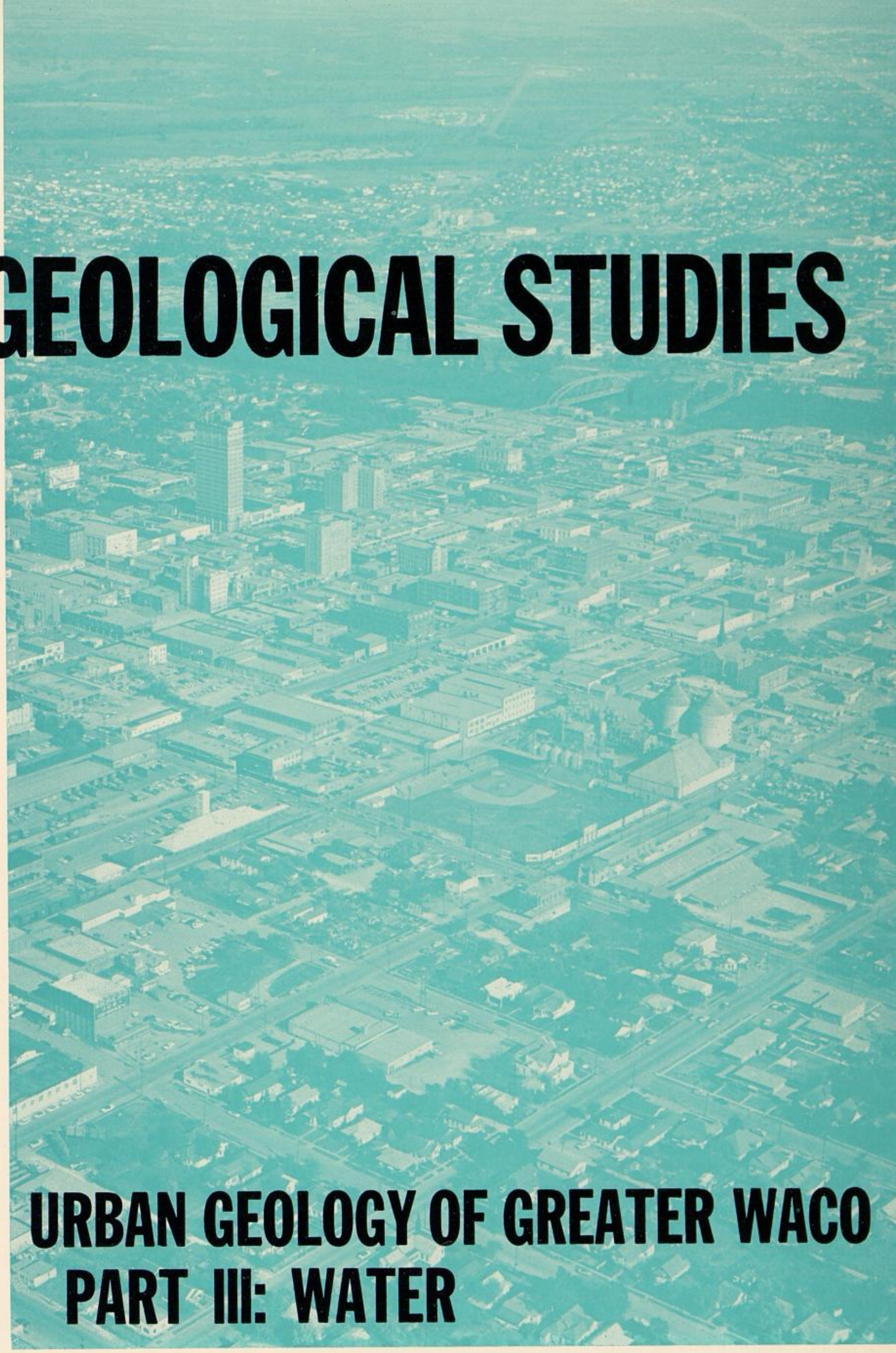
BAYLOR GEOLOGICAL STUDIES



SPRING 1966

Bulletin No. 10

BAYLOR UNIVERSITY – WACO, TEXAS
FOUNDED PRO ECCLESIA PRO TEXANA 1845

URBAN GEOLOGY OF GREATER WACO
PART III: WATER

Surface Waters of Waco

JEAN M. SPENCER

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

The Baylor University Press
Waco, Texas

BAYLOR GEOLOGICAL STUDIES

IN COOPERATION WITH COOPER FOUNDATION

A SERIES ON

URBAN GEOLOGY OF GREATER WACO

PUBLICATION SCHEDULE

Part I: GEOLOGY

Bulletin No. 8, Spring, 1965

Geology and Urban Development by Peter T. Flawn, Director, Texas Bureau of Economic Geology, Austin, Texas.

Geology of Waco by J. M. Burket, Professor of Geology, Tyler Junior College, Tyler, Texas.

Part II: SOILS

Bulletin No. 9, Fall, 1965

Soils and Urban Development of Waco by W. R. Elder, Field Specialist-Soils, Soil Conservation Service, Temple, Texas.

Part III: WATER

Bulletin No. 10, Spring, 1966

Surface Waters of Waco by Jean M. Spencer, Research Geologist, Department of Geology, Baylor University, Waco, Texas.

Bulletin No. 11, Fall, 1966

Subsurface Waters of Waco by H. D. Holloway, Geologist, Texas Water Development Board, Austin, Texas.

Part IV: ENGINEERING

Bulletin No. 12, Spring, 1967

Foundation Geology in Waco by A. M. Hull, Geological Engineer, Chief of Foundations Section, U. S. Corps of Engineers, Fort Worth, Texas.

Geologic Factors Affecting Construction in Waco by E. F. Williamson, Geologist, formerly Material Analyst, Texas Highway Department, Waco, Texas.

Part V: SOCIO-ECONOMIC GEOLOGY

Bulletin No. 13, Fall, 1967

Economic Geology of Waco and Vicinity by W. T. Huang, Professor of Geology, Baylor University, Waco, Texas.

Geology and Community Socio-Economics—A Symposium by authorities on Law, Appraising, Architecture, Public Works and other professions. Symposium Coordinator: R. L. Bronaugh, Professor of Geology, Baylor University, Waco, Texas.

Part VI: CONCLUSIONS

Bulletin No. 14, Spring, 1968

