir inflows and yields. Increased runoff caused by watershed urbanization is significantly contributing to flooding problems in certain locations. The existing flood control reservoirs were planned and designed based on the expectation of ever increasing intensification of flood plain land use. However, the National Flood Insurance Program has resulted in zoning and regulation of 100-year flood plains. With stringent flood plain management, susceptibility to flooding could actually decrease over time as existing activities choose to leave the flood plain and regulation prevents other activities from moving into the flood plain. Reservoir sedimentation reduces available storage capacity. Construction of additional reservoirs, as well as other related types of projects such as conveyance facilities, flood control levees and channel improvements, and electric power plants, affect the operation of existing reservoirs. Technological advancements in hydrologic data collection, streamflow forecasting, system modeling and analysis, and computer technology provide opportunities for refining operating policies.

Multiple Purposes and Uses

Many of the complexities associated with reservoir operation involve allocation of limited storage capacity or water releases to competing purposes and users. Reservoir managers are often in a position of having some users in disagreement regardless of the release decision. Reservoir operation can be a very sensitive issue to citizens affected by a project. Minimizing conflict and dealing with controversy is an integral part of reservoir operation. Some project purposes may be either complementary or conflicting depending on the circumstances. As previously discussed, allocation of water to various municipal, industrial, and agricultural users through the water rights system is a major factor affecting reservoir operation. Several important interactions between water supply and other purposes are cited below.

Water stored for water supply purposes provides an excellent opportunity for recreation. Recreation is enhanced by a constant full conservation pool. Recreation users are detrimentally affected by drawdowns resulting from water supply withdrawals or inundation of boat ramps, camping areas, and other recreational facilities by flood waters temporarily stored in a flood control pool. Minimizing adverse impacts on recreation while fullfilling other project purposes is typically a significant consideration in multiple purpose reservoir operation.

Increasing hydroelectric power generation at existing reservoir projects has received considerable attention during the past decade, both nationwide and in Texas. Investigations continue regarding potentialities for adding more generating units and increasing production from existing units in the state. Most of the water which generates hydroelectric power is released for downstream municipal, industrial, and agricultural water users. Water destined for downstream users is routed through hydroelectric turbines whenever possible. However, with the exception of Texoma Reservoir, little of the total flow through the turbines is released solely for hydroelectric power. Additional savings in natural gas and lignite burned in steam-electric plants could be achieved if additional water was made available for hydroelectric power. Availability of water is the primary limiting factor in hydroelectric power production.

Maintenance of freshwater inflows to bays and estuaries is currently a major issue in Texas. Seven major and several minor estuaries are located along the 400 miles of Texas Gulf coastline. Eleven of the major river basins in the state are associated with these bays and estuaries. The coastal bays and marshlands are areas where seawater from the Gulf of Mexico mixes with freshwater inflows from the rivers to create highly productive and diverse natural environments. The inflow of freshwater is widely recognized as an essential factor in maintaining the biological productivity of Texas bays and estuaries. Freshwater inflows provide nutrients, sediments, and a viable salinity gradient necessary for the survival and vitality of the estuarine biological community including virtually all the coastal fisheries species. Periodic flushing by high inflows inundates river delta marshes, stimulates the cycling of nutrients, transports food materials, and removes or limits many pollutants, parasites, bacteria, and viruses harmful to estuarine-dependent organisms. The seasonal timing of freshwater inflows is very important. Adequate freshwater flow during critical periods is more beneficial to ecological maintenance than abundant flow during noncritical periods. The Texas Department of Water Resources and others have studied the importance of freshwater to each estuarine system in the state, and developed estimates of quantities and seasonal timing of freshwater inflows needed. The role of reservoirs in contributing toward the maintenance of desireable levels of freshwater inflows to the state's bays and estuaries has recently received considerable attention and will likely continue to be scrutinized in the future.

Storage Reallocation

Reservoir operation is based on the conflicting objectives of maximizing the amount of water available for conservation purposes and maximizing the amount of empty space available for storing flood waters. As previously discussed, common practice is to operate a reservoir only for conservation purposes or only flood control or to designate a certain reservoir volume, or pool, for conservation purposes and a separate pool for flood control. Increasing needs for providing water for various uses and for reducing flood damages necessitate that limited reservoir storage capacity be used as beneficially as possible. Consequently, consideration of the interactions and tradeoffs between conservation and flood control operations is becoming increasingly more important. Reallocation of storage capacity between flood control and conservation purposes might be warranted under certain circumstances.

Reallocation of storage capacity between flood control and conservation purposes could be physically implemented simply by lowering or raising the designated top of conservation pool elevation. Storage reallocations could be between pools in a single reservoir or between reservoirs in a multiple reservoir system. Reallocations could be either long-term or seasonal. The division between flood control and conservation storage in a reservoir could be dependent upon the amount of water currently available in other reservoirs in the system or could even consider current soil moisture conditions. Reallocations between flood control and conservation storage capacity could be warranted in two common situations in Texas: (1) conversion of a portion of the capacity in a conservation only reservoir to flood control, and (2) conversion of a portion of the flood control capacity in a multipurpose reservoir to conservation.

Flood control in Texas has generally been viewed as a federal responsibility. Practically all the flood control storage capacity in the state is owned and operated by federal agencies. Difficulties in financing flood control have been a major reason that reservoirs constructed by state and local entities have not included storage capacity designated for flood control. However, national water policy currently emphasizes shifting responsibilities from the federal government to the states. Consequently, the state could assume a greater role in flood control in the future which could stimulate interest in operating nonfederal reservoirs for flood control. Although new institutional arrangements might be necessary, the numerous conservation only projects in the state could conceivably also be operated for flood control. Corps of Engineers reservoirs are usually designed to contain at least 50 to 100-year recurrence interval floods without overtopping the flood control pool. Providing this degree of protection by reallocating a portion of the storage capacity in a conservation reservoir to flood control would normally not be practical due to the large storage volume required. However, lesser degrees of protection could possibly be provided while still maintaining significant conservation storage capacity.

Reallocation of a portion of the flood control storage in a multiple purpose reservoir to conservation might also be warranted under suitable conditions. Several such reallocations have occurred in conjunction with construction of new projects. Upon completion of construction of Ray Roberts Reservoir, a portion of the flood control capacity in Lewisville Reservoir will be reallocated to water supply. Flood control capacity in Ray Roberts Reservoir will compensate for the reallocation in Lewisville Reservoir. Likewise, a reallocation of flood control to conservation capacity is planned for Wright Patman Reservoir upon completion of construction of Cooper Reservoir. In the interim awaiting completion of Cooper, a seasonal rule curve was implemented for Wright Patman in 1968 in which the designated top of conservation pool is raised during certain months of the year to provide additional water supply storage.

Increasing needs for conservation purposes could also justify storage reallocations in cases where new reservoirs are not compensating for the reduction in flood control capacity. For Corps of Engineers projects, the Office of the Chief of Engineers in Washington has the discretionary authority to approve storage allocation changes involving not greater than 15 percent of total storage capacity allocated to all authorized federal purposes or 50,000 acre-feet, whichever is less. Greater changes would require authorization by the U.S. Congress. The local project sponsor would have to concur with and in most cases actually initiate the request for any modifications in operating policies. The Corps of Engineers would be responsive to modifying operating policies, if the changes could be clearly demonstrated to be in the public interest, and local interests strongly supported the changes.

In the past, public agencies and water users have not seriously pursued storage reallocation at existing projects as an alternative to developing new projects. At least, if reallocation was considered, it was determined infeasible without detailed study. However, conversion of storage capacity from flood control to hydroelectric power has received some attention in recent years. The National Hydropower Study included reallocation of storage capacity from flood control to hydropower as one of several means for increasing electric energy production (Davis and Buckley, 1984). The Cowanesque Lake Reformulation Study completed by the Corps of Engineers Baltimore District in 1982 recommended conversion of 31 percent of the flood control storage in a major existing multipurpose reservoir to conservation purposes of hydroelectric power and municipal and industrial water supply. In Texas, the top of conservation pool of Sam Rayburn Reservoir was raised 0.4 feet in 1968 to provide additional water supply. A negligible loss of flood control benefits was associated with this very small reduction in flood control storage capacity. An additional even smaller reallocation from flood control to water supply is presently being considered for Sam Rayburn Reservoir. The Brazos River Authority in cooperation with the City of Waco recently requested the Corps of Engineers Fort Worth District to study the feasibility of converting a portion of the flood control storage in Waco Reservoir to conservation for municipal water supply. After studying various alternatives, the Fort Worth District recommended a reallocation of 47,500 acre-feet, or 8.6 percent, of the existing flood control pool to conservation storage by raising the top of conservation pool seven feet. The reallocation proposal has been submitted to the Office of the Chief of Engineers in Washingthn for approval. Denison Dam, which impounds Texoma Reservoir, was constructed in the early 1940's for flood control and hydroelectric power. A small portion of the storage capacity was reallocated to water supply in the 1950's. Additional similar reallocations of Texoma storage capacity have been considered in recent years. At this time, the examples of proposed and actual storage reallocations cited above are somewhat unique. However, municipal, industrial, and agricultural water users and electrical utilities will likely request storage reallocations for other reservoirs in Texas and the nation as increasing demands continue to be placed upon limited water resources.

Expanded Management Strategies and Analysis Capabilities

Flood control operations are based on known reservoir inflows and streamflows at downstream control points. Streamflows at upstream locations and rainfall on contributing watersheds can also be used to forecast streamflows at pertinent locations several hours in advance of actual occurrence. Real-time hydrometeorological data collection is an important aspect of flood control operation. Automated hydrometeorological data collection and management systems represent a major area of technology advancement in reservoir operation. The Fort Worth District of the Corps of Engineers has recently installed data collection platforms at each of the gaging stations used in reservoir operations. Streamflow and rainfall readings are automatically communicated from the platforms via satellite to a computer system which is accessed by the reservoir control unit. The Corps of Engineers Hydrologic Engineering Center in Davis, California has recently developed watershed modeling and data management software which uses rainfall input from an automated data collection system to forecast streamflows at pertinent locations. The Lower Colorado River Authority has also recently installed a hydrometeorological system to monitor their river basin activities. University of Texas researchers are developing a computer software package for optimally utilizing the LCRA hydrometeorological data collection system. Researchers at Texas A&M University are also investigating the use of radar combined with a rainfall-runoff model to forecast streamflows during real-time reservoir operations. Advanced hydrometeorological data collection and streamflow forecasting systems could be particularly useful for operating primarily conservation reservoirs, with very limited flood control storage capacity, to reduce flood damages to the maximum extent possible.

Reservoir operation involves risks and consequences associated with failing to meet various levels of water supply demands and failing to provide various levels of flood protection. Planning, design, and operation of flood control reservoirs has traditionally been based on analyzing the risks (probabilities) and consequences (damages) associated with alternative plans of action. However, plannning, design, and operation of water supply reservoirs has relied primarily on the concept of firm yield to quantify risk. Firm yield does not provide a very meaningful measure of the likelihood of failing to meet various demand levels or the consequences.

Wurbs, Tibbets, Roy, and Cabezas (1985) point out the tremendous gap between research that has been accomplished in developing methods for analyzing reservoir reliability and optimizing release policies and the practices followed in the actual planning, design, and operation of reservoir projects. As the risk of failing to meet demands increase and reservoir operation decisions become more difficult, the potential usefulness of modeling techniques from the disciplines of water resources systems analysis and stochastic hydrology increases. Consequently, systems analysis and hydrologic modeling techniques should play an even greater role in reservoir operation in the future.

A major current water policy emphasis is the need to shift to a greater reliance on demand management and more efficient water use. Demand management is a primary consideration in analyzing the consequences of failing to meet water supply demands. If the relationship between water demands and water supplies becomes critical enough, water conservation in the sense of demand management should be combined with reservoir operation as integral components of a comprehensive water management process. Certain demand management strategies can be implemented essentially independently of supply management. However, certain emergency demand management strategies might be most effective if implemented only during times of water supply shortage. Severe long-term cutbacks in water use may not be warranted if water is flowing over the spillway of a full reservoir most of the time. However, a contingency plan is needed for when the infrequent severe drought does occur. Demand levels need to be reduced as reservoir storage is depleted. A comprehensive water management plan incorporating effective drought contingency measures could help alleviate the adverse consequences of a reservoir failing to meet certain demand levels. A certain degree of calculated risk could then be incorporated into reservoir operating policies.

Water supply operations are based on meeting demands and assuring a long-term dependable yield. Flood control is handled by separate pools, and several reservoirs have designated hydroelectric power pools. In the future, as water supply operation becomes more complicated, secondary yield and zoning of conservation pools may become important. Water supply releases would then be based upon reservoir levels as well as demands. If water is in the upper conservation pool zone, releases would be unrestricted. As the reservoir levels fall below certain levels, releases would be curtailed and alternative plans of action, such as demand management and increased groundwater pumpage, implemented. Thus, the reservoir operating policy would consist of conservation zones and allowable withdrawals associated with each zone.

Comprehensive system management of existing facilities and resources also has potential for reducing the risk of failing to meet water supply needs. The reliable yield which results from the coordinated joint operation of a system of several reservoirs is greater than the sum of the yields of each reservoir operated independently. A widely publicized recent application of this principle occurred in conjunction with supplying water for the Wasington, D.C. metropolitan area (Office of Water Policy, 1983 and USGS, 1983). The area's water supply comes from three rivers involving four reservoirs. The sum of the safe yields of the three sources was estimated to be 513 million gallons per day, but requirements for water was estimated to reach 750 million gallons per day by the year 2000. However, through analysis of the complete system, ignoring institutional constraints related to having three different water agencies, the existing facilities were found to be capable of meeting water supply requirements through the year 2030. The water supply agencies involved then developed the legal and financial agreements necessary to implement flexible and integrated system operations. The improvements in operating efficiency relied heavily upon water resources systems engineering techniques including mathematical optimization and stochastic hydrologic modeling.

The Corps of Engineers is also interested in improved system operation for flood control. A new organization was recently established in the Tulsa District to provide hydrologic and economic computer modeling services to all the districts in the Southwestern Division. A major focus will be on developing basinwide system models for each of the major river basins in the Southwestern Division including those in Texas.

Conjunctive management of surface and groundwater has long been recognized as a potential strategy for increasing the beneficial use of limited water resources. Ground water aquifers are being mined in Texas while reservoirs are full of evaporating water. Although much of the ground water mining occurs in areas in which surface water is not available, considerable potential exists for greater coordination between ground and surface water use as the state shifts to a greater reliance on surface water. Institutional constraints including water law considerations presently severely limit conjunctive mangement. If and when the state moves toward greater institutional control of ground water, conjunctive management of ground and surface water sources can be expected to become a major consideration in reservoir operation.

It is interesting to note that, as somewhat arbitrarily defined in Table 4, the last widespread drought in Texas occurred in the early 1960's. Although record reservoir storage depletions occurred in 1984, this year and the preceding 20 years had relatively abundant precipitation compared to weather conditions in the early 1960's and 1950's. Consequently, little experience has been accumulated in actually operating reservoirs in Texas under severe drought conditions. Under present and projected future conditions of development and water use, expanded management strategies and analysis capabilities are very important for preparing for the next severe drought, while, at the same time, optimizing the present beneficial use of limited storage capacity for the various purposes.

CHAPTER 7
SUMMARY AND CONCLUSIONS

Surface water management in Texas is facilitated by 182 major reservoirs. Five additional reservoir projects are presently under construction. The 187 reservoirs contain conservation, flood control, and total capacities of 40.0 million acre-feet, 18.5 million acre-feet, and 58.5 million acre-feet, respectively. Storage capacities in individual projects range from five thousand to over five million acre-feet. Streamflow in the state is highly variable and subject to extremes of floods and droughts. Consequently, the major reservoirs are essential for controlling and utilizing the surface water resource.

Municipal, industrial, and agricultural water supply and flood control are the predominate project purposes. Although seasonal fluctuations in water availability and use are important, reservoir operation in the state is based primarily on providing protection against the long-term threat of drought and extreme flood events. Water stored for water supply purposes provides an excellent opportunity for recreation. Reservoir recreation is extremely popular and a major consideration in project operations. Much of the hydroelectric power produced in the state is from water routed through the turbines which is destined for downstream municipal, industrial, or agricultural use.

Reservoir development and management is accomplished within a complex system of organizations, programs, laws, and traditions. Reservoir operating policies are determined largely by institutional considerations. Most of the larger reservoirs are owned and operated by state and federal agencies. A number of major reservoirs are owned and operated by cities and private companies. Conservation storage capacity is typically operated in accordance with contractual arrangements between reservoir operators and other entities which supply water or hydroelectric power to the ultimate users. In some cases, the entity which owns and operates the reservoir deals directly with the ultimate users. The allocation and use of surface water is governed by the water law of the state. Reservoir operation is based upon reservoir owners or water users holding legal rights to the use of the water. Whereas a multitude of entities are involved in managing conservation capacity, flood control operations are very centralized. The International Boundary and Water Commission is responsible for flood control operations on the Rio Grande River. The U.S. Army Corps of Engineers operates the storage capacity designated for flood control in the other reservoirs of the state.

Rapid population and economic growth is resulting in ever increasing demands being placed upon the state's water resources and the institutions and facilities which are instrumental in managing the water resources. Depletion of ground water reserves is resulting in an increased reliance on surface water. The rising cost of fossil fuel during the 1970's has focused attention on increasing hydroelectric power generation. Instream flow needs for fish and wildlife habitat and maintenance of fresh water inflows to bays and estuaries are aspects of surface water management which have received increased attention in recent years. Due to a number of economic, environmental, hydrologic, and institutional factors, construction of additional reservoir projects is much more difficult now than in the past. Consequently, optimizing the beneficial use of the existing reservoirs is becoming increasingly more important.

Reservoir storage capacities and operating policies are generally established prior to construction and tend to remain constant thereafter. However, public needs and objectives and numerous factors affecting reservoir effectiveness significantly change over time. The increasing necessity to use limited storage capacity as effectively as possible warrants periodic reevaluations of operating policies. Operating procedures should be responsive to changing needs and conditions.

Reallocation of storage capacity between flood control and conservation purposes represents one general strategy for modifying operating policies in response to changing needs and conditions. Reservoirs are typically operated only for conservation purposes or only for flood control or a certain reservoir volume, or pool, is designated for conservation and a separate pool for flood control. Reallocations might involve (1) conversion of a portion of the capacity of a conservation only reservoir to flood control or (2) conversion of a portion of the flood control capacity in a multipurpose reservoir to conservation.

Comprehensive integration of water management strategies could be a major future direction for optimizing the beneficial use of limited resources. This could include improved reservoir system operation, integration of demand management with reservoir operation, and conjunctive surface and ground water management. Systems analysis and hydrologic modeling techniques should play an even greater role in the future in providing a quantitative basis for reservoir operation decisions.

REFERENCES

A.H. Belo Corporation, "Texas Almanac and State Industrial Guide 1984-1985," 1984.

Brazos River Authority, "Water Resource Conservation and Development," undated brochure.

Davis, Darryl W. and Buckley, John J., "Output Increase from Existing Hydroelectric Plants," ASCE Journal of Water Resources Planning and Management, Vol. 110, No. 4, October 1984.

Department of Interior, Office of Water Policy, "Water in America 1983," November 1983.

Dowell, C.L. and Breeding, S.D., "Dams and Reservoirs in Texas, Historical and Descriptive Information," Texas Water Development Board, Report 48, June 1967.

Griffiths, John F. and Ainsworth, Grey, "One Hundred Years of Texas Weather, 1880-1979," Monograph Series 1, Office of the State Climatologist, Texas A&M University, December 1981.

Guadalupe-Blanco River Authority of Texas, 1984 Annual Report.

International Boundary and Water Commission, "Joint Projects of the United States and Mexico through the International Boundary and Water Commission," 1981.

International Boundary and Water Commission, United States Section, "1983 Annual Report, Operation of Rio Grande International Dams and Reservoirs."

Langbein, W.B., "Dams, Reservoirs, and Withdrawals for Water Supply - Historic Trends," U.S. Geological Survey Open File Report 82-256, 1982.

Lower Colorado River Authority, 1984 Annual Report.

McDaniels, Louis L., "Conservation Storage Reservoirs in Texas, Some Aspects and Chronology of Surface-Water Resources Development," Bulletin 6404, Texas Water Commission, April 1964.

McNeeley, John G. and Lacewell, Ronald D., "Surface Water Development in Texas," Texas Agricultural Experiment Station, Texas A&M University System, May 1977.

McNeely, John G. and Lacewell, Ronald D., "Water Resource Uses and Issues in Texas," Texas Agricultural Experiment Station, Texas A&M University System, August 1978.

Orton, Robert B., "Climates of the States, Texas," National Oceanic and Atmospheric Administration, Climatology of the United States No. 64-41, June 1969.

Ruesink, Lou Ellen, "Recreation Land Policies of Texas River Authorities Operating Reservoirs," Master of Science Thesis, Texas A&M University, December 1979.

