TEXAS WATER COMMISSION

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BULLETIN 6403

FIFTY YEARS OF WATER DEVELOPMENT

IN TEXAS

By

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FOREWORD

A half-century can reflect a great deal of change particularly in the development and utilization of water resources. In response to numerous inquiries, this publication was prepared as a review of several of the significant developments of surface and ground water, their uses, and related basic-data studies between 1913 and 1963. This is timely as the Texas Water Commission begins its second 50 years in administering the water resources of the State.

Many of the functions of the Texas Water Commission are mentioned; however, this is far from being an exhaustive listing. Description of such functions as that of the State Reclamation Engineer, coordinated activities with the State Water Pollution Control Board, water districts, Texas Water Development Board, and the broad field of water resources planning are beyond the scope of this publication.

This report was originally prepared by the authors for presentation by the undersigned at another 50 years anniversary--that of the Texas Section of the American Society of Civil Engineers--celebrated in San Antonio on October 4, 1963. It was expanded and prepared for publication to meet a growing public interest in the future of the State's water resources program.

TEXAS WATER COMMISSION

John J. Vandertulip

John J. Vandertulip
Chief Engineer

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INTRODUCTION

During the next 32 years, the population of Texas will double. Fifty years from now the State's population will be 2-1/2 times the present 10 million. Metropolitan complexes will exist in place of many of our present cities. New industries will be making products that are yet to be invented. There will be increased reliance on agriculture in Texas to meet the food and fiber requirements of the State and the Nation. An estimated 3-3/4 million new jobs will be needed for the Texans of 50 years from now. Transportation will be needed to provide for the industrial and agricultural products of that time.

Water requirements for future municipal, industrial, and agricultural purposes will be much greater than our present facilities can supply. Planning studies to demonstrate how these various future water needs can be supplied have been made by numerous river authorities and conservation districts, by the Texas Water Commission, and by various Federal agencies, including U. S. Army Corps of Engineers, U. S. Bureau of Reclamation, and the U. S. Study Commission-Texas. It is essential that these planning studies be made on a continuing basis; other studies also are needed.

Although the tremendous future tasks of additional development of our water resources, together with the related problems of flood control, navigation, drainage, and proper treatment and disposal of municipal and industrial wastes, demand a continuous, concerted effort that generally does not permit time for contemplating past accomplishments, it is particularly appropriate at this time to review the development of water resources in Texas during the past 50 years.

On September 1, 1963, the 51st year of operation of the State administrative agency charged with responsibility for water-resource development was begun by the Water Commission. During the first 48-1/2 years of its operation, the agency was known as the Texas Board of Water Engineers. The Board was created September 1, 1913 by an act of the Thirty-Third Legislature. [Acts 33rd Leg., R.S. 1913, ch. 171, p. 359.] The Agency name was changed to the Texas Water Commission effective January 30, 1962. The Commission is composed of three members appointed by the Governor, by and with the consent of the Senate, for terms of 6 years. [Tex. Rev. Civ. Stat. Ann. art. 7477 (Vernon Supp. 1962).] One Commissioner is appointed from each of the three respective Water Divisions of the State. [Tex. Rev. Civ. Stat. Ann. art. 7475 (Vernon 1954).] These Water Divisions are shown in Figure 1. The terms of office of Board members and Commissioners representing the three Water Divisions since 1913 are as follows:

Water Division No. 1

John Wilson	September 1, 1913, to August 31, 1917
W. T. Potter	September 1, 1917, to August 28, 1921
A. H. Dunlap	December 1, 1921, to July 22, 1944
E. V. Spence	July 1945 to November 1, 1949
James S. Guleke	November 1, 1949, to October 31, 1953
Otha F. Dent	November 1, 1953, to ---

Water Division No. 2

J. C. Nagle	September 1, 1913, to August 31, 1917
R. J. Windrow	September 1, 1917, to May 20, 1918
J. A. Norris	May 20, 1918, to March 1, 1936
John W. Pritchett	March 1936 to November 1, 1949
Andrew P. Rollins	November 1, 1949, to January 1955
R. M. Dixon	September 1955 to November 1961
Joe D. Carter	November 10, 1961, to ---

Water Division No. 3

E. B. Gore	September 1, 1913, to October 31, 1917
Charles S. Clark	October 31, 1917, to March 31, 1947
H. A. Beckwith	April 1947 to November 1957
Durwood Manford	November 1957 to November 1961
H. A. Beckwith	November 10, 1961, to ---

Water-resource developments are widespread over the State. These developments have occurred to meet a variety of needs. An indication of the number of scattered points of concentrated water demand, and of the general increase of population is the growing number of cities in Texas having populations of 2,500 or more:

Year	Number of Cities with 2,500 or More Inhabitants
1910	91
1920	119
1930	159
1940	196
1950	272
1960	320

Adequate basic data are necessary to provide a firm foundation for sound water planning and development. The first members of the Board of Water Engineers recognized this, as have succeeding Board Members and Commissioners throughout these 50 years. Because of their importance, the inception and growth of several basic-data programs will be surveyed here as correlative to the development and uses of surface-water and ground-water resources.

Names of cooperative agencies, to whom we are most grateful for participation in the data-collection programs, for the period 1960-63 are included in the Appendix.

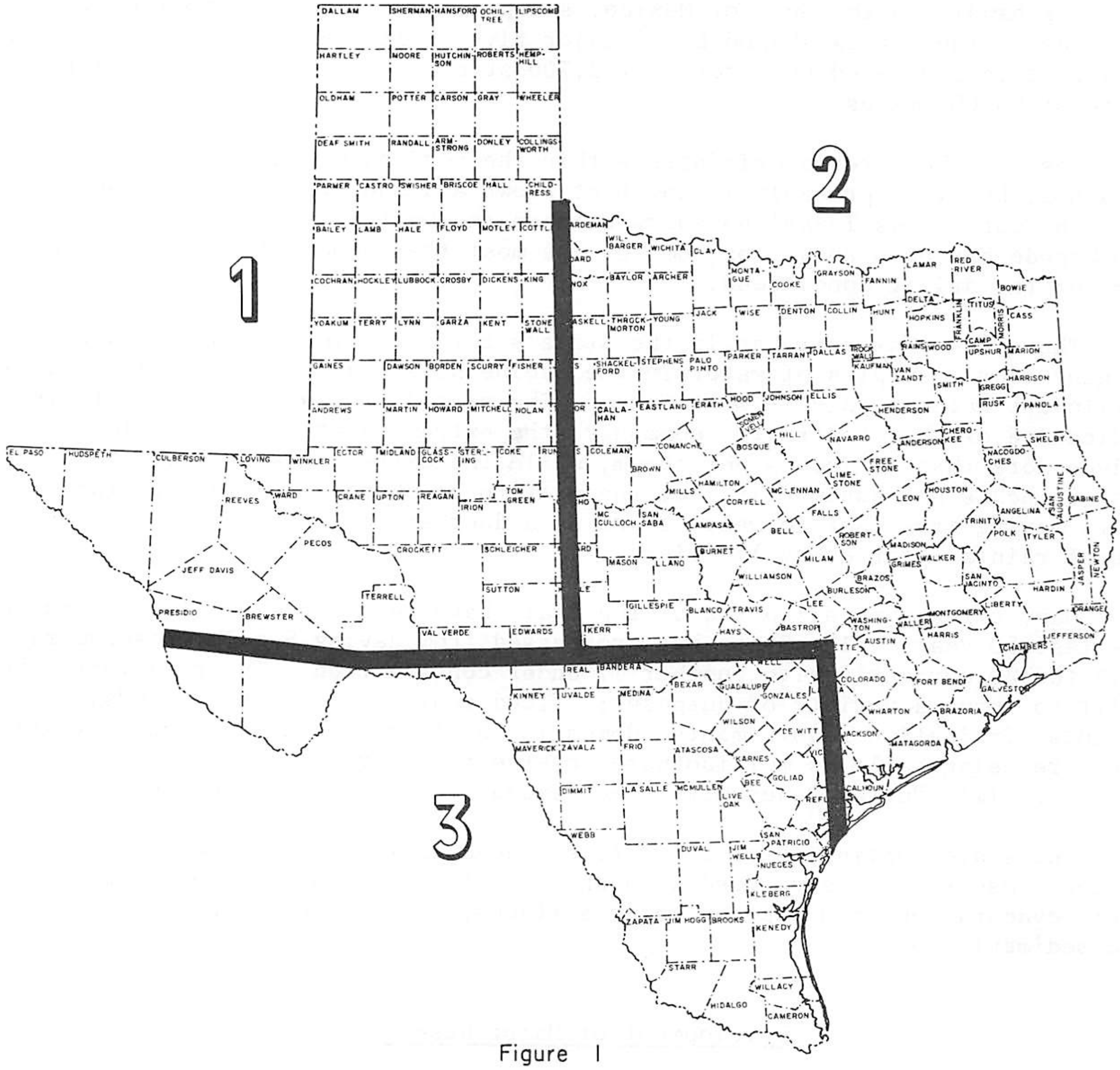

Figure I

STATE WATER DIVISIONS--TEXAS WATER COMMISSION

One Commissioner is Appointed from each of the Three Divisions.