Urban Geology of Greater Waco—Summary and Recommendations by the Editorial Staff, Baylor Geological Studies, Baylor University, Waco, Texas.

FOREWORD

The development and early growth of Waco occurred primarily on the outcrops of the Austin Chalk and the Brazos Alluvium. Few geologically related problems appeared in the early development of the city, primarily because of the stable nature of the chalk and alluvium underlying most foundations in the city; the light weight and simplicity of most early structures; the relatively light loads on streets and roads; the uncomplicated nature of sewage and pipe systems; and the low demands of a small population for water, sand and gravel, sewage disposal and storm drainage.

During and after World War II, Waco expanded from these stable outcrop areas onto the outcrop of the unstable, incompetent shales of the Taylor Formation to the east and Eagle Ford Group to the west. This geographic expansion of Greater Waco during the past twenty years has been accompanied by many new urban problems of geological origin in addition to many existing problems which became critical with rapid urban population growth and expansion.

Among these important urban geological problems are those involving sand and gravel, which are lost to the area by unplanned city growth; foundation problems, which result in the failure of foundations in one area, over-design in another; soil problems involving corrosion of pipes, failure of foundations, variation in excavation costs and drainage problems; water supply problems, including surface and subsurface sources, utilization and pollution; and the quality, quantity and location of economic rocks and minerals in the Waco region.

These and many other problems cannot be solved adequately and economically without considering the role of the earth sciences. Responsible long-range urban development must also involve other geologically related aspects, such as problems of legal nature, property evaluation, city planning, recreation, beautification and development costs.