Sabine River Authority of Texas, 1984 Annual Report.

Southwestern Power Administration, 1984 Annual Report.

Texas Advisory Commission of Intergovernmental Relations, "Handbook of Governments in Texas," 1983.

Texas Department of Water Resources, "Water for Texas, A Comprehensive Plan for the Future," 2 volumes, June 1984.

Texas Department of Water Resources, "Water Planning in Texas, Past-Present-Future," 1984.

Texas Society of Professional Engineers and Texas Section of the American Society of Civil Engineers, "The Effects of Ponds and Small Reservoirs on the Water Resources of Texas," Austin, 1974.

Texas Water Development Board, "Engineering Data on Dams and Reservoirs in Texas," Report 126, Parts I, II, and III, October 1974, November 1973, and February 1971.

U.S. Bureau of Reclamation, "Information Map and Factual Data for Southwest Region Projects," January 1982.

U.S. Army Corps of Engineers, Office of the Chief of Engineers," Digest of Water Resource Policies and Authorities," EP 1165-2-1, March 1981.

U.S. Army Corps of Engineers, Institute for Water Resources and Hydrologic Engineering Center, "National Hydroelectric Power Study, Volume XX, Regional Report, Southwest Power Pool," September 1980.

U.S. Army Corps of Engineers, Institute for Water Resources and Hydrologic Engineering Center, "National Hydroelectric Power Study, Volume XXI, Regional Assessment: Electric Reliability Council of Texas," September 1981.

U.S. Army Corps of Engineers, Southwestern Division, "Water Resources Development in Texas by the U.S. Army Corps of Engineers," 1981.

U.S. Army Corps of Engineers, "Reservoir Regulation," Engineering Manual 1110-2-3600, May 1959.

U.S. Geological Survey, "National Water Summary 1983, Hydrologic Events and Issues," Water Supply Paper 2250, 1984.

Western Area Power Administration, 1984 Annual Report.

Wurbs, Ralph A., "Economic Feasibility of Flood Control Improvements," Journal of Water Resources Planning and Management, American Society of Civil Engineers, Vol. 109, No. 1, January 1983.

Wurbs, Ralph A., Tibbets, Michael N., Cabezas, L. Moris, and Roy, Lonnie C., "State-of-the-Art Review and Annotated Bibliography of Systems Analysis Techniques Applied to Reservoir Operation," Texas Water Resources Institute, Technical Report No. 136, May 1985.

APPENDIX A

INVENTORY OF MAJOR RESERVOIRS IN TEXAS

SCOPE AND ORGANIZATION OF APPENDIX

This appendix is a compilation of information describing each of the 187 reservoirs in Texas with controlled storage capacities greater than or equal to 5,000 acre-feet. These projects were existing or under construction as of April 1985. In Table A-1, the reservoirs located in each river basin are listed in order of increasing storage capacity, and descriptive data is provided for each reservoir. Table A-2 lists reservoir operators with information regarding their reservoirs. The two tables are followed by an alphabetical listing which provides the following information for each reservoir: name of reservoir and dam; former or alternate names of reservoir or dam, if any; river basin and stream; county or counties in which located; organizations which own and/or operate the project; purposes; date of initial impoundment; and conservation and flood control storage capacities. Plate 1 at the back of this report is a map provided by the Texas Department of Water Resources which shows the location of the major reservoirs.

The term "major reservoir" is used herein to refer to a reservoir with a controlled storage capacity of 5,000 acre-feet or greater. The total number of major reservoirs in Texas can vary slightly depending on how this criteria is applied. The 187 major reservoirs cited herein do not include the following "borderline" cases. The J.D. Murphree Wildlife Management Area Impoundments in Jefferson County are a group of several shallow fish hatcheries with individual capacities less than 5,000 acre-feet and a combined capacity of 13,500 acre-feet. Buffalo Springs Lake in the Brazos River Basin was authorized to store slightly greater than 5,000 acre-feet, but the actual storage capacity is less than this amount. Several irrigation reservoirs in Cameron, Hidalgo, and Willacy Counties in the Rio Grande River Basin contain storage capacities somewhat more or less than 5,000 acre-feet. This includes several old loops and bends in the river that have been isolated by the river changing its course and are now used as reservoirs and also several constructed off-channel reservoirs connected to the river by ditches through which they are filled. Several small mine-tailings dams in the state may have capacities greater than 5,000 acre-feet but are also ommitted from the compilation presented herein.

The storage capacity data quoted is for controlled storage only. Surcharge storage above the crest elevation of uncontrolled spillways is not included. The total controlled storage capacity is divided between flood control and conservation storage. Flood control storage space is maintained empty except during and immediately following a major flood event. Conservation storage is used to store water until it is needed. Flood control and conservation capacity in the multiple purpose reservoirs are divided by set top of conservation (bottom of flood control) pool elevations.

The term "conservation storage capacity" is used herein to include all controlled storage capacity which is not specifically allocated to flood control. Conservation storage is divided between active and inactive. The inactive storage contains dead storage and sediment reserve whenever such storage is specifically designated in the source data. The active storage is the conservation storage which has not been specifically identified as either dead storage or sediment reserve. Active conservation storage, or usable storage, is primarily the capacity allocated to store water for withdrawal or release for beneficial purposes under normal operating procedures. To simplify data compilation, all sediment reserve in multiple purpose projects is included in conservation capacity even though a portion may actually be in the flood control pool. Also, very small dead storages identified in several smaller reservoirs were omitted.

SOURCES OF INFORMATION

Information describing the major reservoirs in Texas have been published by the Texas Water Commission (McDaniels, 1964), Texas Water Development Board (Dowell and Breeding dated 1967 and the 3-volume Report 126 dated 1974, 1973, 1971), Texas Agricultural Experiment Station (McNeely and Lacewell, 1977), Texas Department of Water Resources (1984), and in the 1984-1985 Texas Almanac and State Industrial Guide. A Corps of Engineers publication (1981) describes Corps of Engineers water resources development projects in Texas. Other water agencies also have readily available publications describing their projects.

The Texas Natural Resources Information System includes a dam inventory computer file developed and maintained by the Texas Department of Water Resources. The dam inventory file was developed in the 1970's in conjunction with the national dam safety program and is now updated and maintained on a continuing basis. Information is included on the 5,787 dams in the state which meet at least one of the following criteria: (1) have a dam height of at least six feet and storage capacity of at least 50 acre-feet and (2) have a dam height of 25 feet regardless of storage capacity. Data for all dams with storage capacities equalling or exceeding 5,000 acre-feet were provided by the automated retrieval system for the investigation reported herein.

The reservoir data presented in this appendix were compiled from the several publications and the computer file cited above, supplemented in some cases by additional information provided by the reservoir construction and management agencies.

ABBREVIATIONS AND NOTES FOR TABLE A-1

Abbreviations Used Regarding Reservoir Owners

FWSD - Fresh Water Supply District
MIWA - Municipal and Industrial Water Authority
MWA - Municipal Water Authority
MWD - Municipal Water District
MWSD - Municipal Water Supply District
RA - River Authority
WA - Water Authority
WD - Water District
WID - Water Improvement District
WPCD - Water Power Control District
WSD - Water Supply District

Abbreviations Used for Reservoir Purposes

M - municipal and industrial water supply
I - industrial water supply (no municipal use)
Mi - water supply for mining
A - agricultural (irrigation) water supply
P - steam-electric power
H - hydroelectric power
R - recreation

Notes

1. An asterisk (*) indicates that a reservoir was under construction as of April 1985.

2. Reservoir water surface areas are given at both top of conservation and flood control pool elevations.

3. Flood control capacity is limited to controlled storage capacity specifically designated for flood control. Conservation capacity is all controlled storage capacity not specifically designated for flood control. If data sources specifically designate significant amounts of capacity as either dead storage or sediment reserve, the capacity is included in Table A-1 as inactive conservation capacity. Otherwise, conservation capacity is listed in the active column.

TABLE A-1
MAJOR RESERVOIRS IN TEXAS

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: INACTIVE	CONTROLLED STORAGE CAPACITY: CONSERVATION: ACTIVE	CONTROLLED STORAGE CAPACITY: FLOOD CONTROL	CONTROLLED STORAGE CAPACITY: TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-fe
Canadian River Basin									
Rita Blanca	City of Dalhart	R	1941	75	520	-	12,100	-	12,1
Meredith	Canadian River MWA	F,M,R	1965	200	16,500-21,640	43,100	821,300	543,200	1,407,6
Red River Basin									
Bivins	City of Amarillo	M	1926	48	380	-	5,120	-	5,12
Randall	City of Denison	M	1909	70	310	-	6,290	-	6,29
Coffee Mill	U.S. Forest Service	R	1938	27	650	-	8,000	-	8,00
Electra City	City of Electra	M	1950	40	660	-	8,060	-	8,06
Baylor Creek	City of Childress	M,R	1949	66	610	-	9,220	-	9,22
Crook	City of Paris	M	1923	38	1,230	-	9,960	-	9,96
Santa Rosa	W.T. Waggoner Estate	Mi	1929	41	1,500	-	11,570	-	11,57
Bonham	Bonham MWA	M	1969	70	1,020	-	12,000	-	12,00
Wichita	City of Wichita Falls	M,P,R	1901	23	2,200	-	11,000	-	14,00
North Fork Buffalo Creek	Wichita County WCID 3	M	1964	47	1,500	3,000	15,400	-	15,40
Valley	Texas Power & Light	P	1960	55	1,080	-	16,400	-	16,40
Buffalo	U.S. Fish and Wildlife Service	R	1938	37	1,900	-	18,150	-	18,15
Hubert H. Moss	City of Gainsville	M	1966	93	1,130	-	23,210	-	23,210
Farmers Creek	North Montague County WSD	M,Mi	1961	77	1,470	-	25,400	-	25,400
Diversion	City of Wichita Falls and Wichita County WID 2	M	1924	55	3,420	-	40,000	-	40,000
Mackenzie	Mackenzie MWA	M	1974	174	900	-	*46,250	-	46,250
Greenbelt	Greenbelt M&IWA	M	1966	110	1,990	-	58,200	-	58,200
Kickapoo	City of Wichita Falls	M,P,R	1946	62	6,200	-	106,000	-	106,000
Truscott	Corps of Engineers	Brine	1984		2,980	-	107,000	-	107,000
Pat Mayse	Corps of Engineers	F,M,R	1967	96	5,990-7,680	4,600	119,900	64,600	189,100
Arrowhead	City of Wichita Falls	M	1966	62	16,200	-	262,100	-	262,100
Kemp	City of Wichita Falls and Wichita County WID 2	M,P,F	1922	115	16,540-24,720	1,580	318,020	248,300	567,900
Texoma	Corps of Engineers	F,H,M,R	1943	165	89,000-143,300	-	2,722,000	2,660,000	5,382,000

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: INACTIVE	CONSERVATION: ACTIVE	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Sulphur River Basin									
River Crest	Texas Power and Light	P	1953	23	550	-	7,000	-	7,000
Sulphur Springs	Sulphur Springs WD	M	1973	44	1,340	-	13,520	-	13,520
*Cooper	Corps of Engineers	F,M,R	*1991	73	19,305-22,740	37,000	273,000	131,400	441,400
Wright Patman	Corps of Engineers	F,M,R	1956	106	20,300-119,700	-	145,300	2,509,000	2,654,300
Cypress Creek Basin									
Johnson Creek	Southwestern Electric	P	1961	60	650	-	10,100	-	10,100
Welsh	Southwestern Electric	P,R	1975	60	1,360	-	23,590	-	23,590
Ellison Creek	Lone Star Steel	P,I	1943	49	1,520	-	24,700	-	24,700
Monticello	Texas Utilities Company	P	1972	54	2,000	-	40,100	-	40,100
Cypress Springs	Franklin County WD	M	1970	74	3,400	-	72,800	-	72,800
Caddo	Corps of Engineers	M,R	1914;1971	36	26,800	-	129,000	-	129,000
Bob Sandlin	Titus County FWSD 1	M,R	1978	69	9,460	-	202,300	-	202,300
Lake O' the Pines	Corps of Engineers	F,M,R	1957	97	1,060-38,200	-	254,900	587,200	842,100
Sabine River Basin									
Gladewater	City of Gladewater	M,R	1952	48	800	-	6,950	-	6,950
Quitman	Wood County	F,R	1962	42	810	-	7,400	-	7,400
Holbrook	Wood County	F,R	1962	49	650	-	7,700	-	7,700
Winnsboro	Wood County	F,R	1962	45	810	-	8,100	-	8,100
Hawkins	Wood County	F,R	1962	58	780	-	11,570	-	11,570
Brandy Branch	Southwestern Electric	P	1983	80	960	-	29,500	-	29,500
Murvaul	Panola County WSD 1	M,R	1957	46	3,820	-	45,810	-	45,810
Cherokee	Cherokee Water Co.	M,R	1948	45	3,990	-	46,700	-	46,700
Martin	Texas Utilities Service	P	1974	61	5,020	-	77,620	-	77,620
Lake Fork	Sabine River Authority	M	1980	82	27,690	-	635,200	-	635,200
Tawakoni	Sabine River Authority	M,A,R	1960	85	36,700	-	936,200	-	936,200
Toledo Bend	Sabine River Authority	M,A,H,R	1966	112	181,600	-	4,477,000	-	4,477,000

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: INACTIVE	CONSERVATION: ACTIVE	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Neches River Basin									
Pinkston	City of Center	M ,R	1977	64	520	-	7,380	-	7,380
Kurth	Southland Paper Mills	I	1961	37	770	-	16,200	-	16,200
Striker Creek	Angelina-Nacogdoches WC&ID No. 1	M	1957	42	1,250	-	26,960	-	26,960
Jacksonville	City of Jacksonville	M,R	1957	72	1,320	-	30,500	-	30,500
Athens	Athens MWA	M,R	1962	67	1,520	-	32,690	-	32,690
Nacogdoches	City of Nacogdoches	M	1976	75	2,210	-	41,140	-	41,140
Tyler	City of Tyler	M	1949;1966	50	4,800	-	73,700	-	73,700
Steinhagen	Corps of Engineers	F,M,R	1951	45	13,700	-	94,200	-	94,200
Palestine	Upper Neches MWA	M,R	1962	75	25,560	-	411,300	-	411,300
Sam Rayburn	Corps of Engineers	F,M,H,A	1965	120	114,500-142,700	1,452,000	1,446,200	1,099,400	3,997,600
Trinity River Basin									
Kiowa	Lake Kiowa Inc	R	1968	42	560	-	7,000	-	7,000
Halbert	City of Corsicana	M,R	1921	49	650	-	7,420	-	7,420
Trinidad	Texas Power and Light	P	1925	20	740	-	7,450	-	7,450
Terrell City	City of Terrell	M,R	1955	45	830	-	8,710	-	8,710
White Rock	City of Dallas	R	1910	40	1,120	-	10,740	-	10,740
Waxahachie	Ellis County WC&ID 1	M	1956	66	690	-	13,500	-	13,500
North	Dallas Power and Light	P	1957	65	800	-	17,000	-	17,000
Weatherford	City of Weatherford	M	1957	75	1,210	-	19,470	-	19,470
Houston County	Houston County WC&ID 1	M	1966	63	1,280	-	19,500	-	19,500
Forest Grove	Texas Utilities Service	P	1980	53	1,500	-	20,040	-	20,040
Mountain Creek	Dallas Power and Light	P	1937	47	2,710		22,840	-	22,840
Amon G. Carter	City of Bowie	M	1956	71	20,050	-	29,000	-	29,000
Anahuac	Chambers-Liberty Counties Navigation District	A,Mi	1914;1954	10	5,300	-	35,300	-	35,300
Worth	City of Fort Worth	M	1914	50	3,560	-	38,130	-	38,130
Arlington	City of Arlington	M	1957	83	2,270	-	45,710	-	45,710
Fairfield	Industrial Generating Service	P	1969	77	2,350	-	50,600	-	50,600
*Wallisville	Corps of Engineers	M,R		21	19,700	-	58,000	-	58,000

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: INACTIVE	CONSERVATION: ACTIVE	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Bardwell	Corps of Engineers	F,M,R	1965	82	3,570-6,040	14,660	42,800	79,600	137,060
Eagle Mountain	Tarrant County WCID 1	M,A	1934	85	9,200	-	190,300	-	190,300
Navarro Mills	Corps of Engineers	F,M,R	1963	82	5,070-11,700	9,700	53,200	143,300	206,200
Benbrook	Corps of Engineers	F,M,R	1952	130	3,770-10,300	15,750	72,500	170,350	258,600
*Joe Pool	Corps of Engineers	F,M,R	*1985	105	7,470	38,000	138,900	127,100	304,000
Bridgeport	Tarrant County WCID 1	M	1965	91	33,750	-	386,420	-	386,420
Grapevine	Corps of Engineers	F,M,R	1952	137	7,380-12,740	26,000	161,250	238,250	425,500
Ray Hubbard	City of Dallas	M	1968	68	22,740	-	490,000	-	490,000
Cedar Creek	Tarrant County WCID 1	M	1965	91	33,750	-	679,200	-	679,200
Lavon	Corps of Engineers	F,M,R	1953;1979	81	21,400-29,450	92,600	380,000	275,600	748,200
Lewisville	Corps of Engineers	F,M,R	1954	125	23,280-39,080	20,600	436,000	525,200	981,800
*Ray Roberts	Corps of Engineers	F,M,R	*1986	141	29,350-36,900	54,600	749,200	260,800	1,064,600
*Richland	Tarrant County WCID 1	M	*1986		38,850	-	1,135,000	-	1,135,000
Livingston	City of Houston, Trinity River Authority	M,A,R	1968	100	82,600	-	1,750,000	-	1,750,000
Trinity-San Jacinto Coastal Basin									
Cedar Bayou	Houston Power and Light	P	1972	10	2,600	-	20,000	-	20,000
San Jacinto River Basin									
Sheldon	Texas Parks and Wildlife	R	1943	10	1,700	-	5,420	-	5,420
Lewis Creek	Gulf States Utilities	I	1969	54	1,010	-	16,400	-	16,400
Houston	City of Houston	M,A,R,Mi	1954	65	12,240	-	140,520	-	140,520
Addicks	Corps of Engineers	F	1948	49	0-17,220	-	-	204,500	204,500
Barker	Corps of Engineers	F	1945	365	0-17,220	-	-	207,000	207,000
Conroe	San Jacinto River Authority and City of Houston	M,Mi	1973	82	20,980	-	429,890	-	429,890
San Jacinto-Brazos Coastal Basin									
Galveston County	Galveston County WA	M,I	1949	14	810	-	7,310	-	7,310

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPCITY			
						CONSERVATION		FLOOD CONTROL	TOTAL
						INACTIVE	ACTIVE		
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Brazos River Basin									
Davis	League Ranch	I	1959	32	580	-	5,400	-	5,400
Mineral Wells	City of Mineral Wells	M	1920	74	650	-	6,760	-	6,760
Kirby	City of Abilene	M	1928	50	740	-	7,620	-	7,620
Abilene	City of Abilene	M,R	1921	51	590	-	7,900	-	7,900
Lake Creek	Texas Power & Light	P	1952	50	550	-	8,400	-	8,400
Camp Creek	Camp Creek Water Company	M,R	1948	49	750	-	8,550	-	8,550
Cisco	City of Cisco	M	1923	96	440	-	8,800	-	8,800
Daniel	City of Breckenridge	M	1948	60	920	-	9,520	-	9,520
Mexia	Bristone MWSD	M	1961	50	1,200	-	10,000	-	10,000
Sweetwater	City of Sweetwater	M	1930	50	630	-	11,900	-	11,900
William Harris	Dow Chemical Company	I	1947	12	1,660	-	12,000	-	12,000
Alcoa	Aluminum Company of America	I,R	1953	50	880	-	14,750	-	14,750
Bryan Utilities	City of Bryan	P,R	1975	62	830	-	15,230	-	15,230
Smithers	Houston Lighting & Power	P	1957	18	2,480	-	18,700	-	18,700
Brazoria	Dow Chemical Company	I	1954	16	1,260	-	21,970	-	21,970
Pat Cleburne	City of Cleburne	M	1964	78	1,550	-	25,300	-	25,300
Millers Creek	North Central Texas MWA	M	1974	75	1,900	-	25,520	-	25,520
Leon	Eastland County WSD	M,I	1954	90	1,590	-	26,420	-	26,420
Gibbons Creek	Texas Municipal Power Agency	P	1981	50	2,490	-	26,820	-	26,820
Twin Oaks	Texas Power & Light	P	1982	56	1,460	-	30,320	-	30,320
Tradinghouse	Texas Power & Light	P	1968	60	2,010	-	35,120	-	35,120
White River	White River MWD	M,Mi	1963	84	1,280	-	37,950	-	37,950
Palo Pinto	Palo Pinto MWD 1	M	1964	96	2,660	-	42,200	-	42,200
Stamford	City of Stamford	M	1953	78	4,690	-	52,700	-	52,700
Graham	City of Graham	M	1929;1958	57;82	2,550	-	53,680	-	53,680
Fort Phantom Hill	City of Abilene	M,R	1938	84	4,250	-	74,310	-	74,310
Georgetown	Corps of Engineers	F,M,R	1980	162	1,310-3,220	14,000	29,200	87,600	130,800
Aquilla	Corps of Engineers	F,M,R	1983	104	3,280-7,000	25,700	33,600	86,700	146,000
Squaw Creek	Texas Utilities Services	P	1977	159	3,230	-	151,050	-	151,050
Granbury	Brazos River Authority	M,A,P	1969	84	1,300	-	153,500	-	153,500
Limestone	Brazos River Authority	M,A	1978	65	14,200	-	225,400	-	225,400
Granger	Corps of Engineers	F,M,R	1980	115	4,400-11,040	44,100	37,900	162,200	244,200