0 50 100 Miles

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HISTORICAL DEVELOPMENT OF SURFACE-WATER ACTIVITIES

Explanation

The drainage pattern of Texas surface watercourses resembles a giant fan with its handle on the Gulf of Mexico, sweeping the State from northeast to southwest. The fan is shaped by 15 major river basins and 8 coastal drainage areas; it is completed by a total of 3,700 streams that have a combined length of about 80,000 miles.

Most of the streams originate within the borders of the State. One that does not, but that probably is the best known and one of the most colorful, is the Rio Grande. As Texas' boundary between the United States and Mexico, the Rio Grande has been known for some of the most tremendous floods as well as for some of the driest conditions.

There is great contrast in the State's surface-water picture as a whole, ranging from a surplus of water in the Sabine River Basin in the east to an insufficient water supply in West Texas. The vast difference in rainfall also is indicative of this contrast: commonly, the extreme eastern part of Texas receives more than 55 inches per annum, while the extreme western part gets less than 8 inches per annum. In fact the pattern of change is almost uniform in that, moving from east to west, there is a decrease of approximately 1 inch of annual rainfall for every 17 miles.

Many streams in all parts of the State have been harnessed for use during the last 50 years. The State has progressed from having 8 major reservoirs in 1913 to 120 currently with another 17 under construction. The reservoirs are built to serve a variety of purposes: flood control, industrial needs, municipal demands, irrigation requirements, domestic and livestock needs, and recreation. Many are being built as multipurpose reservoirs. Several of these already in use are: Twin Buttes Reservoir, Lake Texoma, and Possum Kingdom Reservoir.

There are continuing problems to be faced on the surface-water scene, and further research is being conducted on many of these. Several discussed herein are: evaporation from exposed water surfaces, the chemical quality of the water, and sedimentation.

Development of Major Reservoirs

A major reservoir is defined as one having a storage capacity of 5,000 acre-feet or more. This definition is usually related to conservation storage, but three exceptions have been made for this discussion: Olmos Reservoir, Barker Reservoir, and Addicks Reservoir, which provide flood-control storage only.

In October 1913, a total of eight major reservoirs were in use in Texas, the eight having a total storage capacity of 358,700 acre-feet. Most of this capacity, 254,000 acre-feet, was created by the completion of Medina Dam in May 1913. Of these 8 reservoirs, 3 with total conservation capacity of 28,700 acre-feet were for municipal water supply; 4 with total capacity of 295,000 acre-feet were for irrigation; and the eighth was Lake Austin, which had been completed in May 1893 for the generation of hydroelectric power. The Austin Dam was partly destroyed by flood in 1900, and reconstruction was not completed until May 1915.

The generation of hydroelectric power at the Austin Dam was not a success, however, until upstream storage was provided and the dam and powerplant rebuilt in 1940.

As of October 1, 1963, there were 120 existing major reservoirs in Texas and 17 under construction. The existing reservoirs have a total storage capacity of 24,100,000 acre-feet, of which 12,900,000 acre-feet is conservation storage capacity and 10,700,000 acre-feet is flood-control storage capacity. There were no reservoirs with specific flood-control storage functions 50 years ago.[1/] Table 1 shows the reservoirs constructed by Federal and nonfederal agencies, and existing at the time of each of the selected years on the table, together with conservation storage capacity, flood-control storage capacity, and total storage capacity. Table 2 lists similar information for the 17 reservoirs still under construction on October 1, 1963.

Of the 12,900,000 acre-feet of storage capacity for conservation uses in existing major reservoirs, only 2-1/2 percent was in existence in October 1913, 3 percent in 1920, 10 percent in 1930, 35 percent in 1940, and 50 percent in 1950; therefore, 50 percent of the conservation storage capacity existing on October 1, 1963 was built since 1950.

Seventeen of the existing major reservoirs have storage capacity specifically designated for flood control, amounting to a total of 10,700,000 acre-feet. The only flood-control storage capacity existing before 1940 was 15,500 acre-feet in Olmos Reservoir. During the decade 1940-50, four reservoirs were built providing an additional total of 2,500,000 acre-feet of storage capacity for flood control; therefore, 76 percent of the flood-control storage capacity existing on October 1, 1963 was built since 1950.

The first dam in Texas for flood control was the Olmos Dam, which was built in San Antonio on Olmos Creek in 1926. The second dam built creating a reservoir with a specifically designated flood-control storage capacity was the Marshall Ford or Mansfield Dam creating Lake Travis on the Colorado River near Austin. Storage of water in Lake Travis began in September 1940.

Lake Travis was the first multipurpose reservoir to provide water storage capacity for municipal, irrigation, mining, and recreation uses; the generation of hydroelectric power; and flood control.

Two reservoirs of earlier date than Lake Travis should be mentioned. They are Bridgeport Reservoir built in 1932, and Eagle Mountain Reservoir built in 1934, both on West Fork Trinity River upstream from Fort Worth. The spillways at the dams creating these reservoirs were designed to provide considerable floodwater retardation that reduced flood heights downstream.

Seventeen major reservoirs under construction as of October 1, 1963, on Texas and boundary streams will provide a total capacity of 15,700,000 acre-feet,

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[1/] A flood-control storage reservoir is one designed to contain floods of a certain volume for the purpose of regulation of downstream flows. When floods exceed this capacity, the reservoir will provide limited regulation of downstream flows but flooding will not be eliminated.

Table 1.--Cumulative number and capacity of major reservoirs constructed from 1913 to October 1, 1963

Year	Number of major reservoirs constructed			Conservation storage capacity in acre-feet			Flood-control storage capacity in acre-feet			Total storage capacity in acre-feet		
	Federal	Nonfederal	Total	Federal	Nonfederal	Total	Federal	Nonfederal	Total	Federal	Nonfederal	Total
1913	0	8	8	0	355,700	355,700	0	0	0	0	358,700	358,700
1920	1	10	11	58,000	388,210	446,210	0	0	0	58,000	391,710	449,710
1930	1	31	32	58,000	1,188,370	1,246,370	0	15,500	15,500	58,000	1,226,520	1,284,520
1940	3	44	47	84,150	4,399,100	4,483,250	0	793,500	793,500	84,150	5,285,400	5,369,550
1950	7	59	66	957,940	5,459,250	6,417,190	1,756,260	793,500	2,549,760	3,267,200	6,356,670	9,623,870
1960	18	87	105	4,511,200	7,613,310	12,124,510	9,280,890	793,500	10,074,390	14,192,300	8,553,900	22,746,200
1963	20	100	120	4,737,000	8,140,110	12,877,110	9,859,790	793,500	10,653,290	15,004,500	9,116,970	24,121,470

Table 2.--Major reservoirs under construction on October 1, 1963

Year	Number of major reservoirs under construction			Conservation storage capacity in acre-feet			Flood-control storage capacity in acre-feet			Total storage capacity in acre-feet		
	Federal	Nonfederal	Total	Federal	Nonfederal	Total	Federal	Nonfederal	Total	Federal	Nonfederal	Total
October 1, 1963	9	8	17	6,750,440	3,550,090	10,300,530	5,199,780	793,500	5,993,280	12,004,700	3,646,040	15,650,740

of which 10,300,000 acre-feet is for conservation uses. Nine of these reservoirs under construction have storage capacity specifically designated for flood control, amounting to a total of 6,000,000 acre-feet.