In recent years the Baylor Geology Department has received a growing number of requests for geological advice in the aforementioned areas of urban development. Although Baylor geologists have supplied free consultation as a public service, there has developed an apparent need for more comprehensive and accessible data on the total spectrum of earth science-urban relationships. The Baylor Geological Studies editorial staff decided in 1962 that a comprehensive publication on the Urban Geology of Waco should prove an asset to the city and its citizens.

Late in 1962 a thorough survey was made to ascertain sources of earth science data pertaining to the Waco area, as well as to locate published references on Urban Geology. Many city, state, and federal agencies, as well as interested individuals, were invited to cooperate in the project.

The Cooper Foundation, a private civic philanthropic foundation in Waco, was approached in January, 1963, for financial support to aid in the preparation and publication of a Waco Urban Geology report. A detailed, budgeted proposal was approved by the foundation to cover the proposed cost of publication and related expenses, totaling $7,000. Baylor University, through its press, accounting facilities, geology department, and Baylor Geological Studies budget accepted the responsibility for the remaining expense. The editorial staff of the Baylor Geological Studies provided free coordination, cartographic-field supervision, and editorial service.

Since the project was initiated early in 1963, it has evolved in concept and scope. The number and nature of contributions expanded as the project matured. The URBAN GEOLOGY OF GREATER WACO includes major contributions from the Baylor Geology Department, Texas Bureau of Economic Geology, U. S. Soil Conservation Service, U. S. Corps of Engineers, Texas Highway Department and Texas Water Development Board. Shorter contributions include papers by an architect, attorney, real estate appraiser, public works engineer and others.

In the spring of 1964, a series of eight public evening seminars were held at Baylor to provide contributors with an opportunity to present a summary of their reports for comments and discussion. A student seminar was conducted at the same time to explore all areas of urban activities which are related to the earth sciences.

Originally, the proposed Urban Geology report was scheduled to be released as a single volume. During preparation the various reports were expanded and complex illustrations were added; other papers were solicited to cover additional areas of importance. Because of the increased scope of the project, ten major and numerous shorter papers are included in the Baylor Geological Studies urban series.

Beginning with Baylor Geological Studies Bulletin No. 8 (Spring, 1965), seven successive semiannual Bulletins will include papers grouped according to Geology, Soils, Water, Geological Engineering, Socio-Economic Geology and Conclusions. Included in the series are multicolor geologic, soil, isopach and structure maps (on U.S. Geological Survey topographic base), charts, illustrations and tables of various types prepared by the Baylor Geological Studies student cartographic staff. Copies of Baylor Geological Studies Bulletins 8-14 (Urban Geology series) will be published and sold for $1.00 each. Sale of URBAN GEOLOGY OF GREATER WACO will be handled by Baylor Geological Studies in agreement with Cooper Foundation.

The editorial staff and contributors intend to provide a comprehensive series on Waco Urban Geology, which may also serve as a model for others interested in this vital area of geologic application and public service. No precise estimate can be placed on the value of information supplied by governmental agencies and individual researchers, or on the value of time donated by authors, editorial staff and interested geologists. The Cooper Foundation grant and the Baylor Geological Studies budget for the seven issues in the series will exceed $15,000—an amount which is conservatively estimated to be less than ten percent of the actual cost of the project if it had been contracted at regular professional and commercial rates.

The editorial staff appreciates this opportunity to provide a public service for the citizens of Waco. We sincerely thank the Cooper Foundation, Baylor University and the various State and Federal Agencies, as well as the many individuals, who made this series possible.

L. F. Brown, Jr., EDITOR, Bulletins 8, 9

Jean M. Spencer, EDITOR, Bulletins 10-14

BAYLOR GEOLOGICAL STUDIES

BULLETIN NO. 10

IN COOPERATION WITH COOPER FOUNDATION

A SERIES ON

URBAN GEOLOGY OF GREATER WACO

PART III: WATER

Surface Waters of Waco

JEAN M. SPENCER

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring, 1966

Baylor Geological Studies

The Baylor Geological Studies Bulletin is published semi-annually, Spring and Fall, by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the State.