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: OTHER	CONSERVATION: SUPPLY	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Hubbard	West Central MWD	M,I,Mi	1962	112	16,250	-	314,280	-	314,280
Proctor	Corps of Engineers	F,M,A,R	1963	86	4,610-14,010	32,700	31,400	310,100	374,200
Somerville	Corps of Engineers	F,M,A,R	1967	80	11,460-24,400	25,900	143,900	337,700	507,500
Possum Kingdom	Brazos River Authority	M,A,R,H,Mi	1941	189	14,440	-	569,380	-	569,380
Stillhouse Hollow	Corps of Engineers	F,M,A,R	1968	200	6,430-11,830	34,900	204,900	390,600	630,400
Waco	Corps of Engineers	F,M,R	1965	140	7,270-19,440	65,100	104,100	553,300	722,500
Belton	Corps of Engineers	F,M,A,R	1954	192	12,300-23,600	76,500	365,500	640,000	1,082,000
Whitney	Corps of Engineers	F,H	1951	159	23,560-49,820	245,200	381,900	1,372,400	1,999,500
Colorado River Basin									
Clyde	City of Clyde	M	1969	63	450	-	5,750	-	5,750
Winters	City of Winters	M	1983	65	640	-	8,370	-	8,370
Marble Falls	Lower Colorado RA	H	1951	99	780	-	8,760	-	8,760
Eagle	Lakeside Irrigation Company	A	1900	6	1,200	-	9,600	-	9,600
Nasworthy	City of San Angelo	M,A	1930	50	1,600	-	12,390	-	12,390
Bastrop	Lower Colorado RA	I	1964	85	910	-	16,590	-	16,590
Inks	Lower Colorado RA	M,A,H,Mi	1938	97	800	-	17,540	-	17,540
Austin	City of Austin	M,H	1939	85	1,830	-	21,000	-	21,000
Hords Creek	Corps of Engineers	F,M,R	1948	91	500-1,260	2,430	5,700	16,620	24,750
Brady	City of Brady	M	1963	104	2,020	-	29,110	-	29,110
Colorado City	Texas Electric Service	M,P	1949	85	1,610	-	30,800	-	30,800
Walter E. Long	City of Austin	M,R	1967	83	1,270	-	33,940	-	33,940
Oak Creek	City of Sweetwater	M	1953	95	2,380	-	39,260	-	39,260
Coleman	City of Coleman	M	1966	90	2,000	-	40,000	-	40,000
Champion	Texas Electric Service	M	1959	114	1,560	880	41,620	-	42,500
Cedar Creek	Lower Colorado RA	P	1977	106	2,420	-	71,400	-	71,400
Lyndon B. Johnson	Lower Colorado RA	H	1951	118	6,380	-	138,500	-	138,500
Brownwood	Brown County WID 1	M,A	1933	120	7,300	-	143,400	-	143,400
J.B. Thomas	Colorado River MWD	M,R	1952	105	7,820	-	202,300	-	202,300
O.C. Fisher	Corps of Engineers	F,M,A,R	1952	128	5,440-12,700	35,100	80,600	277,200	392,900
E.V. Spence	Colorado River MWD	M,Mi	1968	140	14,950	-	484,800	-	484,800
Twin Buttes	City of San Angelo	F,M,A,R	1962	134	9,080-32,660	36,200	150,000	454,400	640,600
Buchanan	Lower Colorado RA	M,H,Mi	1937	146	23,060	-	955,200	-	955,200
Travis	Lower Colorado RA	F,M,A,H,Mi	1940	266	18,930-44,450	28,500	1,144,100	781,400	1,954,000

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: OTHER	CONSERVATION: SUPPLY	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Colorado-Lavaca Coastal Basin									
South Texas Project	Houston Lighting & Power	P	1981	51	7,000	-	187,000	-	187,000
Lavaca River Basin									
Texana	Lavaca-Navidad River Authority	M,A,R	1981	63	11,000	-	157,900	-	157,900
Guadalupe River Basin									
McQueeney	Guadalupe-Blanco RA	H	1928	40	400	-	5,000	-	5,000
H-4	Guadalupe-Blanco RA	H	1931	42	700	-	5,200	-	5,200
Dunlap	Guadalupe-Blanco RA	P	1928	41	410	-	5,900	-	5,900
Coleto Creek	Guadalupe-Blanco RA	P	1980	65	3,100	-	35,080	-	35,080
Canyon	Corps of Engineers	F,M,R	1964	224	8,240-12,890	23,900	366,400	346,400	736,700
San Antonio River Basin									
Olmos	City of San Antonio	F	1926	60	0-890	-	-	12,600	12,600
Victor Braunig	City Public Service Board of San Antonio	P	1962	80	1,350	-	26,500	-	26,500
Calaveras	City Public Service Board of San Antonio	P	1969	70	3,450	-	61,800	-	61,800
Medina	Bexar-Medina-Atascosa Counties WID 1	A	1913	164	5,575	-	254,000	-	254,000
Nueces River Basin									
Upper Nueces	Zavala and Dimmit Counties WID 1	A	1948	60	320	-	7,590	-	7,590
Corpus Christi	Lower Nueces River WSD	M,A,R,Mi	1958	75	21,900	-	269,900	-	269,900
Choke Canyon	City of Corpus Christi	M,R	1982	128	26,000	-	700,000	-	700,000

TABLE A-1
MAJOR RESERVOIRS IN TEXAS
(Continued)

RESERVOIR	PRIMARY OPERATOR/OWNER	PURPOSES	DATE IMPOUNDMENT BEGAN	DAM HEIGHT	SURFACE AREA CON-FC	CONTROLLED STORAGE CAPACITY: CONSERVATION: OTHER	CONSERVATION: SUPPLY	FLOOD CONTROL	TOTAL
				(feet)	(acres)	(acre-feet)	(acre-feet)	(acre-feet)	(acre-feet)
Nueces-Rio Grande Coastal Basin									
Barney M. Davis	Central Power & Light	P	1973	20	1,100	-	6,600	-	6,600
Valley Acres	Valley Acres WD	M,A	1947	15	910	-	7,840	-	7,840
Delta	Hidalgo-Willacy Counties WCID 1	A	1939	17	2,370	-	25,000	-	25,000
Loma Alta	Brownsville Navigation District	M	1963	18	2,490	-	26,500	-	26,500
Rio Grande Basin									
Imperial	Pecos Couty WCID 2	A	1915	29	1,530	-	6,000	-	6,000
Balmorhea	Reeves County WCID 1	A	1917	46	510	-	6,350	-	6,350
San Esteban	William B. Blakemore	R	1911	68	760	-	18,770	-	18,770
Casa Blanca	Webb County	R	1949	76	1,660	-	20,000	-	20,000
Red Bluff	Red Bluff WPCD	A,H	1936	102	11,700	3,000	307,000	-	310,000
Falcon	International Boundary & Water Commission	F,M,A,H,R	1953	150	87,210-98,960	2,800	2,264,800	910,000	3,177,600
Amistad	International Boundary & Water Commission	F,M,A,H,R	1968	254	64,900-84,400	7,600	3,497,400	1,744,000	5,249,000

TABLE A-2
RESERVOIR OPERATORS

OWNER/OPERATOR	BASIN	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL	RESERVOIRS
Federal Agencies						
International Boundary and Water Commission	Rio Grande	2	5,772,600	2,654,000	8,426,600	Amistad, Falcon
Corps of Engineers						
Fort Worth District	Multiple	26	8,547,990	10,728,020	19,276,010	Aquilla, Bardwell, Belton, Benbrook, Canyon, *Cooper, O.C. Fisher, Georgetown, Granger, Grapevine, Hords Creek, Lake O' the Pines, Lavon, Lewisville, Navarro Mills, Wright Patman, *Joe Pool, Proctor, Sam Rayburn, *Ray Roberts, Somerville, B.A. Steinhagen, Stillhouse Hollow, Waco, Whitney, Caddo
Galveston District	Multiple	3	58,000	411,500	469,500	Addicks, Barker, *Wallisville
Tulsa District	Red	3	2,953,500	2,724,600	5,678,100	Pay Mayse, Texoma, Truscott
U.S. Fish and Wildlife Service	Red	1	18,150	---	18,150	Buffalo
U.S. Forest Service	Red	1	8,000	---	8,000	Coffee Mill
		36	17,358,240	16,518,120	33,876,360	
Water Districts						
Tarrant County WCID 1	Trinity	4	2,390,920	---	2,390,920	Bridgeport, Cedar Creek, Eagle Mountain, *Richland
Canadian River MWA	Canadian	1	864,400	543,200	1,407,600	Meredith
Colorado River MWD	Colorado	2	687,100	---	687,100	E.V. Spence, J.B. Thomas
Upper Neches MWA	Neches	1	411,300	---	411,300	Palestine
West Central MWD	Brazos	1	314,280	---	314,280	Hubbard
Red Bluff WPCD	Rio Grande	1	310,000	---	310,000	Red Bluff
Lower Nueces WSD	Nueces	1	269,900	---	269,900	Corpus Christi
Bexar-Medina-Atascosa Counties WID 1	San Antonio	1	254,000	---	254,000	Medina
Titus County FWSD 1	Cypress	1	202,300	---	202,300	Bob Sandlin
Brown County WID 1	Colorado	1	143,400	---	143,400	Brownwood
Franklin County WD	Cypress	1	72,800	---	72,800	Cypress Springs
Greenbelt MIWA	Red	1	58,200	---	58,200	Greenbelt

TABLE A-2
RESERVOIR OPERATORS
(Continued)

OWNER/OPERATOR	BASIN	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL	RESERVOIRS
Mackenzie MWD	Red	1	46,250	---	46,250	Mackenzie
Panola County WSD 1	Sabine	1	45,810	---	45,810	Murvaul
Palo Pinto MWD 1	Brazos	1	42,200	---	42,200	Palo Pinto
White River MWD	Brazos	1	37,950	---	37,950	White River
Chambers-Liberty Counties Navigation District	Trinity	1	35,300	---	35,300	Anahuac
Athens MWA	Neches	1	32,690	---	32,690	Athens
Angelina-Nacogdoches WCID 1	Neches	1	26,960	---	26,960	Striker Creek
Brownsville Navigation District	Nueces-Rio Grande	1	26,500	---	26,500	Loma Alta
Eastland County WSD	Brazos	1	26,420	---	26,420	Leon
North Central Texas MWA	Brazos	1	25,520	---	25,520	Millers Creek
North Montague County WSD	Red	1	25,400	---	25,400	Farmers Creek
Hildalgo-Willacy Counties WCID 1	Nueces-Rio Grande	1	25,000	---	25,000	Delta
Houston County WCID 1	Trinity	1	19,500	---	19,500	Houston County
Wichita County WCID	Red	1	15,400	---	15,400	North Fork Buffalo Creek
Sulphur Springs WD	Sulphur	1	13,520	---	13,520	Sulphur Springs
Ellis County WCID 1	Trinity	1	13,500	---	13,500	Waxahachie
Bonham MWA	Red	1	12,000	---	12,000	Bonham
Bristrone MWSD	Brazos	1	10,000	---	10,000	Mexia
Valley Acres WD	Nueces-Rio Grande	1	7,840	---	7,840	Valley Acres
Zavalla-Dimmit Counties WID 1	Nueces	1	7,590	---	7,590	Upper Nueces
Galveston County WA	San Jacinto-Brazos	1	7,310	---	7,310	Galveston County Industrial
Reeves County WCID 1	Rio Grande	1	6,350	---	6,350	Balmornea
Pecos County WCID 2	Rio Grande	1	6,000	---	6,000	Imperial
Subtotal - Water Districts		39	6,493,610	543,200	7,036,810	
River Authorities						
Sabine RA	Sabine	3	6,048,400	---	6,048,400	Lake Fork, Tawakoni, Toledo Bend
Lower Colorado RA	Colorado	7	2,380,590	781,400	3,161,990	Bastrop, Buchanan, Cedar Creek, Inks, L.B. Johnson, Marble Falls, Travis

TABLE A-2
RESERVOIR OPERATORS
(Continued)

OWNER/OPERATOR	BASIN	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL	RESERVOIRS
Brazos RA	Brazos	3	948,280	---	948,280	Granbury, Limestone, Possum Kingdom
Lavaca-Navidad RA	Lavaca	1	157,900	---	157,900	Texana
Guadalupe-Blanco RA	Guadalupe	4	51,180	---	51,180	Coleto Creek, Dunlap, H-4, McQueeney
Subtotal - River Authorities		18	9,586,350	781,400	10,367,750	
Jointly Owned						
City of Wichita Falls and Wichita County WCID 2	Red	2	359,600	248,300	607,900	Diversion, Kemp
City of Houston and Trinity River Authority	Trinity	1	1,750,000	---	1,750,000	Livingston
City of Houston and San Jacinto River Authority	San Jacinto	1	429,890	---	429,890	Conroe
Subtotal - Jointly Owned		4	2,539,490	248,300	2,787,790	
Cities						
Dalhart	Canadian	1	12,100	---	12,100	Rita Blanca
Wichita Falls	Red	3	382,100	---	382,100	Arrowhead, Kickapoo, Wichita
Gainesville	Red	1	23,210	---	23,210	Hubert H. Moss
Paris	Red	1	9,960	---	9,960	Crook
Childress	Red	1	9,220	---	9,220	Baylor Creek
Electra	Red	1	8,060	---	8,060	Electra
Denison	Red	1	6,290	---	6,290	Randall
Amarillo	Red	1	5,120	---	5,120	Bivins
Gladewater	Sabine	1	6,950	---	6,950	Gladewater
Tyler	Neches	1	73,700	---	73,700	Tyler
Nacogdoches	Neches	1	41,140	---	41,140	Nacogdoches
Jacksonville	Neches	1	30,500	---	30,500	Jacksonville
Center	Neches	1	7,380	---	7,380	Pinkston
Dallas	Trinity	2	500,740	---	500,740	Ray Hubbard, White Rock
Arlington	Trinity	1	45,710	---	45,710	Arlington
Fort Worth	Trinity	1	38,130	---	38,130	Worth

TABLE A-2
RESERVOIR OPERATORS
(Continued)

OWNER/OPERATOR	BASIN	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL	RESERVOIRS
Bowie	Trinity	1	29,000	---	29,000	Amon G. Carter
Weatherford	Trinity	1	19,470	---	19,470	Weatherford
Terrell	Trinity	1	8,710	---	8,710	Terrell
Corsicana	Trinity	1	7,420	---	7,420	Halbert
Houston	San Jacinto	1	140,520	---	140,520	Houston
Abilene	Brazos	3	89,830	---	89,830	Fort Phantam Hill, Abilene, Kirby
Graham	Brazos	1	53,680	---	53,680	Graham
Stamford	Brazos	1	52,700	---	52,700	Stamford
Cleburne	Brazos	1	25,300	---	25,300	Pat Cleburne
Bryan	Brazos	1	15,230	---	15,230	Bryan Utilities
Sweetwater	Brazos	1	11,900	---	11,900	Sweetwater
Breckenridge	Brazos	1	9,520	---	9,520	Daniel
Cisco	Brazos	1	8,800	---	8,800	Cisco
Mineral Wells	Brazos	1	6,760	---	6,760	Mineral Wells
San Angelo	Colorado	2	198,590	454,400	652,990	Twin Buttes, Nasworthy
Austin	Colorado	2	54,940	---	54,940	Walter E. Long, Austin
Coleman	Colorado	1	40,000	---	40,000	Coleman
Sweetwater	Colorado	1	39,260	---	39,260	Oak Creek
Brady	Colorado	1	29,110	---	29,110	Brady
Winters	Colorado	1	8,370	---	8,370	Winters
Clyde	Colorado	1	5,750	---	5,750	Clyde
San Antonio	San Antonio	3	88,300	12,600	100,900	Calaveras, Victor Braunig, Olmas
Corpus Christi	Nueces	1	700,000	---	700,000	Choke Canyon
Subtotal - Cities		48	2,843,470	467,000	3,310,470	
Counties						
Wood	Sabine	4	34,810	---	34,810	Hawkins, Winnsboro, Holbrook, Quitman
Webb	Rio Grande	1	20,000	---	20,000	Casa Blanca
Subtotal - Counties		5	54,810	---	54,810	
Other State Agencies						
Texas Parks and Wildlife	San Jacinto	1	5,420	---	5,420	Sheldon

TABLE A-2
RESERVOIR OPERATORS
(Continued)

OWNER/OPERATOR	BASIN	NUMBER OF RESERVOIRS	STORAGE CAPACITY (ACRE-FEET) CONSERVATION	FLOOD CONTROL	TOTAL	RESERVOIRS
Electric Companies						
Texas Utilities	Multiple	4	288,810	—	288,810	Squaw Creek, Martin, Monticello, Forest Grove
Houston Lighting and Power	Mulitple	3	225,700	—	225,700	South Texas Project, Cedar Bayou, Smithers
Texas Power and Light	Multiple	6	104,690	—	104,690	Tradinghouse, Twin Oaks, Valley, Lake Creek, Trinidad, River Crest
Texas Electric Service	Colorado	2	73,300	—	73,300	Champion, Colorado City
Southwestern Electric	Cypress, Sabine	3	63,190	—	63,190	Johnson Creek, Welsh, Brandy Branch
Industrial Generating Service	Trinity	1	50,600	—	50,600	Fairfield
Dallas Power and Light	Trinity	2	39,840	—	39,840	Mountain Creek, North
Texas Municipal Power Agency	Brazos	1	26,820	—	26,820	Gibbons Creek
Gulf States Utilities	San Jacinto	1	16,400	—	16,400	Lewis Creek
Central Power and Light	Nueces-Rio Grande	1	6,600	—	6,600	Barney M. Davis
Subtotal - Electric Companies		24	895,950	—	895,950	
Other Private Companies						
Cherokee Water Company	Sabine	1	46,700	—	46,700	Cherokee
Dow Chemical Company	Brazos	2	33,970	—	33,970	Brazoria, William Harris
Lone Star Steel	Cypress	1	24,700	—	24,700	Ellison Creek
W.B. Blakemore	Rio Grande	1	18,770	—	18,770	San Estehan
Southland Paper Mills	Neches	1	16,200	—	16,200	Kurth
Aluminum Company of America	Brazos	1	14,750	—	14,750	Alcoa
W.T. Waggoner	Red	1	11,570	—	11,570	Santa Rosa
Lakeside Irrigation	Colorado	1	9,600	—	9,600	Eagle
Camp Creek Water Company	Brazos	1	8,550	—	8,550	Camp Creek
Lake Kiowa Inc.	Trinity	1	7,000	—	7,000	Kiowa
League Ranch	Brazos	1	5,400	—	5,400	Davis
Subtotal - Other Private Companies		12	197,210	—	197,210	
Totals		187	39,974,650	18,558,020	58,532,570	

Lake Abilene and Abilene Dam; Brazos River Basin, Elm Creek; Taylor County; City of Abilene; municipal, industrial, recreation; impoundment began August 1921; 7,900 acre-feet capacity.

Addicks Reservoir and Addicks Dam; San Jacinto River Basin, South Mayde Creek; Harris County; U.S. Army Corps of Engineers, Galveston District; flood control only; completed in 1948; 204,500 acre-feet capacity.

Alcoa Lake and Alcoa Dam; also called Sandow Lake and Sandow Dam; Brazos River Basin, Sandy Creek; Milam County; Aluminum Company of America; industrial and recreation; impoundment began January 1953; 14,750 acre-feet capacity.

Amarillo City Lake and Amarillo City Lake Dam; see Bivins Lake and Bivins Dam.

Anahuac Lake and Anahuac Dam; also called Turtle Bayou Reservoir; Trinity River Basin, Trinity River; Chambers County; Chambers-Liberty Counties Navigation District; industrial, irrigation and mining including oil production; impoundment began 1914, enlargement 1954; 35,300 acre-feet capacity.

Aquilla Lake and Aquilla Dam; Brazos River Basin, Aquilla Creek; Hill County; operated by the U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority has contracted for conservation storage; municipal, industrial, irrigation, recreation; impoundment began April 1983; 33,600 acre-feet conservation capacity; 86,700 flood control capacity.