The completion of these 17 reservoirs under construction will provide conservation storage capacity nearly equal to that in all of the reservoirs built in Texas prior to October 1963, and will increase the storage capacity designated for flood control by 50 percent.

Of the 120 major reservoirs existing and 17 under construction, only 3 are solely for flood control and have no conservation storage capacity. Those are the Olmos Reservoir in San Antonio, and the Barker and Addicks Reservoirs in the Buffalo Bayou watershed, which provide flood protection for Houston.

In addition to the major reservoirs discussed above, there are many others in Texas with capacities less than 5,000 acre-feet that provide conservation storage or flood control or, in some cases, both. In 1951 the Soil Conservation Service, U. S. Department of Agriculture, began constructing floodwater retarding structures on small watersheds. Between 1951 and June 30, 1963, 813 of these structures were built; a few have storage capacity allocated to conservation storage in addition to that allocated to flood control. Of the 813 U. S., Soil Conservation Service reservoirs, 26 have total storage capacities of more than 5,000 acre-feet each, but are not included in the total of 137 reservoirs discussed heretofore.

Uses of Surface Water

Through the 50 years from 1913-63, there have been significant trends in the types of use of the public waters of Texas. In 1913 irrigation was the major use of surface waters, but this has been diminished proportionally by the increase in municipal and consumptive industrial uses, and by the tremendous increase in the amount of water appropriated for the nonconsumptive uses. In particular, this refers to hydroelectric power and nonconsumptive industrial use, which have been mainly adjunct to reservoir development since 1928. A comparison of estimated use in 1913 with that reported to the Texas Water Commission in 1962 is a beginning point for analyzing some of the more significant trends.

Estimated Use in 1913

By the same Act of the Thirty-Third Legislature that created the Board of Water Engineers, a procedure was established by which users of public water were given the opportunity to file in the office of the Water Engineers certified copies of their filings with the county clerks under previous water acts together with sworn statements of the use, or uses, made by them of the water that their filings were intended to cover. The initial filing deadline was July 1, 1914, but later was extended to March 31, 1916. The Certified Filings are probably the best guide to the amount of water used prior to the granting of appropriative water rights that began in 1914. The use of water in 1913 as estimated from the sworn statements in the Certified Filings is as follows:

Municipal and domestic use	27,361 acre-feet
Industrial use (including manufacturing, waterpower and water for steam-electric generating plants, water for steam plants, oil refining, and water for steam locomotives)	17,753 acre-feet
Irrigation (for 594,225 acres)	1,385,227 acre-feet
TOTAL	1,430,341 acre-feet

Reported Use in 1962

Water use as reported to the Water Commission in the water service reports tabulated for 1962 is as follows[2]:

Consumptive use

Municipal or domestic	581,680
Industrial	445,665
Irrigation	2,875,370
Mining	37,490
	3,940,205 acre-feet

Nonconsumptive use

Industrial	5,043,121
Hydroelectric	6,494,369
Recreation	20,596
	11,558,086 acre-feet

Trends in the Type of Water Use

Irrigation

Although the quantity of surface water used for irrigation has doubled since 1913, the proportion of the estimated total consumptive use has decreased from 97 percent in 1913 to 72 percent in 1962. Of course, a significant factor that must not be overlooked is the considerable development of ground water for irrigation. In 1913, 594,225 acres of land were declared irrigated by surface water; by 1939, 778,200 acres were being irrigated by surface water and 267,000 by ground water; but, by 1959, 1,225,700 acres were being irrigated by surface

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[2] 1962 is latest date for which reported use is presently available.

water and 5,914,800 by ground water. In addition, there has been a significant change in use of appropriated water from irrigation to industrial and municipal uses.

Industrial

About 65 percent of the consumptive industrial use in 1913 was for the railroads in furnishing water for steam locomotives. Today this use has disappeared. In 1962, 445,665 acre-feet of water was reported as consumed for industrial purposes. On the other hand 5,043,121 acre-feet was reported as appropriated for nonconsumptive industrial uses that include water used for plant cooling and chemical extraction.

Hydroelectric Power

Another nonconsumptive use that has greatly increased is that of utilizing water for generation of hydroelectric power, either through construction of reservoirs solely for power generation or as part of multipurpose projects. Since the water so used for hydroelectric power generation may pass through several plants on a particular river, such as the Lower Colorado River Authority reservoirs on the Colorado River, the trend in development of hydroelectric power can be better illustrated by the installed generation capacity in terms of kilowatts. The comparison is confined to hydroelectric power generation facilities in reservoirs of 5,000 acre-feet capacity or greater.

The Austin Dam was the first major facility constructed for generation of hydroelectric power, but as previously mentioned, successful generation of power was not attained until 1940. In the years 1928-30, four reservoirs were completed having a total installed capacity of 9,550 kilowatts. These reservoirs were: Lake McQueeney, Lake Dunlap, Devils Lake, and Lake Walk. In 1940, the total installed capacity had been increased to 141,500 kilowatts through the construction of H-4 Reservoir, Red Bluff Reservoir, Inks Lake, Lake Austin, Lake Travis, and Buchanan Reservoir. With the construction of Lake Texoma and Possum Kingdom Reservoir, the total installed capacity in 1950 was 234,000 kilowatts. As of October 1963 the total installed capacity was brought to 370,500 kilowatts by the construction of Whitney Reservoir, Granite Shoals Lake, Marble Falls Lake, and International Falcon Reservoir. Provision of additional generating capacity is contemplated at several of the existing reservoirs. There are three major reservoirs under construction that will add an expected 270,500 kilowatts of generating capacity.

Recreation

There have been many small reservoirs constructed primarily for recreational purposes in the last few years. The larger multipurpose reservoirs furnish facilities for boating, fishing, and other water sports.

Municipal and Domestic Use

The population growth of Texas, along with the increased per capita demand for water for municipal and domestic use and the increasing dependence upon surface-water supplies for such use, is reflected by the following comparison of estimated and reported use:

Year	Estimated Use in acre-feet	Reported Use in acre-feet
1913	27,361	--
1930	--	60,486
1940	--	84,750
1950	--	277,374
1960	--	541,502
1962	--	581,680

Streamflow Measurement

Very little stream gaging had been done in Texas prior to 1913. The first gaging station was established on the Rio Grande near El Paso on May 10, 1889 by the U. S. Geological Survey (USGS). In 1897, Thomas ~~A~~U. Taylor, then professor of civil engineering at The University of Texas but acting in the additional capacity as district hydrographer for the USGS, began a study of a few of the principal streams of Texas. During the next 10 years, Professor Taylor established 12 gaging stations distributed in the Red, Sabine, Trinity, Brazos, Colorado, and Guadalupe River Basins. These stations were operated only a few years, but some were reestablished at a later date. By 1900, 11 additional gaging stations had been established on the Rio Grande and on Texas tributaries by the United States and Mexican Sections of the International Boundary Commission (later the International Water Commission, and presently the International Boundary and Water Commission). Records at only the El Paso station on the Rio Grande and the station on the Pecos River near its mouth are continuous to the present time.

In 1913, the only streamflow stations (more commonly referred to as gaging stations) being operated in Texas or on boundary streams were in the Rio Grande and Red River Basins. At that time the United States Section of the International Water Commission was operating six gaging stations on the main stem of the Rio Grande and two stations on Texas tributaries to the Rio Grande. The Mexican Section of the International Water Commission was operating three stations on the main stem of the Rio Grande and two on Mexican tributaries. Also a gaging station on the Delaware River in Culberson County a quarter of a mile south of the New Mexico-Texas state line was being operated by the state engineer of New Mexico in cooperation with Mr. W. J. Coad of Omaha, Nebraska, and a gaging station on the Wichita River at Wichita Falls was being operated by the Big Wichita River Irrigation Company.