Cover photograph: Aerial view of Downtown Waco. Photograph provided through the courtesy of WINDY DRUM STUDIO, COMMERCIAL PHOTOGRAPHY, Waco, Texas.

Additional copies of this bulletin can be obtained from the Department of Geology, Baylor University, Waco, Texas. $1.00 postpaid.

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ILLUSTRATIONS

Surface Waters of Waco

JEAN M. SPENCER

Research Geologist, Baylor
University, Waco, Texas

ABSTRACT

Waco receives surface water from the Brazos River and its tributary the Bosque River. The Brazos River has a drainage basin of 44,640 square miles, 28,500 square miles of which lie above Waco. The Bosque River has a total drainage basin of about 1670 square miles and is formed by the confluence of the North, Middle, and South Bosque rivers at Waco Reservoir. The Bosque River enters the Brazos River on the northern edge of Waco. Bosque River runoff supplies Waco with municipal water which is stored in Waco Reservoir. Brazos River water is used to supplement Waco's supply when the primary source is inadequate. It also transports treated sewage effluent away from the city.

Waco Reservoir lies on the northwestern edge of Waco above the confluence of the Bosque River with the Brazos River. Enlargement of old Lake Waco by construction of a larger dam was completed by the U.S. Army Corps of Engineers in February 1965. The enlarged lake provides a greater water supply reserve, considerably more flood control storage, and greater sediment storage capacity.

The Brazos River drains salt seeps and gypsum deposits in West Texas. At Waco Brazos River water has a total dissolved solids content of about 1,000 ppm (parts per million) and a total hardness of about 379 ppm. The Bosque River drains an area of limestone, sandstone, and shale formations in Central Texas and quality of the water is good. It has an average total dissolved solids content of about 246 ppm and an average total hardness of 151 ppm. Dilution of Brazos water by water additions at Waco and southward reduces the total dissolved solids content so that Brazos River water generally can be used for industrial and agricultural purposes between Waco and the Gulf Coast.

Waco is located on the western edge of the Gulf Coastal Plain of Texas along the Balcones escarpment. This escarpment is a major structural feature which extends southward through Central Texas and divides the Grand and Black prairie physiographic provinces. This geologic setting affects much of the weather of the area, especially precipitation. Warm, moist Gulf air is forced to rise as it reaches the Balcones escarpment, releasing moisture as it moves inland. Several national rainfall records have been observed in this area.

Because of potentially high rainfall rates, areas along the front of the Balcones escarpment have a high flood potential, especially those lowlying areas where streams are not entrenched. Whitney Reservoir and Waco Reservoir, both designed for flood control as well as water conservation, considerably reduce but do not eliminate the flood potential at Waco.

Within Waco most flood problems are in lowlying areas along the Brazos River and lower sections of the city drained by Waco Creek. Relief sewers help alleviate some of the Waco Creek flood problems.

INTRODUCTION[1]

The prime resource of any area is its water supply. Too much or too little water, as well as the quality of this water, can influence the economy as well as public health. To flood and drought, which have plagued man since earliest times, the urgent problem of water pollution must now be added. Municipal and industrial waste, when not properly treated, can pollute water supplies as can runoff from septic tanks, stock yards, fields on which agricultural chemicals (fertilizers, insecticides, defoliants, etc.) have been used, and storm sewer runoff.

Rivers reflect the geologic environment over or through which they flow. Geologic structure and regional geomorphology control locations of streams. Rocks and minerals of the drainage basin primarily determine water chemistry. Local water problems should be studied with respect to the regional geologic and hydrologic framework and the uniqueness of each local situation within this framework.

[1]Manuscript received fall 1966.