Lake Arlington and Arlington Dam; Trinity River Basin, Village Creek; Tarrant County; City of Arlington; municipal, industrial; impoundment began March 1957; 45,710 acre-feet capacity.

Lake Arrowhead and Lake Arrowhead Dam; Red River Basin, Little Wichita River; Archer and Clay Counties; City of Wichita Falls; municipal; impoundment began October 1966; 262,100 acre-feet capacity.

Lake Athens and Lake Athens Dam; formerly Flat Creek Reservoir and Flat Creek Dam; Neches River Basin, Flat Creek; Henderson County; Athens Municipal Water Authority; municipal, recreation; impoundment began November 1962; 32,690 acre-feet capacity.

Lake Austin and Tom Miller Dam; Colorado River Basin, Colorado River; Travis County; owned by City of Austin, built and operated by the Lower Colorado River Authority under lease expiring December 2007; municipal, industrial, hydropower; impoundment began 1939; 21,000 acre-feet capacity.

Lake Balmorhea and Balmorhea Dam; Rio Grande Basin, Sandia Creek; Reeves County; Reeves County Water Improvement District Number 1; irrigation; impoundment began September 1917; 6,350 acre-feet capacity.

Bardwell Lake and Bardwell Dam; Trinity River Basin, Waxahachie Creek; Ellis County; owned and operated by the U.S. Army Corps of Engineers, FortWorth District, Trinity River Authority has contracted for conservation storage; flood control, municipal, industrial, recreation; impoundment began November 1965; 42,800 acre-feet conservation capacity; 79,600 flood control capacity.

Barker Reservoir and Barker Dam; San Jacinto River Basin, Buffalo Bayou; Fort Bend and Harris Counties; U.S. Army Corps of Engineers, Galveston District; flood control only; completed in 1945; 207,000 acre-feet capacity.

Lake Bastrop and Bastrop Dam; Colorado River Basin, Spicer Creek; Bastrop County; Lower Colorado River Authority; industrial; impoundment began April 1964; 16,500 acre-feet capacity.

Baylor Creek Reservoir and Baylor Creek Dam; Red River Basin, Baylor Creek; Childress County; City of Childress; municipal and recreation; impoundment began December 1949; 9,200 acre-feet capacity.

Belton Lake and Belton Dam; Brazos River Basin, Leon River; Bell and Coryell Counties; owned and operated by U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority and Fort Hood have contracted for conservation storage; flood control, municipal, industrial, irrigation; impoundment began March 1954; 372,700 acre-feet conservation capacity; 640,000 acre-feet flood control capacity.

Benbrook Lake and Benbrook Dam; Trinity River Basin, Clear Fork Trinity River; Tarrant County; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, City of Fort Worth and Benbrook Water and Sewage Authority have contracted for conservation storage; flood control, municipal, industrial, recreation; impoundment began September 1952; 72,500 acre-feet conservation capacity; 170,350 acre-feet flood control capacity.

Big Brown Creek Reservoir and Big Brown Creek Dam; see Fairfield Lake and Fairfield Dam.

Bivins Lake and Bivins Dam; also known as Amarillo City Lake; Red River Basin, Palo Duro Creek; Randall County; City of Amarillo; municipal; impoundment began 1926; 5,120 acre-feet capacity.

Blackburn Crossing Lake and Blackburn Crossing Dam; see Lake Palestine and Blackburn Crossing Dam.

Rita Blanca Lake and Rita Blanca Dam; Canadian River Basin, Rita Blanca Creek; Hartley County; City of Dalhart; recreation; impoundment began September 1941; 12,100 acre-feet capacity.

Lake Bonham and Timber Creek Dam; Red River Basin, Timber Creek; Fannin County; Bonham Municipal Water Authority; municipal; impoundment began November 1969; 12,000 acre-feet capacity.

Bowie Lake and Bowie Lake Dam; see Lake Amon G. Carter and Amon G. Carter Dam.

Brandy Branch Cooling Pond and Dam; Sabine River Basin, Brandy Branch; Harrison County; Southwestern Electric Power Company; steam-electric power; impoundment began 1983; 29,500 acre-feet capacity.

Victor Braunig Lake and Victor Braunig Plant Dam; also called East Lake; San Antonio River Basin, Arroyo Seco; Bexar County; City Public Service Board of San Antonio; steam-electric power; impoundment began December 1962; 26,500 acre-feet capacity.

Brazoria Reservoir and Brazoria Dam; Brazos River Basin, off-channel on Brazos River; Brazoria County; Dow Chemical Company; industrial; impoundment began April 1954; 21,970 acre-feet capacity.

Bridgeport Reservoir and Bridgeport Dam; Trinity River Basin, West Fork Trinity River; Wise County; Tarrant County Water Control and Improvement District No.1; municipal, industrial, recreation; impoundment began April 1932; 386,420 acre-feet capacity.

Brownwood Reservoir and Brownwood Dam Colorado River Basin, Pecan Bayou; Brown County; Brown County Water Improvement District No. 1; municipal, industrial, irrigation; impoundment began July 1933; 143,400 acre-feet capacity.

Brushy Creek Reservoir and Brushy Creek Dam; See Valley Lake and Valley Dam.

Bryan Utilities Lake and Bryan Utilities Lake Dam; Brazos River Basin, un-named creek; Brazos County; City of Bryan; steam-electric power and recreation; impoundment began 1975, 15,230 acre-feet capacity.

Lake Buchanan and Buchanan Dam; Colorado River Basin, Colorado River; Burnet County; Lower Colorado River Authority; municipal, industrial, mining, hydropower; impoundment began May 1937; 955,200 acre-feet capacity.

Buffalo Lake and Umbarger Dam; Red River Basin, Tierra Blanca Creek; Randall County; U.S. Department of the Interior, Fish and Wildlife Service; recreation; impoundment began June 1938; 18,150 acre-feet capacity.

Caddo Lake and Caddo Dam; Cypress Creek Basin, Cypress Bayou; Harrison and Marion Counties; maintained by U.S. Army Corps of Engineers; municipal, industrial and recreation; natural lake, dam constructed in 1914 and reconstructed in 1971; 129,000 acre-feet capacity.

Calaveras Lake and Calaveras Creek Dam; San Antonio River Basin, Calaveras Creek; Bexar County; City Public Service Board of San Antonio; steam-electric power; impoundment began January 1969; 61,800 acre-feet capacity.

Camp Creek Lake and Camp Creek Dam; Brazos River Basin, Camp Creek; Robertson County; Camp Creek Water Company; municipal and recreation; impoundment began November 1948; 8,500 acre-feet capacity.

Canyon Reservoir and Canyon Dam; Guadalupe River Basin, Guadalupe River; Comal County; constructed and operated by the U.S. Army Corps of Engineers, Fort Worth District, Guadalupe-Blanco River Authority has contracted for the conservation storage; flood control, municipal, industrial, recreation; impoundment began June 1965; 366,400 acre-feet conservation capacity; 346,400 acre-feet flood control capacity.

Lake Amon G. Carter and Amon G. Carter Dam; also called Bowie Lake and Bowie Lake Dam; Trinity River Basin, Big Sandy Creek; Montague County; City of Bowie; municipal, industrial; impoundment began May 1956; 29,000 acre-feet capacity.

Casa Blanca Lake and Country Club Dam; Rio Grande Basin, Chacon Creek; Webb County; recreation; impoundment begain 1949; 20,000 acre-feet capacity.

Cedar Bayou Cooling Reservoir; Trinity-San Jacinto Coastal Basin, Cedar Bayou; Chambers County; Houston Lighting and Power Company; steam-electric power; 20,000 acre-feet capacity.

Cedar Creek Reservoir and Cedar Creek Dam; Colorado River Basin, Cedar Creek; Fayette County; Lower Colorado River Authority; steam-electric power; impoundment began 1977; 71,400 acre-feet capacity.

Cedar Creek Reservoir and Joe B. Hoggsett Dam; also called Joe B. Hoggsett Lake; Trinity River Basin, Cedar Creek; Henderson and Kaufman Counties; Tarrant County Water Control and Improvement District No. 1; industrial; impoundment began July 1965; 679,200 acre-feet capacity.

Champion Creek Reservoir and Champion Creek Dam; Colorado River Basin, Champion Creek; Mitchell County; Texas Electric Service Company; municipal, steam-electric power; impoundment began February 1959; 41,600 acre-feet capacity.

Lake Cherokee and Cherokee Dam; Sabine River Basin, Cherokee Bayou; Gregg and Rusk Counties; Cherokee Water Company; municipal, industrial, and recreation; impoundment began October 1948; 46,700 acre-feet capacity.

Cherokee Trail Lake and Fort Sherman Dam; see Lake Bob Sandlin and Fort Sherman Dam.

Lake Cisco and Williamson Dam; Brazos River Basin, Sandy Creek; Eastland County; City of Cisco; municipal; impoundment began 1923; 8,800 acre-feet capacity.

Choke Canyon Reservoir and Choke Canyon Dam; Nueces River Basin, Frio River; Live Oak and McMullen Counties; Constructed by U.S. Bureau of Reclamation; operated and maintained by City of Corpus Christi; municipal, industrial, recreation; impoundment began 1982; 700,000 acre-feet capacity.

Lake Pat Cleburne and Cleburne Dam; Brazos River Basin, Nolan River; Johnson County; City of Cleburne; municipal; impoundment began August 1964; 25,300 acre-feet capacity.

Lake Clyde and Upper Pecan Bayou Dam Site 7; Colorado River Basin, North Prong Pecan Bayou; Callahan County; City of Clyde; municipal; impoundment began November 1969; 5,748 acre-feet capacity.

Coffee Mill Lake and Coffee Mill Dam; Red River Basin, Coffee Mill Creek; Fannin County; U.S. Forest Service; recreation; impoundment began 1938; 8,000 acre-feet capacity.

Colorado City Lake and Colorado City Dam; Colorado River Basin, Morgan Creek; Mitchell County; Texas Electric Service Company; municipal, industrial and hydropower; impoundment began April 1949; 30,800 acre-feet capacity.

Lake Conroe and Conroe Dam; also called Honea Reservoir and Honea Dam; San Jacinto River Basin, West Fork of the San Jacinto River; Montgomery and Walker Counties; San Jacinto River Authority, City of Houston, and Texas Water Development Board; municipal, industrial and mining including oil production; impoundment began January 1973; 429,890 acre-feet capacity.

***Cooper Lake and Cooper Dam;** Sulpher River Basin, South Sulpher River; Delta and Hopkins Counties; under construction by the U.S. Army Corps of Engineers, Fort Worth District; municipal, recreation, and flood control; 273,000 conservation capacity, 131,400 acre-feet flood control capacity.

De Cordova Bend Reservoir and De Cordova Bend Dam; see Lake Granbury.

Lake Corpus Christi and Wesley E. Seale Dam; Nueces River Basin, Nueces River; San Patricio, Live Oak, and Jim Wells Counties; Lower Nueces River Water Supply District; hydropower, municipal, industrial, irrigation, mining and recreation; impoundment began April 1958; 269,900 acre-feet capacity.

Lake Crook and Crook Dam; Red River Basin, Pine Creek; Lamar County; City of Paris; municipal; impoundment began 1923; 9,964 acre-feet capacity.

Lake Cypress Springs and Franklin County Dam; formerly Franklin County Lake; Cypress Creek Basin, Big Cypress Creek; Franklin County; Franklin County Water District and Texas Water Development Board; municipal and industrial; impoundment began July 1970; 72,800 acre-feet capacity.

Lake Dallas and Lake Dallas Dam; see Lewisville Lake and Lewisville Dam.

Dam B Reservoir and Dam B; see B.A. Steinhagen Lake.

Lake Daniel and Gonzales Creek Dam; Brazos River Basin, Gonzales Creek; Stephens County; City of Breckenridge; municipal and industrial; 9,515 acre-feet capacity.

Davis Lake and Davis Dam; Brazos River Basin, Double Dutchman Creek; Knox County; League Ranch; irrigation; impoundment began 1959; 5,395 acre-feet capacity.

Barney M. Davis Cooling Reservoir; Nueces-Rio Grande Coastal Basin, off-channel of Laguna Madre; Nueces County; Central Power and Light; steam-electric power; impoundment began 1973; 6,600 acre-feet capacity.

Decker Lake and Decker Creek Dam; see Walter E. Long Lake.

Delta Lake and Delta Dam (Reservoir Unit 1 and Unit 2); formerly Monte Alto Reservoir and Monte Alto Dam; Nueces-Rio Grande Coastal Basin, off-channel from the Rio Grande; Hidalgo County; Hidalgo-Willacy Counties Water Control and Improvement District Number 1; irrigation; impoundment began 1939; 25,000 acre-feet capacity.

Diable Reservoir and Diable Dam; see Amistad Reservoir and Amistad Dam.

Lake Diversion and Lake Diversion Dam; Red River Basin, Wichita River; Acher and Baylor Counties; City of Wichita Falls and Wichita County Water Improvement District No. 2; municipal and industrial; impoundment began 1924; 40,000 acre-feet capacity.

Lake Dunlap and TP-1 Dam; Guadalupe River Basin; Guadalupe River; Guadalupe County; Guadalupe-Blanco River Authority; hydropower; impoundment began 1928; 5,900 acre-feet capacity.

Eagle Lake and Eagle Lake Dam; Colorado River Basin, off channel from Colorado River; Colorado County; Lakeside Irrigation Company; irrigation; impoundment began 1900; 9,600 acre-feet capacity.

Eagle Mountain Reservoir and Eagle Mountain Dam; Trinity River Basin, West Fork Trinity River; Tarrant County; Tarrant County Water Control and Improvement District No. 1; municipal, industrial, irrigation; impoundment began February 1934; 190,300 acre-feet capacity.

East Lake and the Victor Braunig Plant Dam ; See Victor Braunig Lake

Eddleman Lake and Eddleman Dam; See Lake Graham and the Eddleman and Graham Dam.

Electra City Lake and Electra City Dam; Red River Basin; Beaver and Camp Creeks; Wilbarger County; City of Electra; municipal and industrial; impoundment began 1950; 8,055 acre-feet capacity

Ellison Creek Reservoir and Ellison Creek Dam; also called Lone Star Dam; Cypress Creek Basin, Ellison Creek; Ellison County; Lone Star Steel Company; steam-electric power and industrial; impoundment began January 1943; 24,700 acre-feet capacity.

Fairfield Lake and Fairfield Dam; formerly Big Brown Creek Reservoir and Big Brown Creek Dam; Trinity River Basin, Big Brown Creek; Freestone County; Industrial Generating Company; steam-electric power; impoundment began December 1969, 49,750 acre-feet capacity.

Farmers Creek Reservoir and Farmers Creek Dam; also known as Lake Nocona; Red River Basin, Farmers Creek; Montague County; North Montague County Water Supply District; municipal, industrial, and mining; impoundment began Spring 1961; 25,400 acre-feet capacity.

Ferrells Bridge Dam Reservoir; See Lake O'the Pines and Ferrells Bridge Dam.

O.C. Fisher Lake and Dam; formerly San Angelo Reservoir and Dam; Colorado River Basin, Concho River; Tom Green County; constructed and operated by U.S. Army Corps of Engineers, Upper Colorado River Authority has contracted for conservation storage; flood control, municipal, industrial, irrigation and recreation; impoundment began February 1952; 80,600 conservation capacity; 277,200 acre-feet flood control capacity.

Flat Creek Reservoir and Flat Creek Dam; See Lake Athens and Lake Athens Dam.

Forest Grove Reservoir and Forest Grove Dam; Trinity River Basin, Caney Creek; Henderson County; Texas Utilities Service Company; steam-electric power; impoundment began 1980; 20,040 acre-feet capacity.

Lake Fork Reservoir and Lake Fork Dam; Sabine River Basin, Lake Fork Creek; Rains and Wood Counties; Sabine River Authority; municipal and industrial; impoundment began 1980; 635,200 acre-feet capacity.

Forney Reservoir; See Lake Ray Hubbard.

Fort Phantom Hill Reservoir and Fort Phantom Hill Dam; Brazos River Basin, Elm Creek; Jones County; City of Abilene; municipal and recreation; impoundment began October 1938; 74,310 acre-feet conservation capacity.

Franklin County Lake and Franklin County Dam; See Lake Cypress Springs and Franklin County Dam.

Galveston County Industrial Water Reservoir: San Jacinto-BrazosBasin, off channel of Dickinson Bayou; Galveston County; Galveston County Water Authority; impoundment began 1949; municipal and industrial; 7,308 acre-feet capacity.

Garza-Little Elm Lake and Garza-Little Elm Dam; See Lewisville Lake and Lewisville Dam.

Georgetown Lake and Georgetown Dam; formerly North Fork Lake and North Fork Dam; Brazos River Basin, San Gabriel River; Williamson County; owned and operated by U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority has contracted for conservation storage; flood control, municipal, industrial, and recreation; impoundment began January 1980; 29,200 acre-feet conservation capacity, 87,600 acre-feet flood control capacity.

Gibbons Creek Reservoir and Gibbons Creek Dam; Brazos River Basin, Gibbons Creek; Grimes County; Texas Municipal Power Agency; steam-electric power; impoundment began 1981; 26,824 acre-feet capacity.

Lake Gladewater and Gladewater Dam; Sabine River Basin, Glade Creek; Upshur County; City of Gladewater, municipal and recreation, impoundment began August 1952; 6,950 acre-feet capacity.

Lake Graham and Eddleman and Graham Dam; also called Eddleman and Salt Creek Lakes; Brazos River Basin, Flint and Salt Creeks; Young County; City of Graham; municipal and industrial; impoundment began 1929 (Eddleman Dam) and 1958 (Graham Dam); 45,000 acre-feet capacity.

Lake Granbury and De Cordova Bend Dam; also called De Cordova Bend Reservoir; Brazos River Basin, Brazos River; Hood and Parker Counties; Brazos River Authority; municipal, industrial, irrigation and power; impoundment began September 1970' 153,000 acre-feet capacity.

Granger Lake and Granger Dam; formerly Laneport Lake and Laneport Dam; Brazos River Basin; San Gabriel River; Williamson County; owned and operated by U.S.army Corps of Engineers, Fort Worth District; Brazos River Authority has contracted for conservation storage; flood control, municipal, and industrial; impoundment began January 1980; 37,900 acre-feet conservation capacity, 162,200 acre-feet flood storage capacity.

Granite Shoals Lake; See Lake Lyndon B. Johnson.

Grapevine Lake and Grapevine Dam; Trinity River Basin, Denton Creek; Tarrant County; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Cities of Grapevine and Dallas have contracted for conservation storage; muncipal, industrial; impoundment began July 1952; 162,250 acre-feet conservation capacity; 243,050 acre-feet flood control capacity.

Greenbelt and Greenbelt Dam; Red River Basin, Salt Fork Red River; Donley County; Greenbelt Municipal and Industrial Water Authority and Texas Water Development Board; municipal and industrial; impoundment began December 1966; 58,200 acre-feet capacity.

H-4 Reservoir and H-4 Dam; Guadalupe River Basin, Guadalupe River; Gonzales County; Guadalupe-Blanco River Authority; hydropower; impoundment began 1931; 5,200 acre-feet capacity.

Lake Halbert and Halbert Dam; Trinity River Basin, Elm Creek; Navarro County; City of Corsicana; municipal, industrial, and recreation; impoundment began 1921; 7,420 acre-feet capacity.

William Harris Reservoir and William Harris Dam; Brazos River Basin, off channel between Brazos River and Oyster Creek; Brazoria County; Dow Chemical Company; industrial; impoundment began 1947; 12,000 acre-feet capacity.

Lake Hawkins and Wood County Dam No. 3; Sabine River Basin, Little Sandy Creek; Wood County; Wood County; recreation and flood control; impoundment began August 1962; 11,570 acre-feet capacity.

Joe B. Hoggsett Lake and Joe B. Hoggsett Dam; See Cedar Creek Reservoir and Joe. B. Hoggsett Dam.

Lake Holbrook and Wood County Dam No. 2; Sabine River Basin, Keys Creek; Wood County; Wood County; recreation and flood control; impoundment began September 1962; 7,700 acre-feet capacity.

Honea Reservoir and Honea Dam; See Lake Conroe and Conroe Dam.

Hords Creek Reservoir and Hords Creek Dam; Colorado River Basin, Hords Creek; Coleman County; operated by the U.S. Army Corps of Engineers, Fort Worth District, Central Colorado River Authority has contracted for conservation storage; flood control, municipal, recreation; impoundment began April 1948; 5,700 acre-feet conservation capacity; 16,620 acre-feet flood control capacity.

Lake Houston and Lake Houston Dam; San Jacinto River Basin, San Jacinto River; Harris County, City of Houston; municipal, industrial, irrigation, recreation, and mining, including oil production; impoundment began April 1954; 140,520 acre-feet capacity.