The Act of the Texas Legislature creating the Board of Water Engineers in 1913 specified that:

> It shall be the duty of the Board to make or cause to be made, measurements and calculations of the flow of streams from which water may be appropriated as provided in this Act....

However, no funds were appropriated for the establishment and operation of gaging stations. Later, $10,000 was appropriated for "stream measurements" to be expended during the third year of the Board's operation, which ended August 31, 1916. As a result of this appropriation, the Board entered into a cooperative agreement on July 8, 1915 with the USGS whereby they would begin measuring the discharges of some of the streams on September 1, 1915.

The following quote from the Second Report of the Board of Water Engineers shows that the Board began stream-measurement work in January 1915:

> During the first two years of its existence the Board had no specific fund with which to inaugurate this work, but beginning in January, 1915, it was able to utilize a part of the special fund derived from fees, the use of which was authorized by the Governor, and for this beginning, employed one hydrographer. A few gauging stations, equipped with staff gauges, and one at Austin with an automatic gauge height recorder, were established, which, together with a few which had been established by the District Engineer of the USGS, whose headquarters are Atlanta, Georgia, and who had only a small fund to work with, amounted to eight stations, all told, at the beginning of the fiscal year on September 1, 1915.

The same report shows that 27 gaging stations were installed during the year ending August 31, 1916, making a total of 35 in operation at the end of the year. During that year, stream gaging on the Rio Grande in Texas was limited to accumulating a partial year's record at Eagle Pass.

The cooperative agreement between the State and the USGS for stream-measurement work has been renewed each year. The stream-measurement work has fluctuated through the years since 1916 according to funds available. In 1922, a total of 44 gaging stations was being operated, not including a number on canals. The disastrous floods in 1921 stimulated interest in this work, and resulted in an increased State appropriation for the biennium 1924-25. The number of stations grew to more than 150 in 1925. The increased appropriation was not continued, and the number of stations operated decreased to about 80 in 1937. In 1938, the U. S. Army Corps of Engineers provided funds for the establishment or reestablishment of about 50 gaging stations. The support of Federal and State agencies, municipalities, and other interested parties, especially river authorities and water districts, has provided a steady growth of stream-measurement work since 1941, although State-appropriated funds for this purpose did not increase significantly until 1946.

The State provided funds for the establishment of 30 gaging stations during the 1962-63 biennium, and for 20 stations during 1964-65. The continuing support of stream-measurement work by State and Federal agencies and other interested parties has resulted in increasing the number of gaging stations, as of June 30, 1963, to 375 streamflow-measuring stations, 45 reservoir content measuring stations, and 109 partial-record stations.[3] In addition, the International Boundary and Water Commission, United States and Mexico, was operating 46 stations on the Rio Grande and on Texas tributaries to the Rio Grande.

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[3] A partial-record station is one at which periodic measurements of stream discharge are made.

During the next year, a total of 40 new gaging stations will be established with funds from various sources.

The greatest deficiency in the stream-measurement work has been the lack of records for small areas as almost all early gaging stations were on the larger streams. An effort has been made to correct that deficiency during the past 2 years by establishing stations on small streams.

Chemical Quality of Surface Water

Before 1900, fewer than 25 chemical analyses had been made of surface waters in Texas. These analyses were made by the Texas Experiment Station, by the railroads, and by the USGS. In 1905 the first systematic program of stream analysis in Texas by the USGS began with the establishment of chemical-quality stations on the Colorado River at Austin and on the Rio Grande near El Paso and at Laredo. By the end of 1907, these three stations and one started on the Brazos River at Waco in 1906 were no longer in operation. In 1930, the International Boundary and Water Commission reactivated the sampling station on the Rio Grande at El Paso, and also established a few sampling stations at other points on the river.

In July 1939, the USGS established eight stations on the Pecos River and tributaries in Texas in cooperation with the Red Bluff Water Power Control District as a part of the Pecos River Joint Investigation. Upon conclusion of the investigation in 1940, all stations except Pecos River at Orla were terminated.

The year 1942 marked the beginning of continuous cooperative matching of USGS funds by the State and local agencies for financing collection of data on the chemical quality of Texas streams. In that year the Board of Water Engineers allotted $700 for this purpose. By 1944, through funds contributed by the Board, the Red Bluff Water Power Control District, and the Pecos River Compact Commission, daily samples were being collected and analyzed at four stations. Through the initiative of the Board and local agencies, the four cooperative stations were expanded to 20 by June 1947; to 40 by June 1961; and to 58 by June 1963. Ten additional stations on the Rio Grande and tributaries presently are being operated by the International Boundary and Water Commission. The records from these stations are published annually in Texas Water Commission reports. In 1953 the first specific appropriation, in the amount of $10,000, was made by the Legislature for investigation of the chemical quality of the waters of the State.

Through the years a few miscellaneous samples were collected on Texas streams at points other than daily stations, but in 1961 the Water Commission and the USGS began a reconnaissance study to supplement the data collected at daily chemical-quality stations. The program is outlined in detail in Texas Water Commission Circular No. 62-01. Briefly, samples are being collected at about 80 sites on Texas streams, particularly at sites where water-development projects are planned, or are in operation, and where no chemical-quality data is available. These data and those collected at daily stations will be used to delineate problem areas, sources of water of usable quality, and areas needing more extensive investigation. The results of the reconnaissance study will be released in a series of basin reports starting with the Sabine River Basin report, scheduled for release this year. Chemical quality of surface-water work also has been done in connection with a number of low-flow investigations on various streams.

Another important part of studies of chemical quality by the Water Commission and the USGS is the investigation of stratification in Texas reservoirs. A progress report on these studies has been published as Texas Water Commission Memorandum Report No. 63-01. Studies in 1963 are confined to the Brazos River Basin and include Possum Kingdom, Whitney, Belton, and Hubbard Creek Reservoirs.

The Texas State Department of Health by a mutual cooperative agreement with the Parks and Wildlife Department maintains a network of 268 chemical-quality sampling stations at which one or more samples are collected each month.

In 1963 the U. S. Public Health Service was operating six quality-of-water stations in Texas and on boundary streams within its national quality network. The U. S. Public Health Service also has operated a number of quality stations on the Red River and its Texas tributaries in recent years.

Sediment in Streams

The first recorded exploratory work in Texas toward the measurement of sediment loads in Texas streams was accomplished by Mr. W. W. Follett on the Rio Grande near El Paso. This work covered a period from June 1889 to December 1912, including some periods of no record. Mr. J. C. Nagle, who was then Dean of Engineering at Texas A & M College and who later became the first Chairman of the Board of Water Engineers, performed a series of experimental measurements of sediment loads on the Wichita River near Wichita Falls and on the Brazos River near College Station. His work covered a period beginning in February 1900 and ending in February 1902. Dean T. U. Taylor of The University of Texas Engineering College also made surveys, and ran experimental volumetric measurements on sedimentation of Lake Austin on the Colorado River above Austin during this early period. These pioneers originated sediment measurement in Texas.

Since its creation in 1913, the Board of Water Engineers has recognized the problem of the economic life of storage reservoirs. Efforts toward obtaining measurements of sedimentation to cope with this problem resulted in an initial plan to establish a sediment-measuring network. In 1923, an agreement between the Board and the Bureau of Agricultural Engineering, U. S. Department of Agriculture, established and provided for the operation of the first network of sediment-sampling stations in the State. Owing to the limited funds available, it was impossible to extend the detailed investigation to all streams of the State known to have satisfactory reservoir sites. The Brazos River Basin was selected as a drainage area typical, in its various sections, of conditions prevailing on other drainage areas. Nine sampling stations comprised this original network. Some of the original locations were abandoned early in the program and relocated at other points as experience dictated. With time and additional funds, the network was slowly expanded into other river basins of the State.