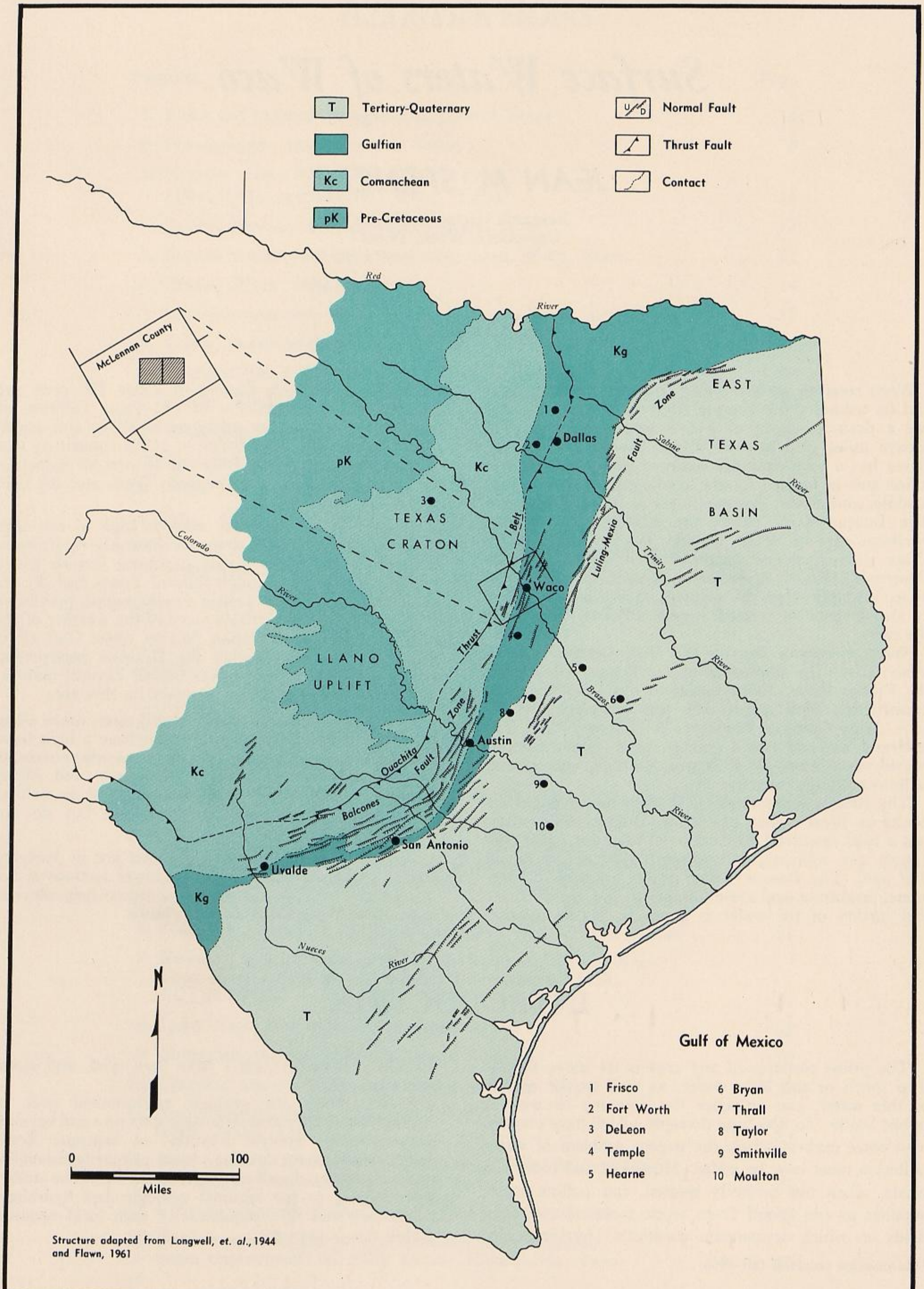

Fig. 1. Index and regional geologic map, Central Texas.

PURPOSE

The purpose of this study is to examine the surface water resources of Waco, Texas; to investigate the influence of regional and local geology on these water resources; and to make this information available in report form for use in urban planning. For the purpose of this report, surface water is defined as all water above ground and includes precipitation, water quality and water availability, stream sediment, as well as flood potential and drought.