Houston County Lake and Houston County Dam; Trinity River Basin, Little Elkhart Creek; Houston County; Houston County Water Control and Improvement District No. 1; municipal and industrial; impoundment began November 1966; 19,500 acre-feet capacity.

Hubbard Creek Reservoir and Hubbard Creek Dam; Brazos River Basin, Hubbard Creek; Shackleford and Stephens Counties; West Central Municipal Water District; municipal, industrial and mining including oil production; impoundment began December 1962; 314,280 acre-feet capacity.

Lake Ray Hubbard and Rockwall Forney Dam; formerly Forney Reservoir; Trinity River Basin, East Fork Trinity River; Dallas and Kaufman Counties; City of Dallas; municipal; impoundment began December 1968; 490,000 acre-feet capacity;

Imperial Reservoir and Imperial Dam; Rio Grande Basin, Pecos River; Pecos and Reeves Counties; Pecos County Water Control and Improvement District No. 2; irrigation; impoundment began 1915; 6,000 acre-feet conservation capacity.

Inks Lake and Roy Inks Dam; Colorado River Basin, Colorado River; Burnet County; Lower Colorado River Authority; municipal, irrigation, mining and hydropower; impoundment began 1938; 17,540 acre-feet capacity.

International Amistad Reservoir and Dam; also called Diable Reservoir and Diable Dam; Rio Grande Basin, Rio Grande River; Val Verde County; International Boundary and Water Commission; conservation, recreation, irrigation, hydropower and flood control; impoundment began May 1968; 3,497,400 acre-feet conservation capacity; 1,744,000 flood control capacity.

International Falcon Reservoir and Dam; Rio Grande Basin, Rio Grande; Starr County, Texas and Estado de Tamaulipas, Mexico;International Boundary and Water Commission; municipal, industrial, irrigation, flood control, hydropower and recreation; impoundment began August 1953; 2,667,600 acre-feet conservation capacity, 910,000 flood control capacity.

Iron Bridge Dam Lake; See Lake Tawakoni and Iron Bridge Dam;

Lake Jacksonville and Buckner Dam; Neches River Basin, Gum Creek; Cherokee County; City of Jacksonville; municpal and recreation; impoundment began June 1957; 30,500 acre-feet capacity.

Johnson Creek Reservoir and Johnson Creek Dam; Cypress Creek Basin, Johnson Creek; Marion County; Southwestern Electric Power Company; industrial; impoundment began August 1961; 10,100 acre-feet capacity.

Lake Lyndon B. Johnson and Alvin Wirtz Dam; formerly Granite Shoals Lake; Colorado River Basin; Colorado River; Burnet and Llano Counties; Lower Colorado River Authority; hydroelectric power; impoundment began May 1951; 138,500 acre-feet capacity.

Lake Kemp and Lake Kemp Dam; Red River Basin; Wichita River; Baylor County; City of Wichita Falls and Wichita County Water Improvement District No. 2; municipal, steam-electric power, and irrigation; impoundment began October 1922, reconstruction by U.S. Army Corps of Engineers 1974; 319,600 acre-feet conservation capacity, 248,300 acre-feet flood control capacity.

Lake Kickapoo and Lake Kickapoo Dam; Red River Basin, North Fork LittleWichita River; Archer County; City of Wichita Falls; municipal; impoundment began February 1946; 106,000 acre-feet capacity.

Lake Kiowa and Kiowa Dam; Trinity River Basin, Indian Creek; Cooke County; Lake Kiowa, Inc; recreation; impoundment began March 1968; 7,000 acre-feet capacity.

Kirby Lake and Kirby Dam; Brazos River Basin, Cedar Creek; Taylor County; City of Abilene; municipal; impoundment began 1928; 7,620 acre-feet conservation capacity.

Lake Kurth and Kurth Dam; also called Southland Paper Mills Reservoir; Neches River Basin, off channel of Angelina River; Angelina County; Southland Paper Mills; industrial; impoundment began September 1961; 16,200 acre-feet capacity.

Lake Creek Lake and Lake Creek Dam; Brazos River Basin, Manos Creek; McLennan County; Texas Power and Light Company; steam-electric power; impoundment began June 1952; 8,400 acre-feet capacity.

Lake O'the Pines and Ferrells Bridge Dam; also called Ferrells Bridge Dam Reservoir; Cypress Creek Basin, Cypress Creek; Camp, Harrison, Marion, Morris, and Upshur Counties; operated by the U.S. Army Corps of Engineers, Fort Worth District, Northeast Texas MWD has contracted for conservation storage; municipal, industrial, recreation, and flood control; impoundment began August 1957; 252,040 acre-feet conservation capacity; 336,100 acre-feet flood control capacity.

Lakeview Lake and Lakeview Dam; See Joe Pool Reservoir and Joe Pool Dam.

Lampasses Reservoir and Lampasses Dam; See Stillhouse Hollow Lake and Stillhouse Hollow Dam.

Laneport Lake and Laneport Dam; See Granger Lake and Granger Dam.

Lavon Lake and Lavon Dam; Trinity River Basin, East Fork Trinity River; Collin County; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, North Texas Municipal Water District has contracted for conservation storage; flood control, municipal, and industrial; impoundment began September 1953, project enlarged 1979; 380,000 acre-feet conservation capacity; 275,600 acre-feet flood control capacity.

Lewis Creek Reservoir and Lewis Creek Dam; San Jacinto River Basin, Lewis Creek; Montgomery County; Gulf States Utilities Company; steam-electric power; impoundment began February 1969; 16,400 acre-feet capacity.

Lewisville Lake and Lewisville Dam; also called Lake Dallas and Lake Dallas Dam and Garza-Little Elm Lake and Garza-Little Elm Dam; Trinity River Basin, Elm Fork Trinity River; Denton County; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Cities of Dallas and Denton have contracted for conservation storage; flood control, municipal, industrial and recreation; impoundment began November 1954; 436,000 acre-feet conservation capacity; 525,200 acre-feet flood storage capacity.

Limestone Lake and Limestone Dam; Brazos River Basin, Navasota River; Leon, Limestone, and Robertson Counties; Brazos River Authority; municipal, industrial, and irrigation; impoundment began 1978; 225,400 acre-feet capacity.

Lake Livingston and Livingston Dam; Trinity River Basin, Trinity River; Polk, San Jacinto, Trinity, and Walker Counties; City of Houston and the Trinity River Authority; municipal, industrial and irrigation; impoundment began October 1968; 1,750,000 acre-feet capacity.

Loma Alta Reservoir and Loma Alta Dam; Nueces-Rio Grande Coastal Basin, off channel from the Rio Grande; Cameron County; Brownsville Navigation District; municipal, industrial; impoundment began 1963; 26,500 acre-feet capacity.

Lone Star Reservoir and Lone Star Dam; See Ellison Creek Reservoir and Ellison Creek Dam.

Walter E. Long Lake and Dam; formerly Decker Lake; Colorado River Basin, Decker Creek; Travis County; City of Austin; municipal, industrial; recreation; impoundment began January 1967; 33,940 acre-feet capacity.

McGee Bend Reservoir and McGee Bend Dam; See Sam Rayburn Reservoir and Sam Rayburn Dam.

Lake McQueeney and Abbott Dam; Guadalupe River Basin, Guadalupe River; Guadalupe County; Guadalupe-Blanco River Authority; hydropower; impoundment began 1928; 5,000 acre-feet capacity.

Mackenzie Reservoir and Mackenzie Dam; Red River Basin; Tule Creek; Swisher and Brisco Counties; Mackenzie Municipal Water Authority; municipal; impoundment began April 1974; 46,250 acre-feet capacity.

Marble Falls Lake and Max Starcke Dam; also called Max Starcke Lake; Colorado River Basin, Colorado River; Burnet County; Lower Colorado River Authority; hydropower; impoundment began July 1951; 8,760 acre-feet capacity.

Martin Lake and Martin Dam; Sabine River Basin, Martin Creek; Panola and Rusk Counties; Texas Utilities Services; steam-electric power; impoundment began 1974; 77,619 acre-feet capacity.

Pat Mayse Lake and Pat Mayse Dam; Red River Basin, Sanders Creek; Lamar County; operated by the U.S. Army Corps of Engineers, Tulsa District, City of Paris has contracted for conservation storage; municipal, industrial and flood control; impoundment began September 1967; 119,900 acre-feet conservation capacity; 64,600 acre-feet flood control capacity.

Medina Lake and Medina Dam; San Antonio River Basin, Medina River; Medina and Bandera Counties; Bexar-Medina-Atascosa Counties Water Improvement District No. 1; irrigation; impoundment began May 1913; 254,000 acre-feet capacity.

Lake Meredith and Sanford Dam; also called Lake Sanford; Canadian River Basin, Canadian River; Hutchison, Moore, and Potter Counties; constructed by Bureau of Reclamation, owned and operated by Canadian River Municipal Water Authority; municipal, flood control, and recreation; impoundment begain 1965; 864,400 acre-feet conservation capacity; 543,200 acre-feet flood control capacity.

Lake Mexia and Bristone Dam; Brazos River Basin, Navasota River; Limestone County; Bristone Municipal Water Supply District; municipal and industrial; impoundment began June 1961; 10,000 acre-feet capacity.

Millers Creek Reservoir and Millers Creek Dam; Brazos River Basin, Millers Creek; Baylor and Throckmorton Counties; North Central Texas Municipal Water Authority; municipal; impoundment began 1974; 25,520 acre-feet capacity.

Lake Mineral Wells and Mineral Wells Dam; Brazos River Basin, Rock Creek; Parker County; City of Mineral Wells; municipal; impoundment began 1920; 16,760 acre-feet capacity.

Monte Alto Reservoir and Monte Alto Dam; See Delta Lake and Delta Dam (Reservoir Unit 1 and Unit 2).

Monticello Reservoir and Monticello Dam; Cypress Creek Basin, Blundell Creek; Titus County; Texas Utilities Generating Company; steam-electric power; impoundment began August 1972; 40,100 acre-feet capacity.

Hubert H. Moss Lake and Fish Creek Dam; Red River Basin, Fish Creek; Cooke County; City of Gainsville; municipal and industrial; impoundment began April 1966; 23,210 acre-feet capacity.

Mountain Creek Lake and Mountain Creek Dam; Trinity River Basin, Mountain Creek; Dallas County; Dallas Power and Light Company; industrial; impoundment began March 1957; 22,840 acre-feet capacity.

Mud Creek Dam Lake; See Lake Tyler and Mud Creek Dam.

Murvaul Lake and Murvaul Dam; also called Panola Lake and Panola Dam; Sabine River Basin, Murvaul Bayou; Panola County; Panola County Fresh Water Supply District No. 1; municipal, industrial and recreation; impoundment began 1957; 45,810 acre-feet capacity.

Nacogdoches Lake and Nacogdoches Lake Dam; Neches River Basin, Bayo Loco Creek; Nacogdoches County; City of Nacogdoches; municipal, impoundment began July 1976; 41,140 acre-feet capacity.

Lake Nasworthy and Nasworthy Dam; Colorado River Basin, South Concho River; Tom Green County; City of San Angelo; municipal, industrial and irrigation; impoundment began March 1930; 12,390 acre-feet capacity.

Navarro Mills Lake and Navarro Mills Dam; Trinity River Basin, Richland Creek; Navarro and Hill Counties; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Trinity River Authority has contracted for conservation storage; municipal and flood control; impoundment began March 1963; 53,200 acre-feet conservation capacity; 143,200 acre-feet flood storage capacity.

Lake Nocona and Lake Nocona Dam; see Farmers Creek Reservoir and Farmers Creek Dam.

North Lake and North Lake Dam; Trinity River Basin, South Fork Grapevine Creek; Dallas County; Dallas Power and Light Company; steam-electric power; impoundment began March 1957; 17,000 acre-feet capacity.

North Fork Lake and North Fork Dam; See Georgetown lake and Georgetown Dam.

North Fork Buffalo Creek Reservoir and North Fork Buffalo Creek Dam; Red River Basin, North Fork Buffalo Creek; Wichita County; Wichita County Water Control and Improvement District No. 3; municipal; impoundment began November 1964; 15,400 acre-feet capacity.

Oak Creek Reservoir and Oak Creek Dam; Colorado River Basin, Oak Creek; Coke and Nolan Counties; City of Sweetwater; municipal, industrial; impoundment began May 1953; 39,360 acre-feet capacity.

Olmos Reservoir and Olmos Dam; San Antonio River Basin, Olmos Creek; Bexar County; City of San Antonio; flood control only; impoundment began 1926; 12,600 acre-feet flood control capacity.

Lake Palestine and Blackburn Crossing Dam; also called Blackburn Crossing Lake; Neches River Basin, Neches River; Anderson, Cherokee, Henderson, and Smith Counties; Upper Neches River Municipal Water Authority; municipal, industrial, and recreation; impoundment began May 1962; 411,300 acre-feet capacity.

Palmetto Bend Reservoir and Palmetto Bend Dam; See Texana Lake and Texana Dam.

Lake Palo Pinto and Palo Pinto Creek Dam; Brazos River Basin, Palo Pinto Creek; Palo Pinto County; Palo Pinto County Municipal Water District No. 1 and City of Mineral Wells; municipal and industrial; impoundment began April 1964; 42,200 acre-feet capacity.

Panola Lake and Panola Dam; See Murvaul Lake and Murvaul Dam.

Wright Patman Lake and Wright Patman Dam; formerly Lake Texarkana and Texarkana Dam; Sulpher River Basin, Sulpher River; Bowie and Cass Counties; operated by the U.S. Army Corps of Engineers, Fort Worth District, City of Texarkana has contracted for conservation storage; flood control, municipal, industrial and recreation; impoundment began June 1956; 145,300 acre-feet conservation capacity; 2,363,700 acre-feet flood control capacity.

Pinkston Reservoir and Pinkston Dam; formerly Sandy Creek Reservoir; Neches River Basin, Sandy Creek; Shelby County; City of Center; municipal; impoundment began 1974; 7,380 acre-feet capacity.

***Joe Pool Reservoir and Joe Pool Dam;** also called Lakeview Lake and Lakeview Dam; Trinity River Basin; Mountain Creek; Dallas, Ellis and Tarrant Counties; under construction by the U.S. Army Corps of Engineers, Fort Worth District, Trinity River Authority has contracted for conservation storage; flood control, municipal, and recreation; impoundment scheduled for December 1985; 176,900 acre-feet conservation capacity; 123,100 acre-feet flood storage capacity.

Possum Kingdom Lake and Morris Sheppard Dam; Brazos River Basin, Brazos River; Palo Pinto, Stephens and Young Counties; Brazos River Authority; municipal, industrial, irrigation, recreation, power, and mining including oil production; impoundment began March 1941; 569,380 acre-feet capacity.

Proctor Lake and Proctor Dam; Brazos River Basin, Leon River; Comanche County; owned and operated by U.S. Armu Corps of Engineers, Fort Worth District, Brazos River Authority has contracted for conservation storage; flood control, municipal, industrial, irrigation, and recreation; impoundment began September 1963; 31,400 acre-feet conservation capacity; 310,100 acre-feet flood control capacity.

Lake Quitman and Wood County Dam No. 1; Sabine River Basin, Dry Creek; Wood County; Wood County; recreation and flood control; impoundment began May 1962; 7,440 acre-feet capacity.

Lake Randall and Randall Dam; Red River Basin, Shawnee Creek; Grayson County; City of Denison; municipal; impoundment began 1909; 6,290 acre-feet capacity.

Sam Rayburn Reservoir and Sam Rayburn Dam; formerly McGee Bend Reservoir and McGee Bend Dam; Neches River Basin, Angelina River; Angelina, Jasper, Nacogdoches, Sabine and San Augustine Counties; operated by the U.S. Army Corps of Engineers, Fort Worth District, Lower Neches Valley Authority has contracted for conservation storage; municipal, industrial, irrigation, hydroelectric power, recreation, and flood control; impoundment began March 1965; 1,446,200 acre-feet conservation capacity; 1,099,100 acre-feet flood control capacity.

Red Bluff Reservoir and Red Bluff Dam; Rio Grande Basin, Pecos River; Reeves and Loving Counties; Red Bluff Water Power Control District; irrigation and hydropower; impoundment began September 1936; 307,000 acre-feet capacity.

River Crest Lake and River Crest Levee; Sulphur River Basin, off channel of Sulphur River; Red River County; Texas Power and Light Company; steam-electric power; impoundment began November 1953; 7,000 acre-feet capacity.

***Richland Creek Reservoir and Richland Creek Dam;** Trinity River Basin, Richland Creek; Freestone and Navarro Counties; under construction by Tarrant County Water Control and Improvement District No. 1; municipal; initial impoundment scheduled for 1985; 1,135,000 acre-feet capacity.

***Ray Roberts Lake and Ray Roberts Dam;** formerly Aubrey Lake and Dam; Trinity River Basin, Elm Fork Trinity River; Cooke, Denton, and Grayson Counties; under construction by the U.S. Army Corps of Engineers, Fort Worth District, Cities of Dallas and Denton have contracted for conservation storage; flood control, municipal, industrial, recreation; initial impoundment scheduled for 1986; 749,200 acre-feet conservation capacity, 260,800 acre-feet flood control capacity.

Salt Creek Lake; See Lake Graham and Graham Dam.

San Angelo Reservoir and Dam; See O.C. Fisher Lake and Dam.

Bob Sandlin Lake and Fort Sherman Dam; also called Cherokee Trails Lake; Cypress Creek Basin, Big Cypress Creek; Camp, Franklin, Titus, and Wood Counties; Titus County Fresh Water Supply District No. 1; municipal, industrial, and recreation; impoundment began 1978; 202,300 acre-feet capacity.

Sandon Lake and Sandon Dam; See Alcoa Lake and Dam.

Sandy Creek Reservoir and Sandy Creek Dam; See Pinkston Reservoir and Dam.

San Estaban Lake and San Esteban Dam; Rio Grande Basin, Alamito Creek; Presidio County; (1969) Mr. William B. Blakemore; recreation; impoundment began 1911; 18,770 acre-feet capacity.

Sanford Lake; See Lake Meredith and Sanford Dam.

Santa Rosa Lake and Santa Rosa Dam; Red River Basin, Beaver Creek; Wilbarger County; W. T. Waggoner Estate; mining; impoundment began 1929; 11,570 acre-feet capacity.

Sheldon Reservoir and Sheldon Dam; San Jacinto River Basin, Carpenters Bayou; Harris County; Texas Parks and Wildlife Department; recreation and fish hatchery; impoundment began December 1943; 5,420 acre-feet capacity.

Smithers Lake and Smithers Lake Dam; also called Lake George; Brazos River Basin, Dry Creek; Fort Bend County; Houston Lighting and Power; steam-electric power; impoundment began October 1957; 18,700 acre-feet capacity.

Somerville Lake and Somerville Dam; Brazos River Basin, Yegua Creek;Burleson, Lee, and Washington Counties; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority has contracted for conservation storage; flood control, municipal, industrial, and irrigation; impoundment began January 1967; 143,900 acre-feet conservation capacity; 337,700 acre-feet flood control capacity.

Southland Paper Mills Reservoir; see Lake Kurth and Kurth Dam.

South Texas Project Reservoir; Colorado River Basin; off channel of Colorado River; Matagorda County; Houston Lighting and Power; steam-electric power; 187,000 acre-feet capacity.

E.V. Spence Reservoir and Robert Lee Dam; also called Robert Lee Lake; Colorado River Basin, Colorado River; Coke County; Colorado River Municipal Water District; municipal, industrial, and mining; impoundment began December 1968; 484,800 acre-feet capacity.

Squaw Creek Reservoir and Squaw Creek Dam; Brazos River Basin, Squaw Creek; Hood and Somervell Counties; Texas Utilities Services Company; steam-electric power; impoundment began 1977; 151,047 acre-feet capacity.

Lake Stamford and Stamford Dam; Brazos River Basin, Paint Creek; Haskell County; City of Stamford; municipal and industrial; impoundment began June 1953; 52,700 acre-feet capcity.

B.A. Steinhagen Lake and Town Bluff Dam; Also known as Town Bluff Reservoir, and Dam B Lake and Dam B; Neches River Basin, Neches River; Jasper and Tyler Counties; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Lower Neches Valley Authority has contracted for conservation storage; municipal, industrial, and recreation; impoundment began April 1951; 94,200 acre-feet capacity.

Stillhouse Hollow Lake and Stillhouse Hollow Dam; also called Lampases Reservoir and Lampases Dam; Brazos River Basin, Lampasas River; Bell County; owned and operated by U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority has contracted for conservation storage; flood control, municipal, industrial, irrigation, recreation; impoundment began February 1968; 204,900 acre-feet conservation capacity; 390,600 acre-feet flood control capacity.

Striker Creek Reservoir and Striker Creek Dam; Neches River Basin, Striker Creek; Cherokee and Rusk Counties; Angelina and Nacogdoches Counties Water Control and Improvement District No. 1; municipal and industrial; impoundment began May 1957; 26,960 acre-feet capacity.