From the small beginning of a 9-station sediment-sampling network within the Brazos River Basin in 1924, the program was expanded to other basins where sediment information was needed. The first recorded sediment data were collected by the USGS at El Paso in June 1889. In the ensuing 74-year period a total of 92 sediment-sampling stations have been operated in the State. Sediment sampling on the Rio Grande is performed by the International Boundary and Water Commission. Other agencies also operate sediment sampling stations in Texas. All records are published. As the surface-water program in Texas expands, additional sediment information will be needed.

The Texas Water Commission presently is maintaining 34 daily sediment-sampling stations. These stations range over a wide area of the State. Basins being sampled are: Sulphur, Sabine, Neches, Trinity, San Jacinto, Brazos, Colorado, Lavaca, Guadalupe, San Antonio, and Nueces.

In 1963 the International Boundary and Water Commission was operating 15 sediment-sampling stations in the Rio Grande Basin. The USGS was maintaining 3 daily sampling stations, 2 trap-efficiency stations, and 37 miscellaneous reconnaissance-sampling stations.

Evaporation Stations

Prior to 1913 practically all evaporation measurements were made in conjunction with agricultural studies. Most records during this period cover only the growing season of the year. Some of the earliest records were taken at the old U. S. Department of Agriculture experimental stations at San Antonio, Chillicothe, Dalhart and Amarillo. These evaporation stations were established in 1907 and 1908 using the Bureau of Plant Industry type pan, a 6-foot-diameter circular tank sunk 2 feet into the ground. Evaporation records also were obtained using the square ground pan, sometimes known as the Colorado pan, in connection with rice-irrigation studies in Liberty County as early as 1901. Little concern was given to standardization of equipment and techniques. Results of measurements during this early period are generally deemed erratic.

The establishment of substations of the Texas Agricultural Experiment Station throughout Texas during 1916-18 greatly extended the coverage of evaporation measurements in Texas. The Bureau of Plant Industry pan was adopted as the standard pan for these stations, and daily records were obtained throughout the year. The U. S. Weather Bureau-type pan first came into use in Texas in 1916. This 4-foot-diameter circular pan, set above ground, is still employed for evaporation measurements by the Weather Bureau and by several cooperating agencies having stations at widely scattered points in the State. The Young screened-pan was first employed in Texas for irrigation studies about 1942. This 2-foot-diameter circular pan, sunk 33 inches into the ground and covered with a wire-mesh screen, has gained wide acceptance, and has been adopted by the Texas Water Commission and other agencies. Standardization of evaporation equipment and its installation has been emphasized during the past several years. The first station with Water Commission standards was constructed and placed in operation at Buchanan Dam in 1943. In recent years a concerted effort by the Water Commission and the Texas Agricultural Experiment Stations through a working cooperative agreement resulted in standardization of these stations. Generally, the Young screened-pan is the only pan now utilized at these stations.

Water-evaporation rates are a critical item in the design and operation of storage reservoirs. Evaporation is, in fact, the ultimate controlling factor of economic surface-water development under arid conditions. Evaporation data, therefore, remains of critical importance in development of the State's water resources.

In 1963 the Water Commission, in cooperation with the Texas Agricultural Experiment Station and with other interested agencies, was operating a network of 44 standard evaporation stations. This network covers all areas of the State, extending from Amarillo to Brownsville, and from Beaumont to El Paso. Texas is one of the few states with a statewide network of evaporation stations.

Additional evaporation measurements were being made by other agencies in the State that supplement the Water Commission network. Included are six stations operated by the International Boundary and Water Commission in the Rio Grande Basin and 18 stations at U. S. Weather Bureau installations across the State.

Special Hydrologic Studies

The State-sponsored cooperative programs have provided numerous hydrologic investigations and reports, several of which will be reviewed. Investigations of channel gains and losses have been made on various streams since 1918. Special measurements have been made and reports prepared on outstanding floods since 1921. A report has been published on the magnitude and frequency of floods in Texas. Hydrologic investigations have been made and reports presented on the effects of conservation practices and of urbanization on runoff and surface-water yields. A report has been published about the effect on evaporation caused by the addition of heat to a power plant cooling reservoir. An intensive hydrologic data collection program is underway in 13 small watersheds of Texas, the purpose of which is threefold: (a) to provide basic hydrologic data for small watersheds; (b) to provide hydrologic data through a series of extended climatic cycles that, when analyzed and interpreted, will lead to a better understanding of the effect of small floodwater-control structures on the water yield and mode of occurrence of surface water in small watersheds; and (c) to provide the U. S. Soil Conservation Service and other water-project planners with factual information for planning and designing land-treatment and flood-control measures. Low-flow investigations are conducted to determine recharge to underground aquifers, sustenance of streamflow from land storage and ground water, and the origin of contamination of surface waters. Delivery-of-water investigations have been made to determine the efficiency of channel conveyance from supply reservoirs to points of delivery.

HISTORICAL DEVELOPMENT OF GROUND-WATER ACTIVITIES

Explanation

More than half of the surface of Texas is underlaid by great natural underground water reservoirs. This ground water, of great economic value to the State, has been developed rapidly during the past 50 years.

In early times, the principal use of ground water was in meeting small-scale domestic and livestock requirements in rural areas. Even as small towns grew, ground water continued to meet domestic needs largely through individually owned private wells. Later, as water demands increased, community wells were drilled. At present about 80 percent of the municipal facilities in the State depend on ground water for their supply. Similarly, the use of ground water for industry and, more particularly, for irrigation has placed ever increasing demands on the underground water reservoirs of the State.

Ground water can be found in all geologic formations in Texas, and many formations yield abundant supplies. Those that yield large quantities of water over large areas, often called major or principal aquifers, include: (1) Ogallala Formation of the High Plains; (2) the Edwards Limestone and Trinity Sand of west-central Texas; (3) the Edwards Limestone along the Balcones fault zone; (4) the Trinity Sands in north-central Texas; (5) the Carrizo-Wilcox Sands of south and east Texas; (6) the Gulf Coast Sands; and (7) the various alluvial deposits in the El Paso area, Salt Basin, Pecos Valley, north Texas, lower Rio Grande Valley, and the central Brazos River Valley.

Development and Uses of Ground Water

Few reliable ground-water use figures, indicative of ground-water development, are available prior to 1930, and record of the early history of ground-water development in Texas is partially lost. In 1930 the ground-water used for municipal supply totaled 248,000 acre-feet; for industrial supply, probably over 100,000 acre-feet; and for irrigation use, about 109,000 acre-feet. By 1940 the use of ground water had increased to more than 270,000 acre-feet for municipal purposes, nearly 160,000 acre-feet for industrial purposes, and about 300,000 acre-feet for irrigation purposes. The relatively large increase during the period 1930 to 1940 in the amount of ground water used for irrigation was largely a result of the drought of the 1930's. Although this expansion was significant at the time, it was small compared with the tremendous increase in irrigation use that was to result from the drought of the 1950's.

The industrial use of ground water grew significantly from 1940 to 1944. During these war years, the use of ground water for industrial purposes more than doubled. Since 1945, however, its use in industry has not expanded appreciably.

The municipal use of ground water, while always significant, greatly increased during the 1950's. This resulted both from the drought of that time and from the 24-percent increase of the Texas population during that period.

The largest increase in the use of ground water in Texas has been for irrigation (Table 3). This development began about 1947 when approximately 1 million acre-feet was pumped. In the 10 years that followed, the pumpage of ground water increased from 1 million to nearly 10 million acre-feet. All of the irrigated areas in Texas shared in this expansion; however, the principal contributing area was the Southern High Plains. In the Southern High Plains there were approximately 3,000 irrigation wells in 1945. At present there are more than 47,000 wells. The area currently supplies 11 percent of the nations's cotton and 35 percent of the nation's grain sorghums.

Approximately half of the water currently used in Texas for municipal and industrial purposes comes from ground-water reservoirs. Because more than three times as much ground water as surface water is used for irrigation, and because the irrigation use is so large when compared to municipal and industrial usage, about 75 percent of the water presently used consumptively in Texas comes from ground-water sources.

Municipal establishments using ground water in 1962 totaled 1,326 and industrial establishments totaled 919. Probably about 11 million acre-feet of ground water was used in 1962 with an estimated 10 million acre-feet being used for irrigation purposes.