Numerous local, state and federal agencies and organizations are studying water in Central Texas. Those on a state and local level with continuing programs include the Brazos River Authority, the Texas State Department of Health, the Texas Water Development Board, and the Waco City Water and Engineering Departments. Federal agencies include the U. S. Geological Survey, the U. S. Soil Conservation Service, the U. S. Weather Bureau, and the U. S. Army Corps of Engineers. Short term water studies are initiated from time to time by various other organizations including the Department of Geology, Baylor University. These studies contribute valuable information about the geohydrology of Central Texas. Basic geologic and hydrologic data used in this study have been obtained from all of these sources.

HISTORICAL BACKGROUND

The development of Waco is, as it has been in the past, largely dependent upon its water resources. The Hueco Indians, for whom the city is named, settled in the Waco area because of a spring which flows into the Brazos River. Legend held that water from this spring, described by early explorers as pure and icy, would enable the tribe to flourish forever. The spring, located on the southwest side of the Brazos River suspension bridge, was enclosed in a small park in the early 1930's

In 1844 George Barnard established an Indian trading post about seven miles southeast of the Waco spring on a small stream now known as Tradinghouse Creek. Five years later Captain Shapley P. Ross was granted a permit to operate a ferry service across the Brazos River at Waco. This ferry service made Waco the travel hub of Central Texas and was the only all-weather crossing for a hundred miles along the Brazos River.

A main branch of the historic Chisholm Trail passed through Waco because cattle could ford the Brazos at this location and grazing was good in McLennan County. Herds of cattle could cross the Goode ford which was at the foot of the present Jefferson Avenue or the Norris ford which was at the foot of the present Webster Avenue.

In 1870 a 475 foot suspension bridge was built across the Brazos River and replaced the Ross ferry. This was the longest single span suspension bridge in the world at that time. During high water cattle crossed the river over the bridge for a toll of five cents a head.

A private company installed the first water system in Waco in 1872. A second private water company was formed in 1889 and in 1899 these companies merged. Artesian wells drilled into the Trinity Sand provided water for these companies. In 1904 the City of Waco bought the private water company and in 1912 built a purification plant to augment the water supply with Brazos River water. In 1930 a dam was built on the Bosque River to provide a surface reservoir for municipal water. A second and larger dam was completed in 1965 by the U. S. Army Corps of Engineers on the Bosque River. This dam enlarged the lake and thus ensures Waco of a larger water reserve.

PREVIOUS INVESTIGATIONS

Surface water records of the Waco area are included as data in many reports and publications, especially those of the Texas Water Development Board, the U. S. Geological Survey, and the U. S. Weather Bureau. More information is available about the Brazos River than about the Bosque River or smaller creeks within the Waco area.

Official weather records for the City of Waco are kept by the U. S. Weather Bureau station at the municipal airport. These records are published monthly and annually by the U.S. Department of Commerce and may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402. Weather information also may be obtained from the Texas State Climatologist, 3600 Manor Road, Austin, Texas 78723.

Runoff and river discharge records are maintained by the Texas Water Development Board (successor to the Texas Water Commission and the Texas Board of Water Engineers) and the U. S. Geological Survey and are published in bulletins of the Texas Water Commission and the Texas Board of Water Engineers and reports of the Texas Water Development Board and the U. S. Geological Survey. Runoff and discharge records for the Waco area are included in data given for the Brazos River basin. These reports can be obtained from the Texas Water Development Board, P.O. Box 12386, Austin, Texas 78711 or the U. S. Geological Survey—Water Resources Division, 300 East 8th Street, Austin, Texas 78701.

Unpublished water quality records of the Brazos and Bosque rivers are maintained by the Waco City Water Department. Water quality studies are also conducted by the Texas State Department of Health, the Texas Water Development Board and the U.S. Geological Survey and are available as published and unpublished reports.

The U. S. Soil Conservation Service, the U.S. Geological Survey, and the Texas Water Development Board have compiled silt load data of rivers and streams in Texas. A silt load station was operated on the Brazos River at Waco from 1924 to 1933. A sedimentation study of old Lake Waco between 1930 and 1947 was made by the U. S. Soil Conservation Service.