Sulpher Springs Lake and Sulpher Springs Lake Dam; formerly White Oak Creek Reservoir and White Oak Creek Dam; Sulpher River Basin, White Oak Creek; Hopkins County; Sulpher Springs Water District; municipal; impoundment began July 1973; 13,520 acre-feet capacity.

Swauano Creek Reservoir and Swauano Creek Dam; See Welsh Reservoir and Welsh Dam.

Sweetwater Lake and Sweetwater Dam; Brazos River Basin, Bitter and Cottonwood Creeks; Nolan County; City of Sweetwater; municipal and industrial, impoundment began 1930; 11,900 acre-feet capacity.

Lake Tawakoni and Iron Bridge Dam, also called Iron Bridge Dam and Lake; Sabine River Basin, Sabine River; Hunt, Rains, and Van Zandt Counties; Sabine River Authority; municipal, industrial, irrigation, and recreation; impoundment began October 1960; 936,200 acre-feet conservation capacity.

New Terrell City Lake and Terrell Dam; Trinity River Basin, Muddy Cedar Creek; Kaufman County; City of Terrell; municipal, recreation; impoundment began November 1955; 8,712 acre-feet capacity.

Texana Lake and Texana Dam; Formerly Palmetto Bend Reservoir and Dam, Lavaca River Basin, Navidad River and Sandy Creek; Jackson County; constructed by U.S. Bureau of Reclamation, owned and operated by Lavaca-Navidad River Authority and Texas Water Development Board; municipal and irrigation; impoundment began 1981; 157,900 acre-feet capacity.

Lake Texarkana and Texarkana Dam; See Wright Patman Lake and Wright Dam.

Lake Texoma and Denison Dam; Red River Basin, Red River; Cooke and Grayson Counties; owned and operated by U.S. Army Corps of Engineers, Tulsa District; hydropower, flood control, conservation, and recreation; impoundment began October 1943; 2,722,000 acre-feet conservation capacity; 2,660,000 acre-feet flood control capacity.

J.B. Thomas Lake and Colorado River Dam; Colorado River Basin, Colorado River; Scurry and Borden Counties; Colorado River Municipal Water District; municipal, industrial, and recreation; impoundment began July 1952; 202,300 acre-feet capacity.

Toledo Bend Reservoir and Toledo Bend Dam; Sabine River Basin, Sabine River; Newton, Sabine and Shelby Counties; Sabine River Authority of Texas and Louisiana; municipal, industrial, irrigation, hydropower, and recreation; impoundment began October 1966; 4,472,900 acre-feet capacity.

Town Bluff Reservoir and Town Bluff Dam; See B.A. Steinhagen Lake.

Tradinghouse Creek Reservoir and Tradinghouse Creek Dam; Brazos River Basin, Tradinghouse Creek; McLennan County; Texas Power and Light Company; steam-electric power; impoundment began July 1968; 35,124 acre-feet capacity.

Lake Travis and Mansfield Dam; Colorado River Basin, Colorado River; Travis and Burnet Counties; Lower Colorado River Authority; municipal industrial, irrigation, mining, hydropower, flood control, and recreation; impoundment began September 1940; 1,144,100 acre-feet conservation capacity, 781,400 acre-feet flood control capacity.

Trinidad Lake and Trinidad Levee; Trinity River Basin, off-channel of Trinity River; Henderson County; Texas Power and Light Company; hydropower; impoundment began 1925; 7,450 acre-feet capacity.

Truscott Brine Lake and Truscott Brine Lake Dam; Red River Basin; Bluff Creek; Knox County; constructed by U.S. Army Corps of Engineers, Tulsa District; impoundment began 1984; 107,000 acre-feet capacity.

Turtle Bayou Reservoir; See Anahuac Lake and Anahuac Dam.

Twin Buttes Reservoir and Twin Buttes Dam; Colorado River Basin, South Concho River; Spring Creek and Middle Concho River; Tom Green County; constructed by the Bureau of Reclamation, conservation storage maintained and operated by the City of San Angelo, flood control storage operated by the U.S. Army Corps of Engineers; municipal, industrial, flood control, irrigation, and recreation; impoundment began December 1962; 177,800 acre-feet conservation capacity, 905,050 acre-feet flood control capacity.

Twin Oaks Reservoir and Twin Oaks Dam; Brazos River Basin, Duck Creek; Robertson County; Texas Power and Light Company; steam-electric power; impoundment began 1982; 30,319 acre-feet capacity.

Lake Tyler and Mud Creek Dam and Whitehouse Dam; also called Mud Creek Dam Lake; Neches River Basin, Mud Creek and Prairie Creek; Smith County; City of Tyler; municipal and industrial; impoundment began November 1966 (Mud Creek) and January 1949 (Whitehouse); 73,700 acre-feet capacity.

Upper Nueces Reservoir and Upper Nueces Dam; Nueces River Basin, Nueces River; Zavala County; Zavala and Dimmit Counties Water Improvement District Number 1; irrigation; impoundment began March 1948; 7,590 acre-feet capacity.

Valley Lake and Valley Dam; formerly Brushy Creek Reservoir and Dam; Red River Basin, Brushy Creek; Fannin and Grayson Counties; Texas Power and Light Company; steam-electric power; impoundment began December 1960; main water supply is pumped from Red River; 16,400 acre-feet capacity.

Valley Acres Lake and Valley Acres Dam; Nueces-Rio Grande Coastal Basin, off channel from the Rio Grande; Hidalgo County; Valley Acres Water District; irrigation, and municipal; impoundment began 1947; 7,840 acre-feet capacity.

Waco Lake and Waco Dam; Brazos River Basin, Bosque River; McLennan County; owned and operated by the U.S. Army Corps of Engineers, Fort Worth District, Brazos River Authority and City of Waco has contracted for conservation storage; flood control, municipal, industrial, and recreation; impoundment began February 1965; 104,100 acre-feet conservation capacity; 553,300 acre-feet flood control capacity.

***Wallisville Lake and Wallisville Dam;** Trinity River Basin, Trinity River; Chambers and Liberty Counties; under construction by the U.S. Army Corps of Engineers, Galveston District; municipal, industrial and irrigation; 58,000 acre-feet capacity.

Lake Waxahachie and South Prong Dam; Trinity River Basin, South Prong Creek; Ellis County; Ellis County Water Control and Improvement District No. 1; municipal and industrial; impoundment began November 1956; 13,500 acre-feet capacity.

Weatherford Lake and Weatherford Dam; Trinity River Basin, Clear Fork Trinity River; Parker County; City of Weatherford; municipal and industrial; impoundment began March 1957; 19,470 acre-feet capacity.

White River Lake and White River Dam; Brazos River Basin, White River; Crosby County; White River Municipal Water District; municipal, industrial,and mining including oil production; impoundment began October 1963; 37,950 acre-feet capacity.

White Rock Lake and White Rock Dam; Trinity River Basin, White Rock Creek; Dallas County; City of Dallas; recreation; impoundment began 1910; 10,740 acre-feet capacity.

Whitney Lake and Whitney Dam; Brazos River Basin, Brazos River; Bosque, Hill and Johnson Counties; owned and operated by U.S. Army of Engineers, Fort Worth District, Brazos River Authority has contracted for the water supply storage; flood control and hydroelectric power; impoundment began December 1951; 627,100 acre-feet conservation capacity; 1,372,400 acre-feet flood control capacity.

Lake Wichita and Lake Wichita Dam; Red River Basin, Holiday Creek; Archer and Wichita Counties; City of Wichita Falls; municipal, steam-electric power, and recreation; impoundment began 1901; 14,000 acre-feet capacity.

Lake Winneboro and Wood County Dam No. 4; Sabine River Basin, Big Sandy Creek; Wood County; Wood County; recreation and flood control; impoundment began July 1962; 8,100 acre-feet conservation capacity.

Winters Lake and Winters Dam; Colorado River Basin, Elm Creek; Runnels County; City of Winters; municipal; 8,370 acre-feet capacity.

Lake Worth and Lake Worth Dam; Trinity River Basin, West Fork Trinity impoundment began March 1957; 17,000 acre-feet capacity.

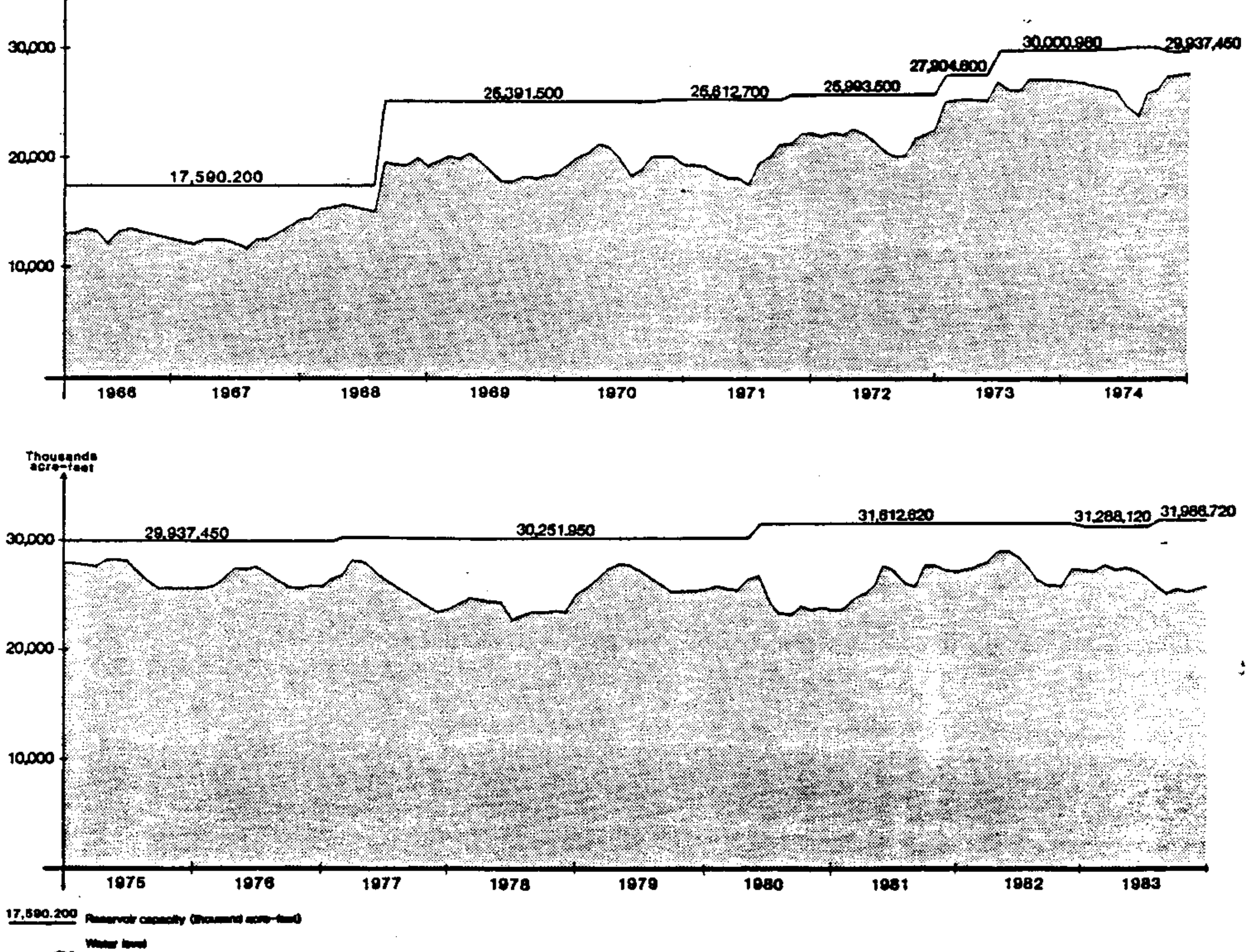
APPENDIX B

HISTORICAL RESERVOIR STORAGE LEVELS

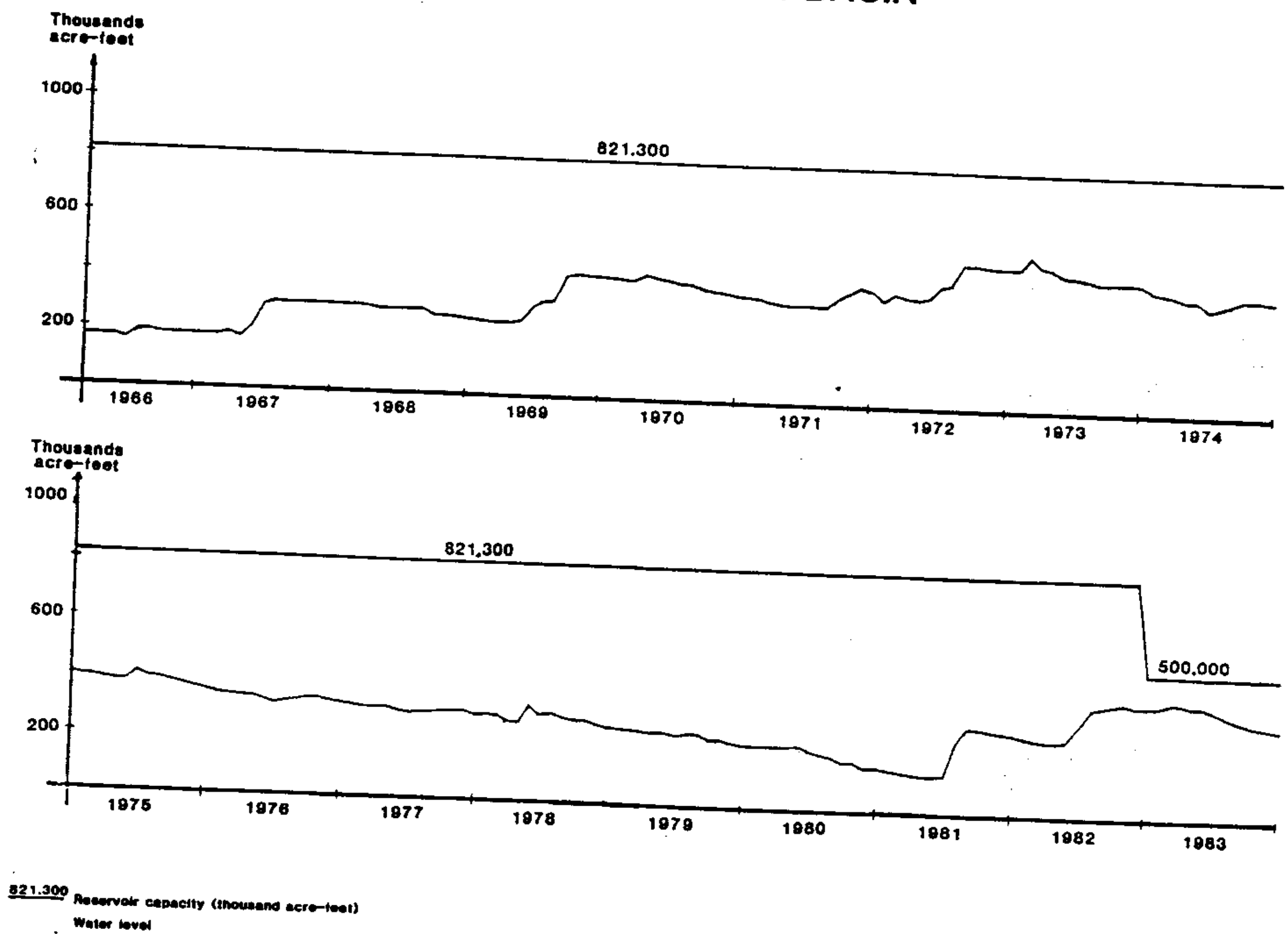
APPENDIX B
INTRODUCTION

The Texas Department of Water Resources (TDWR) publishes monthly conservation storage data for selected reservoirs, which presently include 71 projects containing 98 percent of the total conservation capacity of the major reservoirs. The number and capacity of reservoirs included has varied over the years as new projects were constructed. Adjustments have also been made occasionally in the capacities cited for existing projects. The storages contained in each reservoir near the end of the month are tabulated. The data is published in the TDWR monthly newsletter "Texas Water" and its predecessor "Water for Texas". The monthly storage data taken from these publications were compiled and plotted to provide the following graphs. Reservoir capacity and storage content are plotted for the 18-year period from 1966 through 1983 for each major river basin and the state as a whole. These plots provide a convenient visual summary of the past fluctuations in reservoir storage levels on a basinwide basis.