Table 3.--Ground-water use

Year	Municipal (acre-feet)	Industrial (acre-feet)	Irrigation (acre-feet)
1930	248,000	--	109,100
1935	260,000	162,000	251,950
1940	273,000	157,000	302,000
1945	302,000	324,000	799,500
1950	350,000	330,000	2,400,000
1955	536,637	328,263	6,998,100
1960	544,444	323,208	9,350,200*
1962	694,806	365,145	--

* 1959 data

History of Ground-Water Investigations

Studies of geology with reference to ground water were made by the U. S. Geological Survey in various parts of Texas in the period 1890 to 1915. During the 1890's, investigations were made in the High Plains, in the Edwards Plateau and Coastal Plain adjacent to Austin and San Antonio, and in the Black and Grand Prairies of north-central Texas. The results of these investigations were published in early reports of the USGS. During this early period, other regional investigations of the geology and ground water were made in the panhandle of Texas, northeastern Texas, Wichita region, southeastern Coastal Plain, and LaSalle and McMullen Counties.

The present program of ground-water studies in cooperation with the USGS started in the fall of 1929. Attention was first given to the Winter Garden area, the Balcones fault zone and adjacent territory, Uvalde and Medina Counties, the Glen Rose area in Somervell County, and the Toyah Basin in Reeves County. In 1930-32 studies were started in the Houston-Galveston area, San Antonio area, and other localities. During the Depression in 1933-36, State appropriations and the matching appropriations by the Federal Government were cut to about 30 percent of the amount appropriated earlier, and a large part of the cooperative program had to be abandoned.

During 1933-34, a small allocation of funds was made by the U. S. Administration of Public Works for ground-water studies in the High Plains and in the central Gulf Coast region. In the latter part of 1935, a materially larger allocation of funds was made by the Works Progress Administration for a widespread inventory by counties of water wells and springs in Texas. This appropriation was renewed each year at a gradually decreasing rate until 1941; the WPA program was carried out by the Board of Water Engineers in cooperation with the USGS and Texas Bureau of Industrial Chemistry.

In the period 1935 to 1937, the cities of Houston, El Paso, and Lufkin contributed funds for special investigations in their respective areas, and these funds were matched by Federal funds. In 1937, the State appropriations were increased, and the regular cooperative ground-water program was restored to its former level. It has been carried on ever since with few cuts and with some increases.

During 1940-45, many investigations made in connection with the defense program were largely responsible for the establishment and maintenance of training camps and war industries in all parts of the State. Since 1945, the work has been devoted in considerable part to locating and evaluating ground-water resources that are available for public-supply, industrial, and irrigation use.

The material collected and published during the period 1900-55 represents the largest volume of basic ground-water data ever collected and published on any state. Of course Texas is much larger than any other state except Alaska, and as already pointed out the water demands and use in the State were skyrocketing during the 1940's and 1950's. Although much had been done, still more remained to be accomplished; therefore, a plan to supply adequate ground-water information over the entire State was prepared by the Board of Water Engineers, and submitted to the 56th Legislature. This plan outlined programs of investigation designed to provide essential information on all the State's underground water reservoirs.

Three types of studies were recommended in the 1958 report, and have been programmed by the Texas Water Commission: reconnaissance studies, detailed investigations, and continuing observations.

Preparation of an urgently needed statewide plan for the development of available water resources required that reconnaissance ground-water studies be made over the State, because time and personnel were not available to complete highly desirable, detailed appraisal-type investigations. These reconniassance studies were made chiefly to determine the magnitude of ground-water supplies potentially available from the principal water-bearing formations. The results obtained are suitable for generalized evaluations of ground-water conditions over large areas. They are, however, not adequate for detailed water planning, or for the planning of local water supplies. The reconnaissance studies were begun in the summer of 1959, and several reports on their results already have been published. These studies were conducted at a total cost of approximately $760,000, shared by the State and Federal Governments.

Detailed Investigations

Approximately 34 of the 254 counties in Texas were covered with detailed ground-water investigations as of 1960. This represented 14 percent of the total area of Texas. With the conclusion of the reconnaissance program, work began at an accelerated rate on detailed, appraisal-type ground-water investigations of local areas, counties, and other geographic units. Such study is to provide more refined quantitative data required for proper planning and development of Texas' entire water resources program, and for use by the people in each area for optimum development of the available ground-water supplies. In these detailed programs of investigations, the major water-bearing formations are studied, and small ground-water supplies, which may be of local importance, are inventoried. These detailed investigations sometimes include study of special ground-water problems such as encroachment of inferior quality water, subsidence of the land surface caused by ground-water withdrawals, discharge of saline ground water into surface streams, contamination of ground water from various sources, and the relationship of ground-water recharge and discharge to streamflow.

Detailed ground-water investigations completed since 1960, together with those currently underway, cover about 13 percent of the area of Texas. These investigations when added to those previously completed provide detailed coverage of about 27 percent of Texas. The list of counties currently being studied includes Camp, Franklin, Morris, Titus, DeWitt, Gaines, Gonzales, Houston, LaSalle, McMullen, Menard, Orange, Jackson, Atascosa, Frio, San Augustine, Sabine, Jasper, Newton, Guadalupe, Crockett, and Mitchell. Nearly all of these investigations are financed cooperatively by Federal, State, and local governments.

Continuing Investigations

As more and more of the State is covered by appraisal-type ground-water investigations, and as the development of ground water approaches more closely the maximum possible, continuing-type ground-water investigations become more and more necessary. Persistent data gathering and evaluation on natural ground-water recharge and discharge, withdrawals from wells, levels in wells, and the chemical character of water are necessary to refine more general data and to provide comprehensive knowledge needed to solve the problems of ground-water supply and development. In this respect, new wells must be inventoried periodically in areas of heavy development, and all data analyzed and interpreted for use by the public.

In some parts of the State, detailed continuing studies have been conducted for many years by the USGS in cooperation with local interests and the Water Commission. These areas at present include the Houston-Galveston area, the Edwards reservoir area extending from Kinney County along the Balcones fault zone into Hays County, and the El Paso area. The need for ground-water information in each of these areas is determined by each region's particular problems, and the continuing-study programs are tailored carefully to consider the specific problems.

Periodic progress reports on the results of these investigations are published by the Water Commission, and are made available to the public and local groups responsible for the wise conservation and development of ground-water supplies.

Water Level Observation Program

The Water Commission presently maintains a network of observation wells to determine changes in water levels in the principal ground-water reservoirs in the State. Data on water levels in selected observation wells on a long-term basis are essential, as water levels provide the key in all investigations for determining the amount of ground water available for present development and predicting the adequacy of the supplies to meet future needs. Water-level data are as essential to ground-water studies as stream-gaging data are to surface-water studies.

Prior to 1960 the water-level observation program was maintained by the USGS in cooperation with the Water Commission. In April 1960, the direction of this program was assumed by the Commission. Transfer of water-level records to the Commission was begun in the middle part of 1960. Actual take-over of the measurement responsibility by the Commission was limited to about 1,100 wells in 1960.

The water-level program gradually has been revised and expanded; however, more expansion is needed. As of 1963 the program consisted of 3,475 yearly observation wells and 32 continuous water-stage recorders. At present about two-thirds of the State is adequately covered by observation wells. Those areas where coverage generally is inadequate include the Gulf Coast and east Texas areas. Expansion of the program into these parts of the State is limited by the availability of personnel.

Water Use Program

Very little ground-water-use data was collected in the early part of this century. In 1918 the Texas State Department of Health received the authority for collecting pumpage data from municipalities with approved water supplies. In the forties the USGS in cooperation with the Board of Water Engineers collected pumpage data on the public water supplies of Texas. In the fifties the Bureau of Business Research collected industrial pumpage data, which were used in the publication of reports dealing with the Red River Basin, West Texas, and the Texas Gulf Coast.

In 1955 the Board of Water Engineers began collecting ground-water-use data from municipalities and industries on an annual basis. Since 1955 the program has been enlarged to provide more accurate information on the municipal and industrial use of ground water in Texas.