The Brazos River Authority, with headquarters in Waco, is the state agency responsible for water resources development of the Brazos River basin. This organization is developing plans for a regional sewage treatment plant within the Waco area.

The City of Waco Engineering department has information on internal drainage within Waco. Forrest and Cotton, Inc., Consulting Engineers of Dallas, Texas, has prepared an extensive report on the storm drainage and flood control system of lower Waco Creek

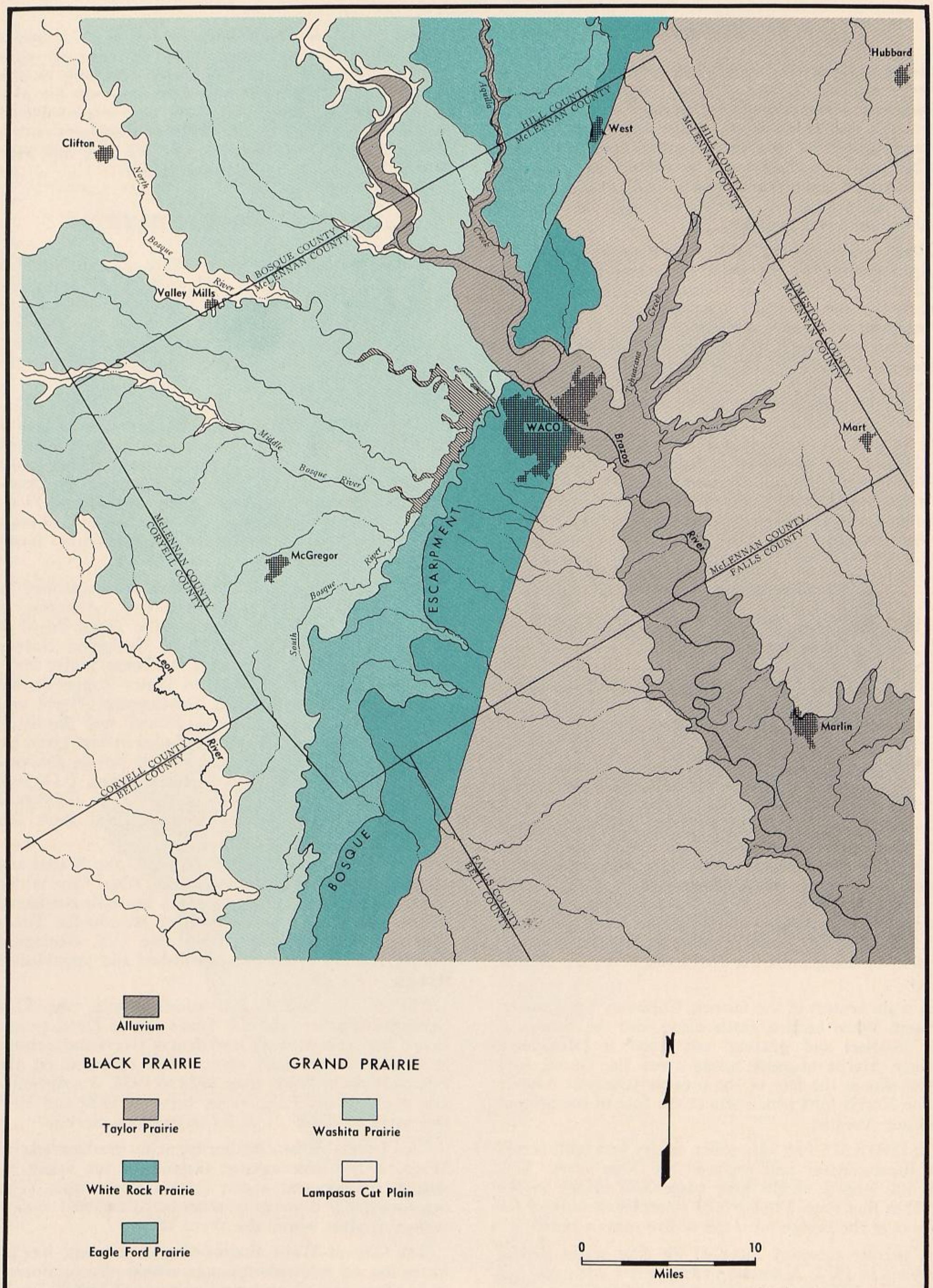

Fig. 2. Physiographic map, Central Texas.

basin for the City of Waco. This information is available in unpublished report form.