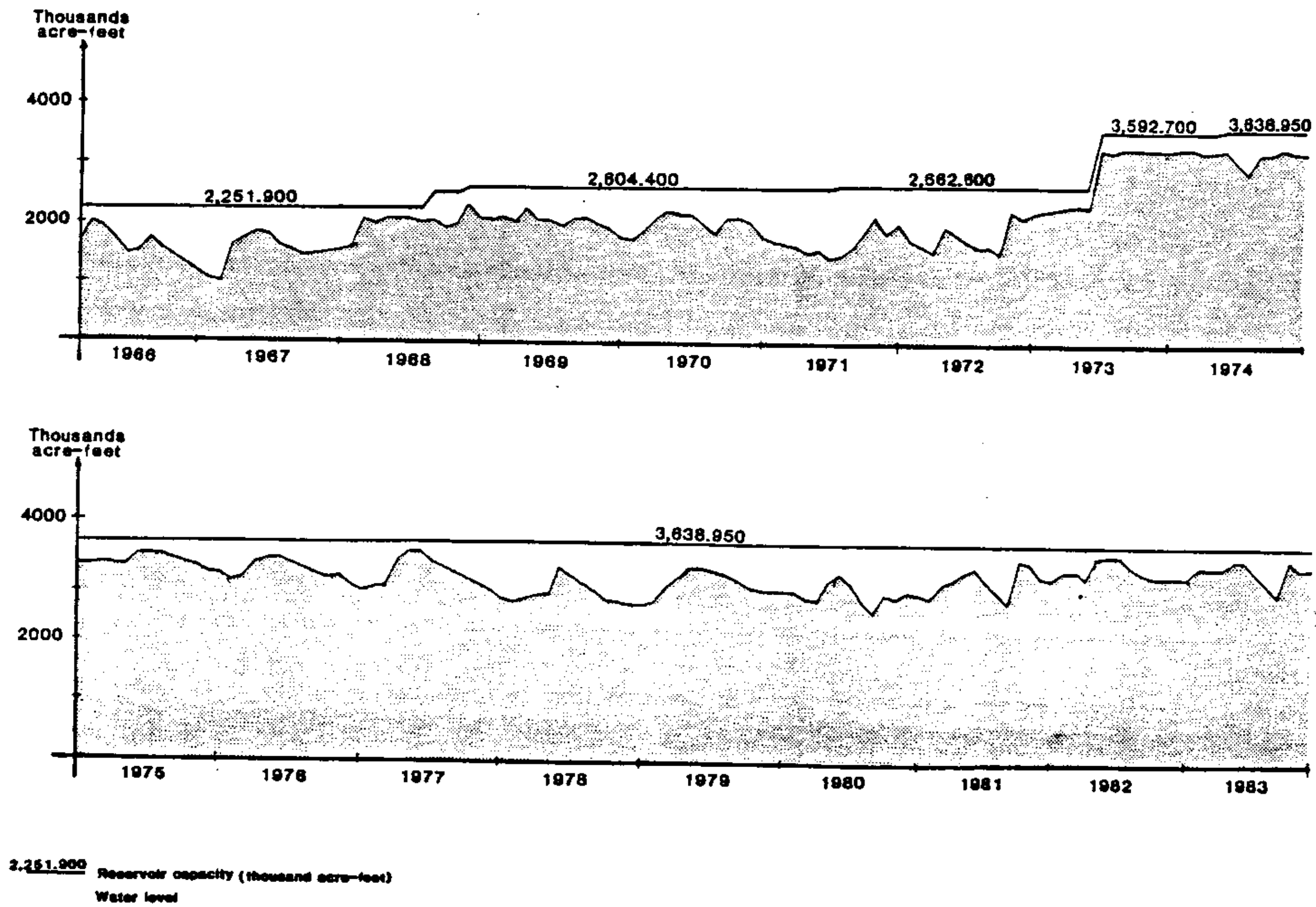
STATE OF TEXAS



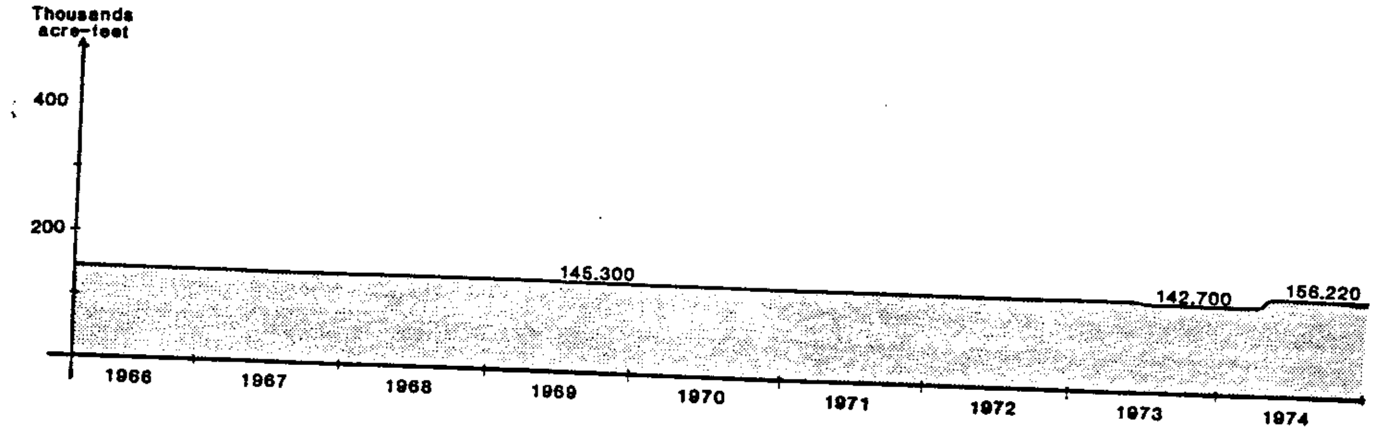
CANADIAN RIVER BASIN

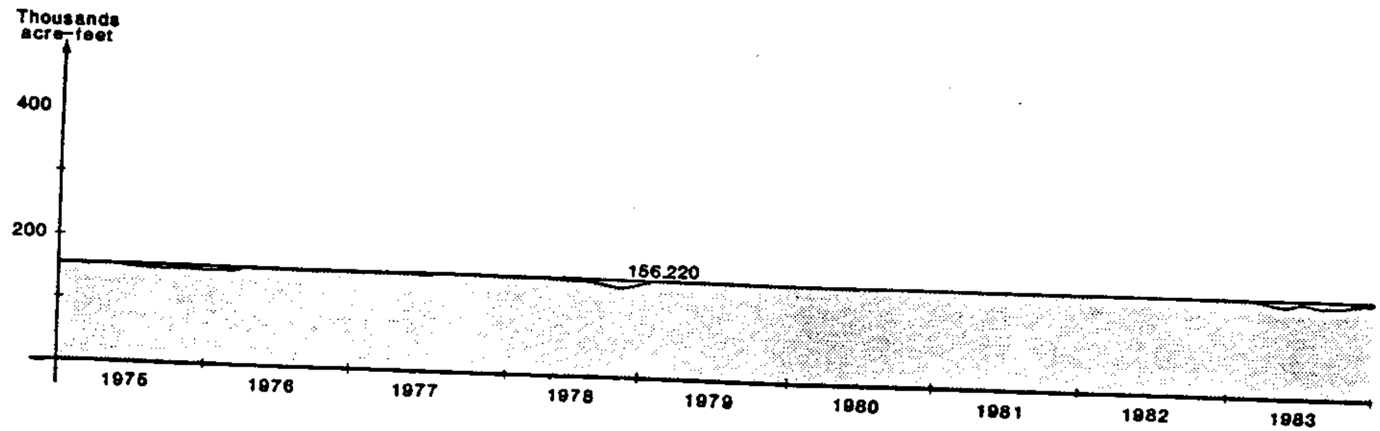


RED RIVER BASIN



SULPHUR RIVER BASIN

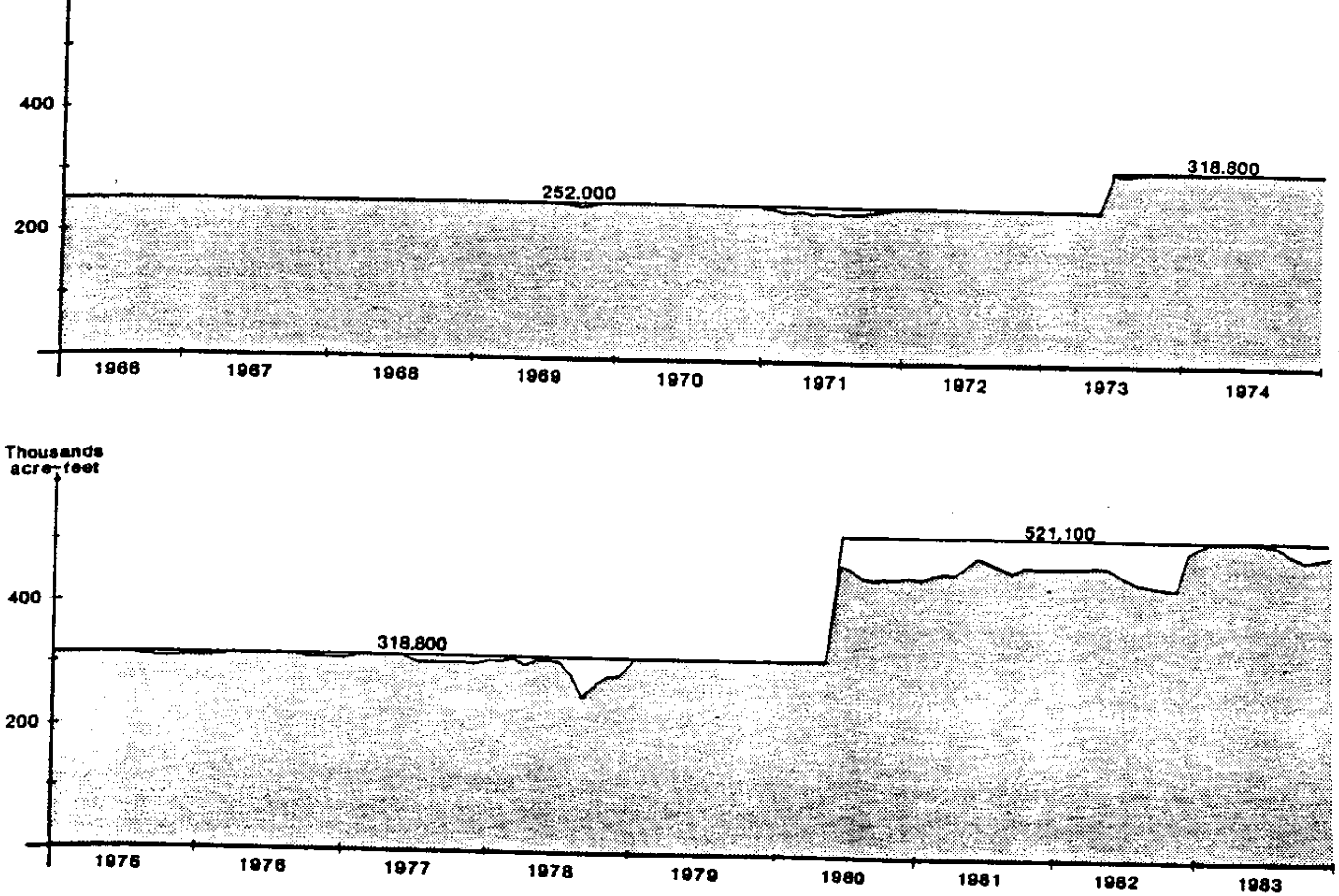




145.300 Reservoir capacity (thousand acre-feet)

Water level

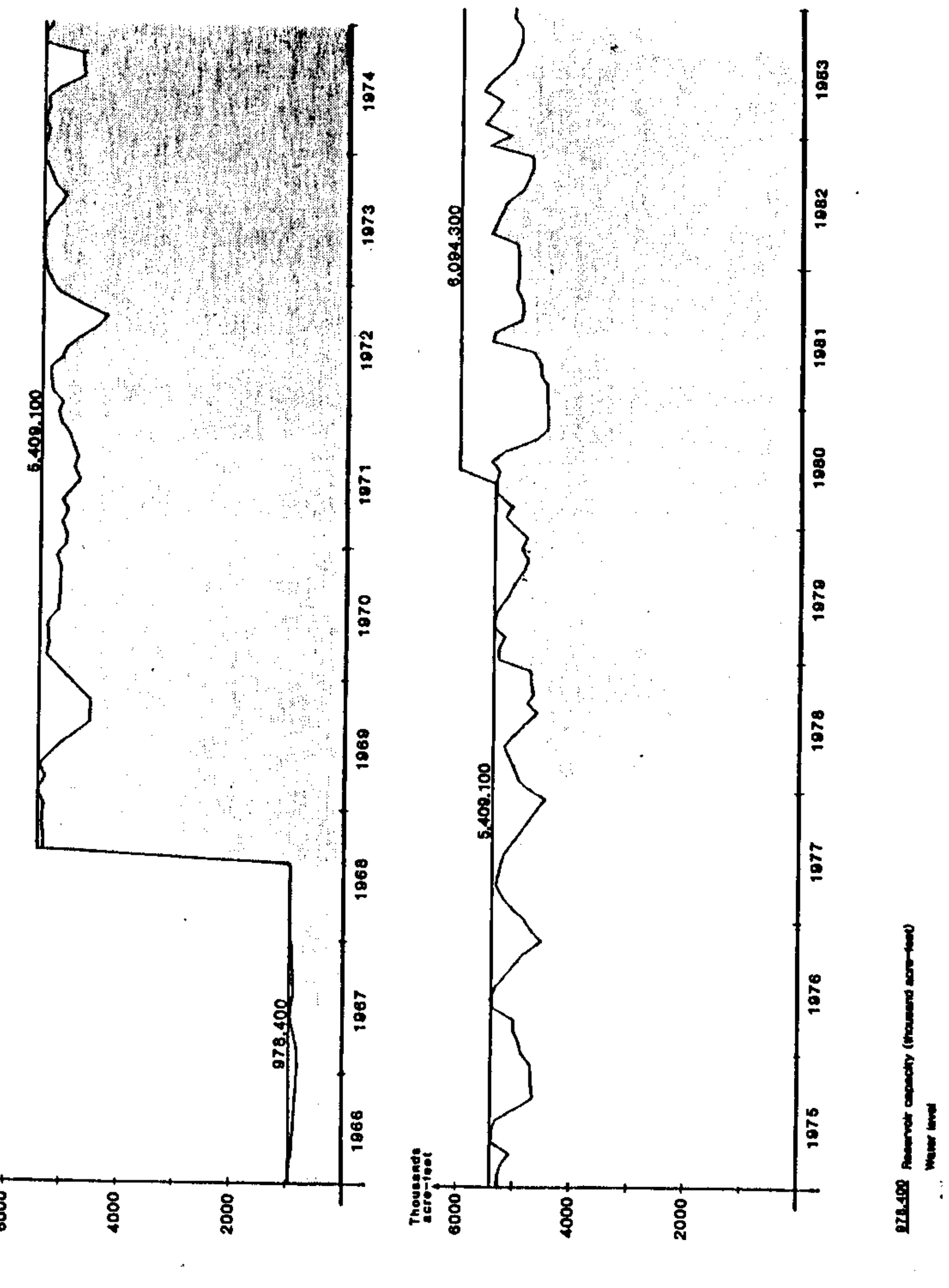
CYPRESS CREEK BASIN



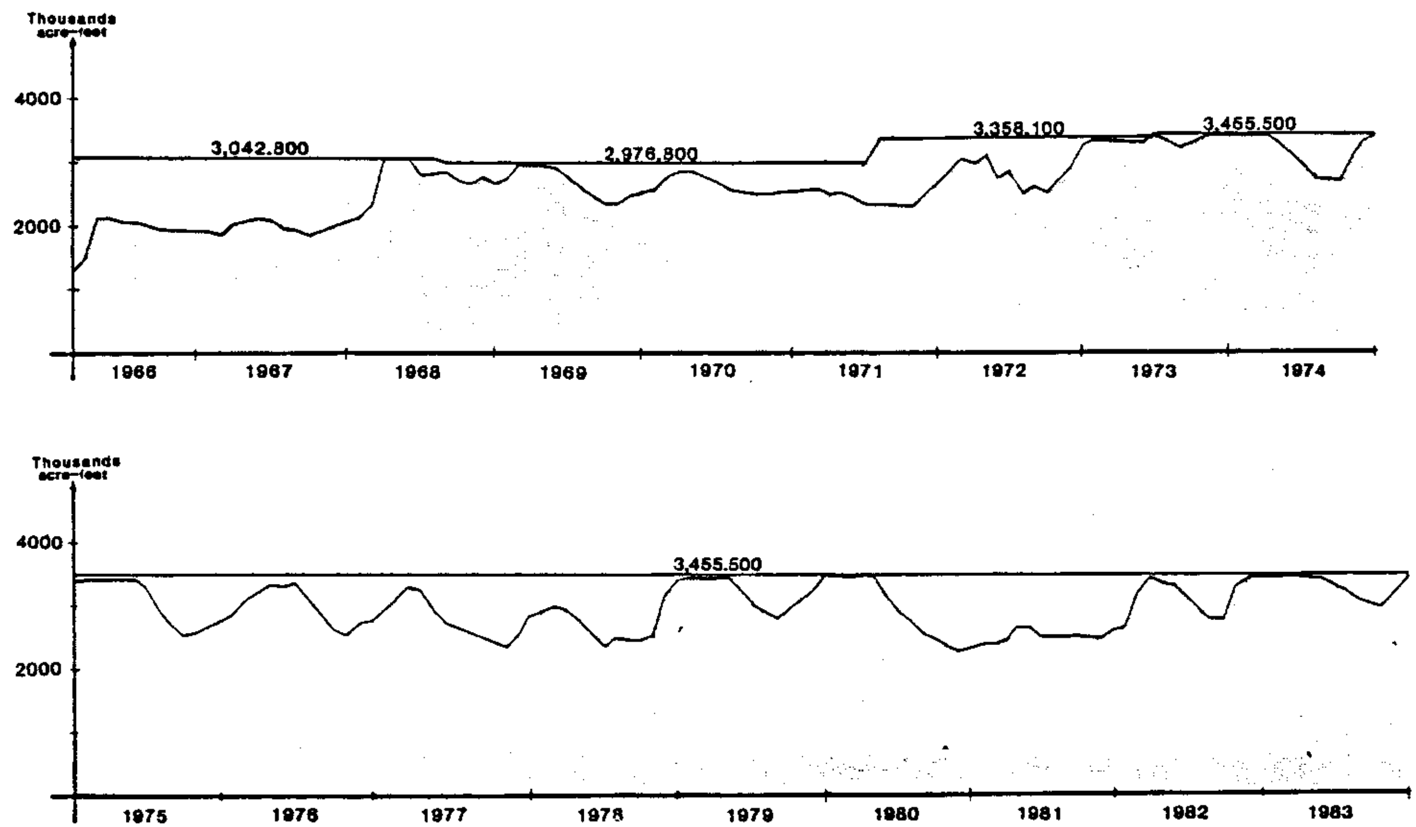
252,000 Reservoir capacity (thousand acre-feet)

Water level

SABINE RIVER BASIN



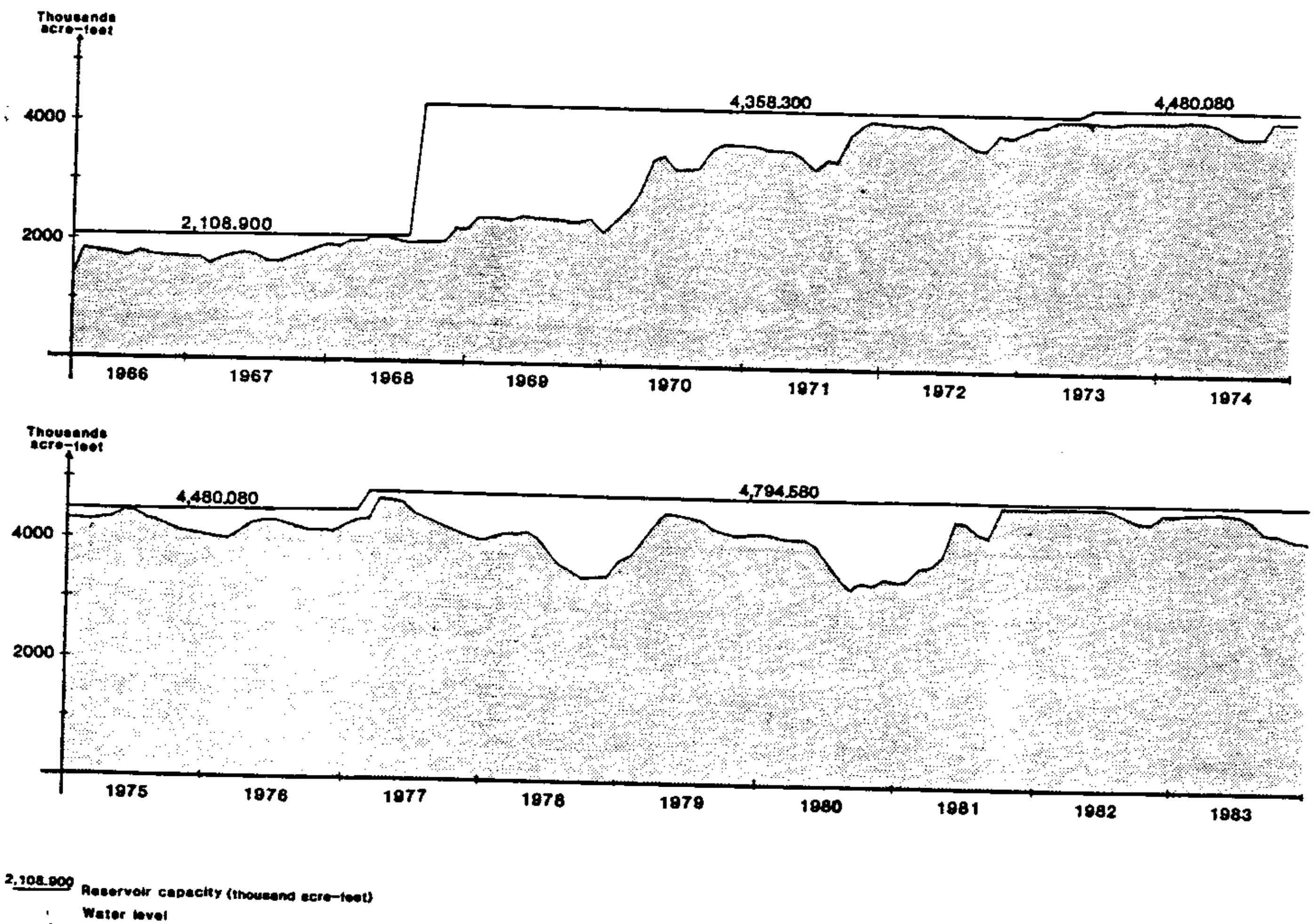
NECHES RIVER BASIN



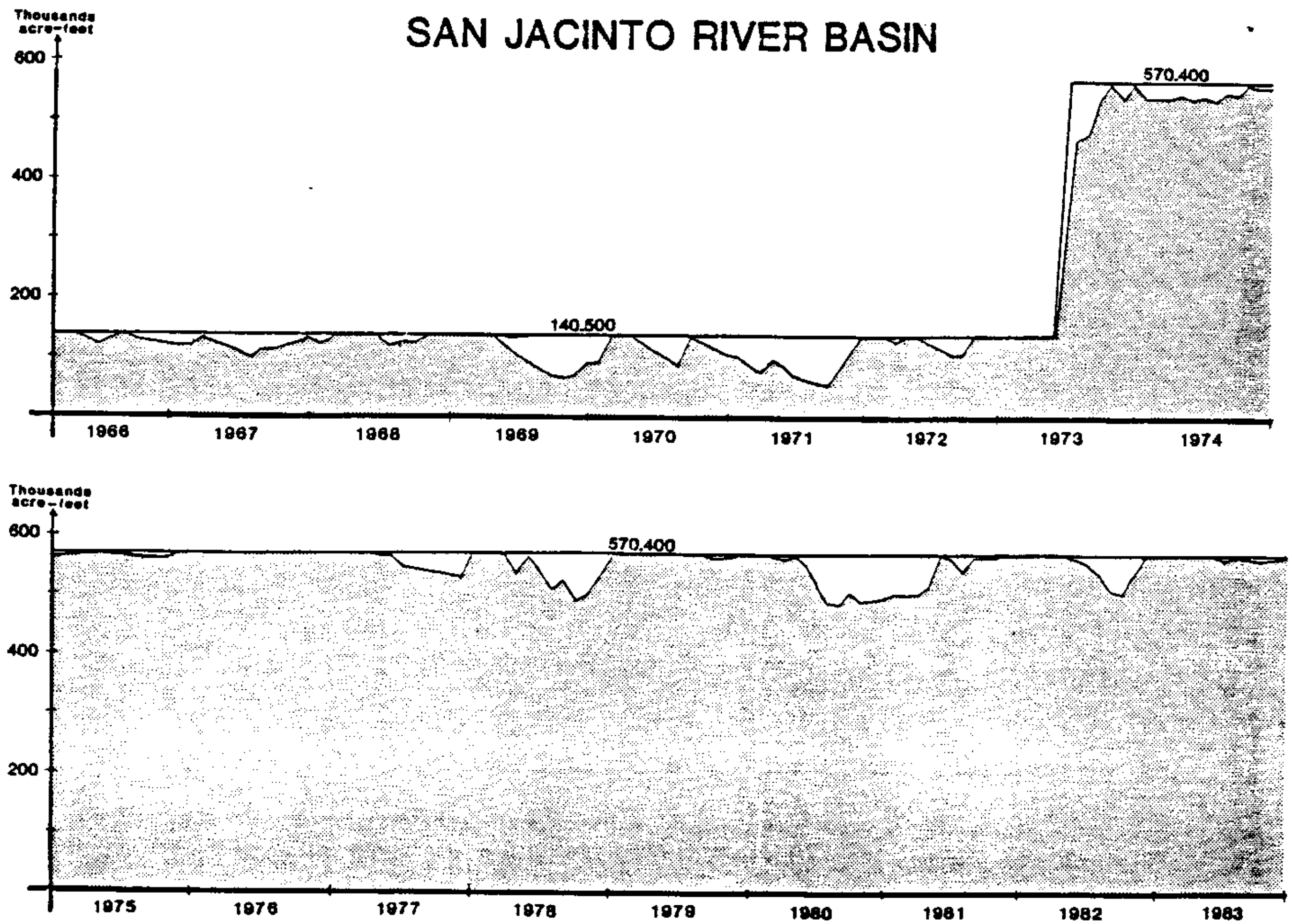
3,042.800 Reservoir capacity (thousand acre-feet)