Water-use data are vital to planning and investigating water resources. The data are utilized not only by the Water Commission, but by many other agencies and individuals engaged in water planning. Two of the specific applications of water-use data are: determination of the quantity of ground water withdrawn from storage in the ground-water reservoirs of the State, and provision of a means, through correlation of water use and water-level data, of determining recharge to the ground-water reservoirs. Water-use information also is helpful in determining anticipated demands during periods of drought through the correlation of water-use records with rainfall data.

The municipal and industrial ground-water-use data are collected by means of questionnaires, in cooperation with other agencies, and by direct field contact. In recent years the information requested on the questionnaire was expanded to include the monthly and maximum daily pumpage, as well as differentiating the various uses of industrial and other commercial establishments for process, cooling, and sanitary purposes. Electronic data-processing equipment is used to facilitate the handling and storage of the large amount of data collected, and to facilitate handling numerous requests for such data.

At present there is no statewide program for the collection of water-use data for either irrigation or water-flooding purposes.

Other Programs

In addition to those programs already discussed, the Commission's present activities include several programs designed to protect the fresh ground waters of the State from deterioration in quality. Although these programs have no direct relation to the past development of ground-water resources, they will have an ever-increasing value to future development. The programs provide information for the protection of usable water in drilling and producing operations of the oil and gas industry, regulation of industrial and municipal waste-disposal projects, and investigation of ground-water contamination. All of these water-quality-protection activities of the Commission have been started since 1955, some as late as 1961.

HISTORICAL DEVELOPMENT OF THE TOPOGRAPHIC MAPPING PROGRAM

The earliest organized program of topographic mapping in Texas was initiated by the U. S. Geological Survey in the early 1880's. This mapping was done primarily to provide reconnaissance-type maps for a large portion of central and far-west Texas. The maps were 30-minute quadrangles published at a scale of 1:125,000 with contour intervals ranging from 25 to 100 feet, depending on the topography of the area.

The program, which resulted in publication of 63 quadrangles covering approximately 59,300 square miles in Texas, was completed in 1908. At the turn of the century, the U. S. Army Corps of Engineers entered the mapping picture; but for the most part the maps produced by the Corps were purely tactical, showing the general lay of the land intended primarily for military use. The Corps' efforts were concentrated in the southern portion of Texas below the 30th parallel and between the 95th and 100th meridians. The maps published east of the 98th meridian were mostly 30-minute quadrangles and those to the west were mostly 15-minute quadrangles.

The first major effort to produce first-class topographic maps on a 7 1/2-minute basis was made by the Harris County Commissioners' Court in 1915 and 1916. The entire county was mapped to 1-foot contour intervals at a scale of 1:31,680. The Commissioners' Courts of Cameron and Galveston Counties followed suit from 1929 through 1932 by having their counties completely mapped to 1-foot contour intervals. This unfortunately marked the end of an era because no governmental agency has done any 1-foot contour mapping since that time.

The need for first-class topographic maps covering major proposed reservoir sites throughout Texas was recognized by the members of the State Board of Water Engineers in the early years following their organization in 1913. Funds were first appropriated for topographic mapping by the Thirty-Seventh Legislature in 1921. Subsequent Legislatures through the Fortieth appropriated additional funds that eventually resulted in the mapping of approximately 8,400 square miles or the equivalent of 7 1/2-minute quadrangles, 132 in number. This mapping was 20-foot contour work except for some work done at 2-foot contour intervals in Orange County.

Mapping progress during the 1930's was very slow, primarily because of the general economic condition of the Nation during the Depression. Activity increased greatly in the 1940's and early 1950's when the War Department provided funds for the 7 1/2-minute mapping of the entire coastal region of Texas from Louisiana to Mexico and extending inland an average of 60 miles. The U. S. Army Corps of Engineers, through the Army Map Service, also mapped a large portion of southwest Texas on a 15-minute basis between longitudes 100° and 102° and latitudes 29° and 30°.

The USGS accelerated its mapping activity in Texas during the 1950's. Most of this work was done in east Texas, but considerable emphasis was placed on the Red River Basin, the Dallas-Fort Worth area, and the central Texas region from Waco to San Saba.

As the need for more first-class maps throughout the State became more urgent, the Water Commission again urged the appropriation of funds for a cooperative mapping program with the USGS. Such a program provides for the State to choose those areas in Texas where mapping is the most needed to assist in planning water-resource developments. Funds for the mapping program were included by the Fifty-Fifth Legislature in the 1957 Water Planning Act. That act provided $200,000 for topographic mapping for each of the fiscal years 1958 and 1959.

The cooperative program is a procedure whereby the Federal Government matches dollar for dollar any monies put up by the State or local interests. Usually the State matches the local funds and this amount is then matched by the USGS, amounting to a 1/4-1/4-1/2 matching program. An exception to this procedure occurred in 1958, however, when the San Jacinto River Authority contracted directly with the USGS for $60,000. Due to the expensive mapping costs encountered in this area, funds soon were expended, and additional funds were made available in 1959 in the amounts of $28,000 each by the San Jacinto River Authority and the Water Commission matched by $56,000 from the USGS to complete this project.

The Fifty-Sixth Legislature again appropriated $400,000 for the 1960-61 biennium for the continuation of the cooperative mapping program. The Fifty-Seventh Legislature increased the appropriation for topographic mapping for the 1962-63 biennium to $600,000.

The Fifty-Eighth Legislature continued this valuable work by appropriating $600,000 for mapping for the current 1964-65 biennium. A contract for the full appropriation recently has been executed by the Water Commission and the USGS. Under this cooperative program, mapping has been initiated on 489 quadrangles, 118 of which have been published as of September 1, 1963, and work equivalent to completion of 107.1 quadrangles has been accomplished on the remaining 371 quadrangles.

In addition to the State funding described above, $138,000 has been contributed by local interests since 1957. Mapping agreements have been executed with 8 districts and authorities and 1 municipality covering the mapping of 42 quadrangles. As of September 1, 1963, published maps have been received for 33 quadrangles, and work equivalent to completion of 6.2 quadrangles has been accomplished on the remaining 9 quadrangles. This brings the total amount under contract since 1957 for the State and local cooperative program to $2,073,700 which covers the mapping of 531 quadrangles. Of this total, 151 quadrangles have been published and work equivalent to completion of 113.3 quadrangles has been accomplished on the remaining 380 quadrangles.

In addition to the 7 1/2-minute and 15-minute mapping programs in Texas, almost all of the State is covered by a special series of topographic maps to a scale of 1:250,000 prepared by the Army Map Service during the 1950's. Each of these maps covers 2 degrees of area, and has contour intervals ranging from 25 to 200 feet, depending on the type of terrain covered. The only portion of Texas not covered by these maps lies along the Rio Grande between longitude 100° and 106°. Editions covering that area will be published when additional information is obtained from Mexico.

Topographic maps have undergone frequent reevaluation as newer and better maps have been produced. The good, usable maps 40 years ago may serve no useful purpose today. Maps become obsolete primarily due to growth and development of an area, the improvement of mapping techniques, and the need for larger scale maps.

The Texas Water Commission uses three broad categories to classify the relative usefulness of all available topographic maps. First-order maps must comply with the National Map Accuracy Standards which were adopted by the USGS in 1947. They may be either 7 1/2-minute or 15-minute series. Second-order maps are those made subsequent to 1930 by either the USGS or the U. S. Army Corps of Engineers, compiled from aerial photographs and based on the 1927 and 1929 North American datum. These maps are usable, but need revision. Third-order maps are those made prior to 1930, not compiled from aerial photographs, and based on the North American datum prior to the resurvey. These maps are useless for most purposes, and the areas covered need to be re-mapped. Maps made earlier than 1920 generally are not shown on Commission map indexes unless the contour interval is such that the map still has some usefulness.

Using the classifications described above, the status of topographic mapping in Texas on September 1, 1963, based on a total of 4,400 quadrangle (7 1/2-minute) areas, is as follows:

First-order maps available	1,527 quads.	34.7%
Mapping in progress	910 quads.	20.7%
Second-order maps available	307 quads.	7.0%
Third-order maps available	175 quads.	4.0%
Unmapped	1,481 quads.	33.6%
Total	4,400 quads.	100.0%

THE NEXT 50 YEARS

Development of water resources during the last 50 years has been considerable. But, as Oliver Wendell Holmes said, "I find the great thing in this world is not so much where we stand, as in what direction we are moving." During the next 50 years the prospect for Texas is for an intensively industrialized and wealthy State if its abundant water resources are cultivated and managed wisely.

APPENDIX

ENTITIES COOPERATING IN PROGRAMS WITH THE TEXAS WATER COMMISSION, 1960-63

Acknowledged on the following pages are those entities that have worked with the Commission in various cooperative water-resource investigations.

Cooperators in surface-water investigations are listed under four categories: streamflow and reservoir content, quality of surface water, sedimentation, and evaporation.

For the ground-water investigations, all cooperators are grouped into a single list as many of them work with the Commission in several types of ground-water investigations.

Cooperators who have assisted the Topographic Mapping Program are presented separately in a single list.

SURFACE-WATER INVESTIGATIONS

Streamflow and Reservoir Content

Cooperator	City
Arlington, City of	Arlington, Texas
Bistone Municipal Water Supply District	Mexia, Texas
Brady, City of	Brady, Texas
Brazos River Authority	Waco, Texas
Canadian River Municipal Water Authority	Borger, Texas
Colorado River Municipal Water Supply District	Big Spring, Texas
Corpus Christi, City of	Corpus Christi, Texas
Dallas, City of	Dallas, Texas
Dallas, County of	Dallas, Texas
Dallas Power & Light Company	Dallas, Texas
Dow Chemical Company	Freeport, Texas
Edwards Underground Water District	San Antonio, Texas
Graham, City of	Graham, Texas
Guadalupe-Blanco River Authority	Seguin, Texas
Harris County Flood Control District	Houston, Texas
Houston, City of	Houston, Texas
Houston Lighting & Power Company	Houston, Texas
Lampasas, City of	Lampasas, Texas
Lower Colorado River Authority	Austin, Texas
Lower Neches Valley Authority	Beaumont, Texas
Palo Pinto County Municipal Water District No. 1	Mineral Wells, Texas
Red Bluff Water Power Control District	Pecos, Texas
Reeves County Water Improvement District No. 1	Balmorhea, Texas
Richmond Rice Association	Richmond, Texas

Cooperator	City
Sabine River Authority	Orange, Texas
San Angelo, City of	San Angelo, Texas
San Antonio City Public Service Board	San Antonio, Texas
San Antonio River Authority	San Antonio, Texas
San Jacinto River Authority	Conroe, Texas
South Texas Water Company	Rosharon, Texas
Tarrant County Water Control and Improvement District No. 1	Fort Worth, Texas
Texas Electric Service Company	Fort Worth, Texas
United States Geological Survey	Austin, Texas
United States Soil Conservation Service	Temple, Texas
Upper Neches River Water Authority	Palestine, Texas
West Central Texas Municipal Water District	Abilene, Texas
White River Municipal Water District	Crosbyton, Texas
Wichita Falls, City of	Wichita Falls, Texas
Wood, County of	Quitman, Texas

Quality of Surface Water

Brazos River Authority	Waco, Texas
Canadian River Municipal Water Authority	Borger, Texas
Chambers-Liberty Counties Navigation District	Anahuac, Texas
Colorado River Municipal Water Supply District	Big Spring, Texas
Dallas, City of	Dallas, Texas
Dow Chemical Company	Freeport, Texas
Houston, City of	Houston, Texas
Lower Colorado River Authority	Austin, Texas
Lower Neches Valley Authority	Beaumont, Texas
Red Bluff Water Power Control District	Pecos, Texas

Cooperator	City
Sabine River Authority	Orange, Texas
Tarrant County Water Control and Improvement District No. 1	Fort Worth, Texas
Texas Electric Service Company	Fort Worth, Texas
United States Geological Survey	Austin, Texas
United States Soil Conservation Service	Temple, Texas
West Central Texas Municipal Water District	Abilene, Texas
Wichita Falls, City of	Wichita Falls, Texas

Sedimentation

Brazos River Authority	Waco, Texas
Chambers-Liberty Counties Navigation District	Anahuac, Texas
Corpus Christi, City of	Corpus Christi, Texas
Lower Colorado River Authority	Austin, Texas
United States Geological Survey	Austin, Texas
United States Soil Conservation Service	Temple, Texas

Evaporation

Brazos River Authority	Waco, Texas
Brownsville Navigation District	Brownsville, Texas
Childress, City of	Childress, Texas
Corpus Christi, City of	Corpus Christi, Texas
Dow Chemical Company	Freeport, Texas
Houston, City of	Houston, Texas
Lower Colorado River Authority	~~Bushland~~ Austin, Texas
Mexia, City of	Mexia, Texas
Sabine River Authority	Orange, Texas
Sulphur Springs, City of	Sulphur Springs, Texas

Cooperator	City
Sweetwater, City of	Sweetwater, Texas
Texas Agricultural Experiment Station	College Station, Texas
Texas A & M University, Range and Forestry Division	College Station, Texas
Texas Parks and Wildlife Department	Austin, Texas
United States Agricultural Research Service	Bushland, Texas
United States Geological Survey	Austin, Texas
United States Soil Conservation Service	Temple, Texas
United States Weather Bureau	Fort Worth, Texas
Wichita Falls, City of	Wichita Falls, Texas

GROUND-WATER INVESTIGATIONS

Alice, City of	Alice, Texas
Bexar Metropolitan Water District	San Antonio, Texas
Brazos River Authority	Waco, Texas
Caldwell County Commissioners' Court	Lockhart, Texas
Crockett County Commissioners' Court	Ozona, Texas
DeWitt County Commissioners' Court	Cuero, Texas
Edwards Underground Water District	San Antonio, Texas
El Paso, City of	El Paso, Texas
Gaines County Commissioners' Court	Seminole, Texas
Galveston, City of	Galveston, Texas
Gonzales County Commissioners' Court	Gonzales, Texas
Guadalupe-Blanco River Authority	Seguin, Texas
Guadalupe County Commissioners' Court	Seguin, Texas
Harrison County Commissioners' Court	Marshall, Texas
High Plains Underground Water Conservation District No. 1	Lubbock, Texas
Houston, City of	Houston, Texas

Cooperator	City
Jackson County Commissioners' Court	Edna, Texas
Jasper County Commissioners' Court	Jasper, Texas
Lower Neches Valley Authority	Beaumont, Texas
Menard Chamber of Commerce	Menard, Texas
Mitchell County Commissioners' Court	Colorado City, Texas
Newton County Commissioners' Court	Newton, Texas
Nolan County Commissioners' Court	Sweetwater, Texas
North Plains Ground Water Conservation District No. 2	Dumas, Texas
Orange Chamber of Commerce	Orange, Texas
Orange, City of	Orange, Texas
Panhandle Ground Water Conservation District No. 2	White Deer, Texas
Refugio County Water Control and Improvement District No. 2	Refugio, Texas
Sabine County Commissioners' Court	Hemphill, Texas
Sabine River Authority	Orange, Texas
San Antonio, City of	San Antonio, Texas
San Augustine County Commissioners' Court	San Augustine, Texas
Tyler Chamber of Commerce	Tyler, Texas
United States Geological Survey	Austin, Texas

TOPOGRAPHIC MAPPING PROGRAM

Brazos River Authority	Waco, Texas
Collingsworth County Water Control and Improvement District No. 1	Wellington, Texas
Edwards Underground Water District	San Antonio, Texas
High Plains Underground Water Conservation District No. 1	Lubbock, Texas
North Texas Municipal Water District	Wylie, Texas
San Jacinto River Authority	Conroe, Texas

Cooperator	City
Stephenville, City of	Stephenville, Texas
Tarrant County Water Control and Improvement District No. 1	Fort Worth, Texas
United States Geological Survey	Denver, Colorado
West Central Texas Municipal Water District	Abilene, Texas