— Water level

TRINITY RIVER BASIN

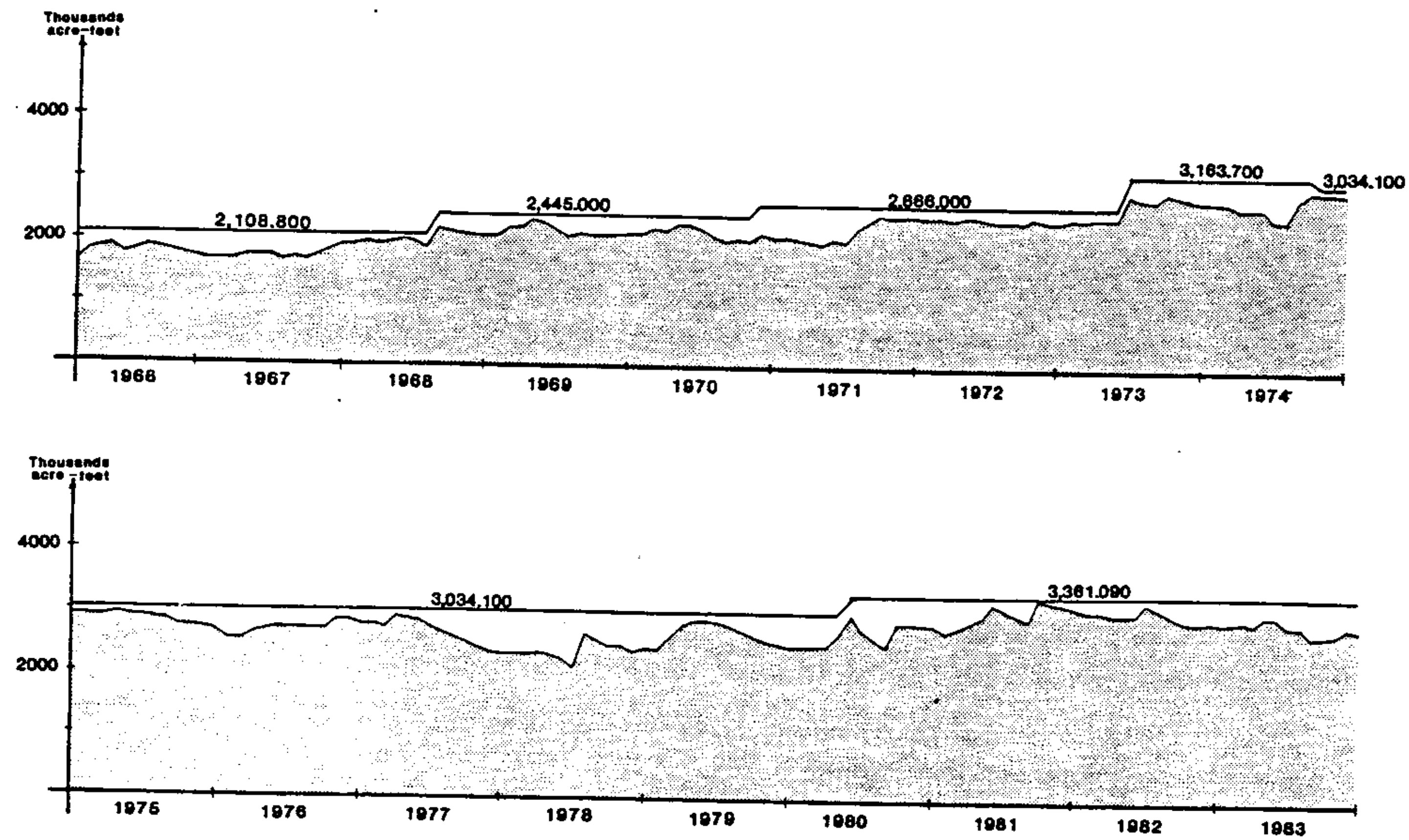


SAN JACINTO RIVER BASIN



140,500 Reservoir capacity (thousand acre-feet)
Water level

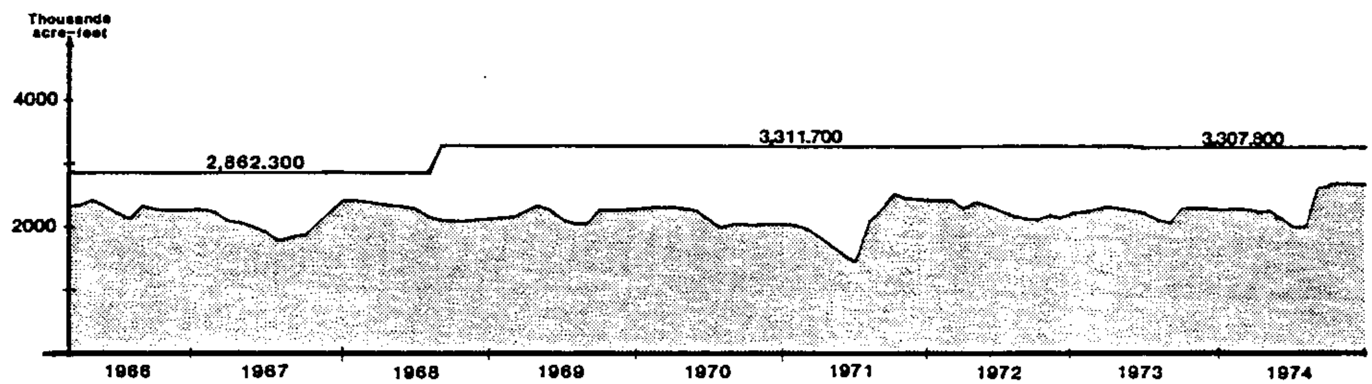
BRAZOS RIVER BASIN

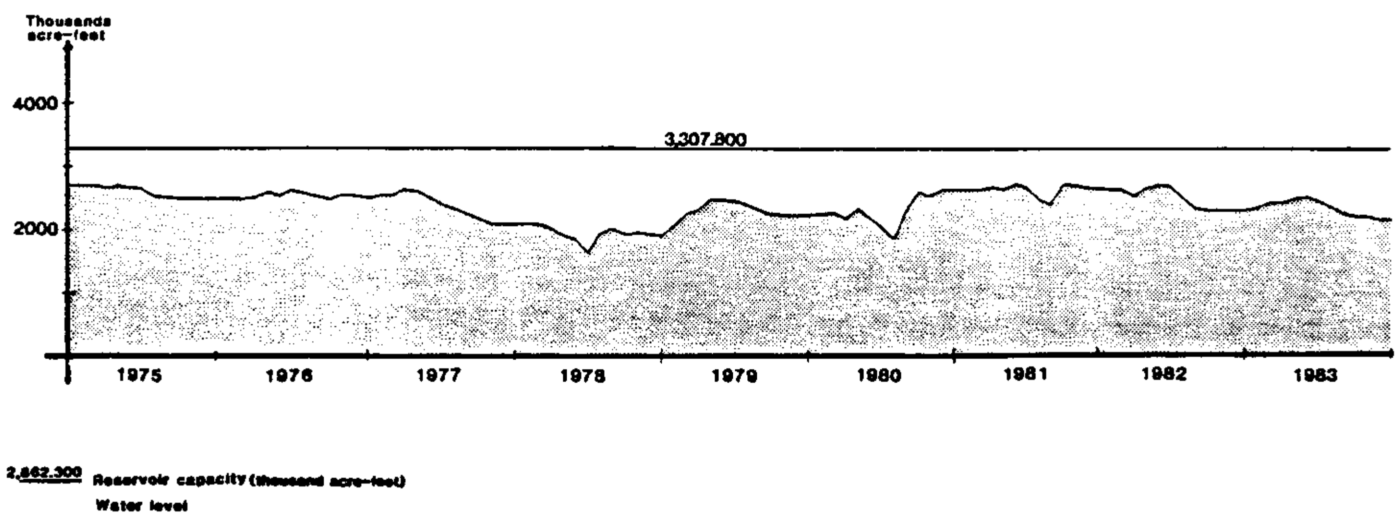


2,108,800 Reservoir capacity (thousand acre-feet)

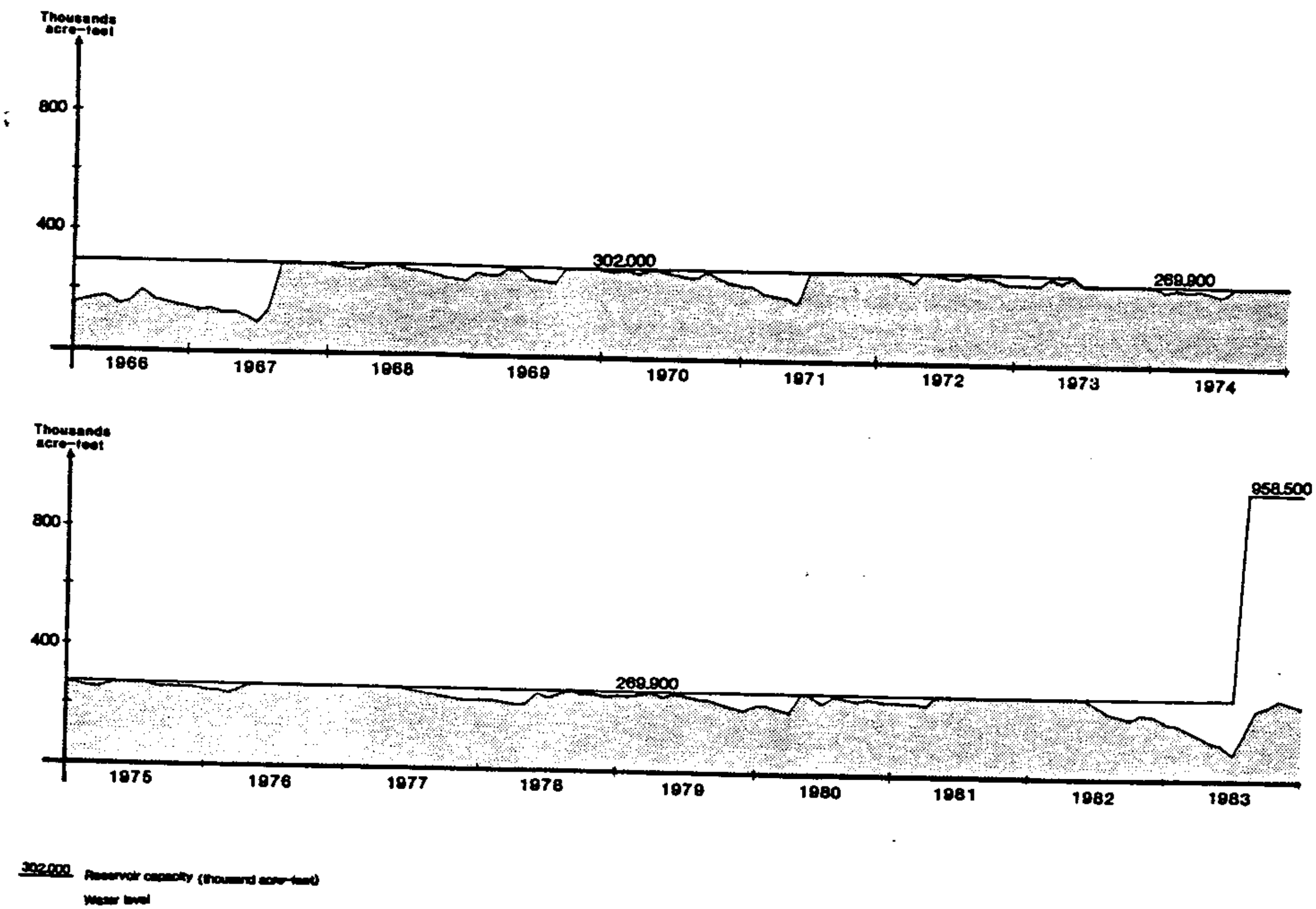
Water level

COLORADO RIVER BASIN

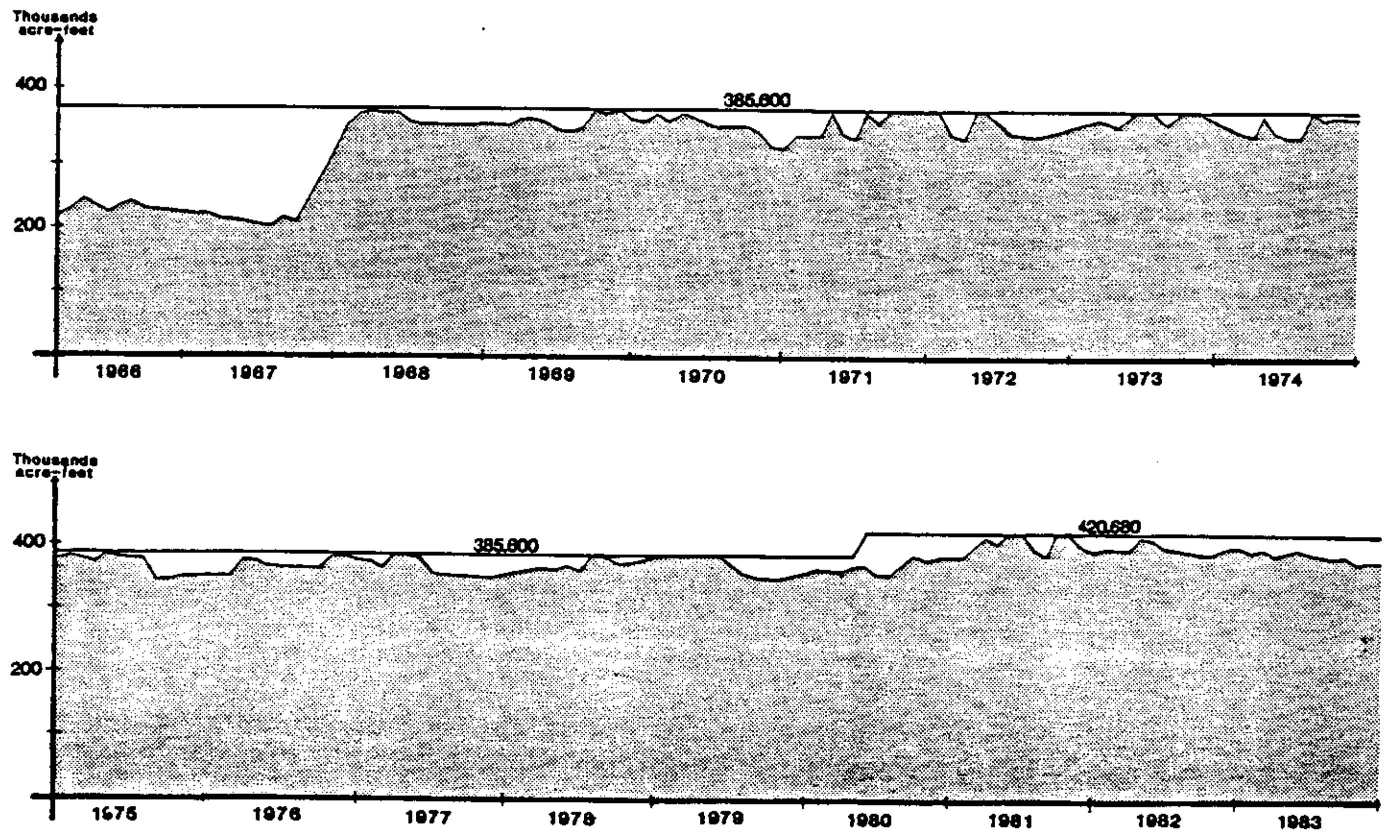




NUECES RIVER BASIN

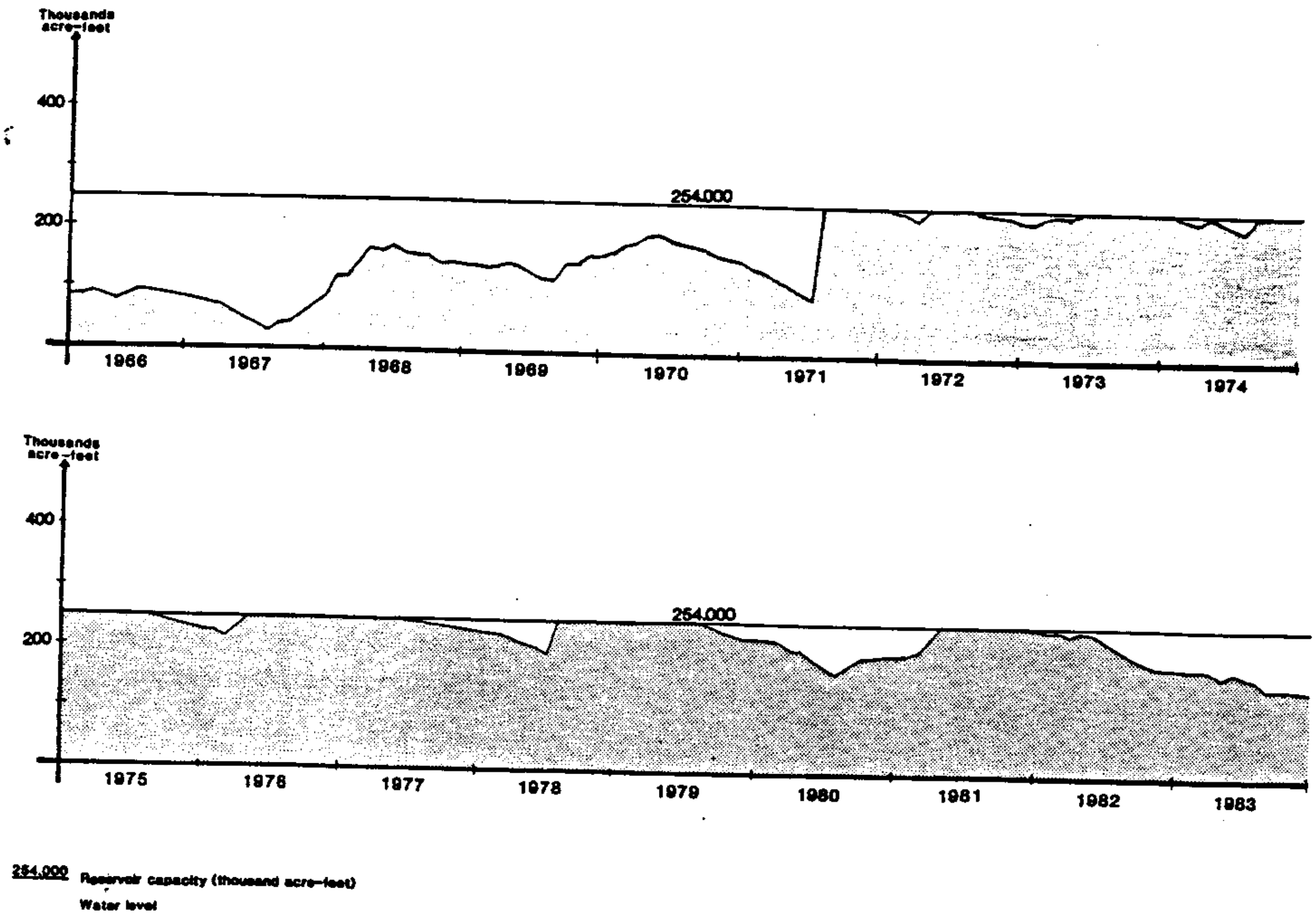


GUADALUPE RIVER BASIN



385,600 Reservoir capacity (thousand acre-feet)
Water level

SAN ANTONIO RIVER BASIN



RIO GRANDE BASIN