The Department of Geology, Baylor University has reports and theses, published and unpublished, on the geohydrology of Central Texas. Additional information on surface water in the Waco area is to be found as parts of bulletins and reports of various other agencies and organizations. Specific references used for this report are listed in the reference section.

ACKNOWLEDGMENTS

The writer wishes to thank the many organizations and individuals who made information available for this report. A special note of appreciation is extended to the Texas Water Development Board for advice and data, as well as to the Waco City Water Department and the U. S. Weather Bureau, Waco, for providing extensive information on the Waco area.

GEOGRAPHY

Waco lies on the western edge of the Gulf Coastal Plain of Texas (fig. 1). The city is underlain by coastward dipping Cretaceous rocks of upper Comanchean and lower Gulfian age. These rocks include the Eagle Ford Group, the Austin Chalk, and the Taylor Marl. Sandy terraces and alluvium of the Brazos River are Quaternary in age (Flawn and Burkett, 1965, Pls. I, II).

Two major physiographic provinces are represented in the Waco area. The Blackland Prairie is underlain by rocks of the Taylor and Austin formations and the Eagle Ford Group. The Washita Prairie is underlain by limestone rocks of the Washita Group. The eastern four-fifths of the city lies on the Blackland Prairie; the western part of the city lies on the Washita Prairie (fig. 2).

The Grand and Black prairies are separated by the Bosque escarpment, a regional segment of the Balcones escarpment. Though it normally faces southeastward, in the Waco area this escarpment is a northwestward facing cuesta and fault-line scarp. It extends from Dallas southward through Waco to San Antonio where it turns westward toward Uvalde. In the Waco area the escarpment is capped by the Austin Chalk.

The Brazos River system drains Waco. It bisects the city from northwest to southeast as it flows toward the Gulf of Mexico. In the Waco area the Brazos River leaves the rolling and hilly country of the Grand Prairie of Central Texas and enters the flatlying Blackland Prairie and upper Gulf Coastal Plain. The Bosque River system, a major tributary of the Brazos River, drains an area west of the Balcones escarpment and joins the Brazos River north of Waco downstream from Waco Reservoir.

A trellis drainage pattern characterizes Brazos River tributaries on the Grand and Black prairies. In the eastern part of Waco where the non-resistant lower Taylor Marl crops out, streams display a more dendritic pattern.

Seven natural and artificial drainage basins drain Waco (figs. 13, 14). Six of these drainage basins empty into the Brazos River. These include Primrose Creek, Waco Creek, Business District, Barron's Branch, Wilson's Creek, and East Waco. Waco Creek, which has the largest drainage basin, carries most of the city's storm drainage. A seventh drainage basin, located in the northwestern part of the city, empties into Lake Waco.

CLIMATE

CLIMATE ZONE

Because of its location on the western edge of the Gulf Coastal Plain of Texas, Waco experiences both the humid coastal climate of East Texas and the more continental climate of the interior regions. This location includes Waco on the western margin of Koppen's Cfa or Humid Subtropical climate zone and near the eastern margin of the BSh or hot Steepe climate zone. The Cfa climate classification includes temperate rainy areas with hot summers (mean July temperatures above 71.6°F). The BSh classification includes dry hot areas with mean annual temperatures above 64.4°F.

TEMPERATURE

At Waco the mean annual temperature (1897-1965) is 67.2°F (table 1) and the mean relative humidity is 67 percent. Winters are mild; temperatures reach below 32°F an average of 28 days a year. Lowest recorded temperature was -5°F observed February 12, 1899 and January 31, 1949.

Highest temperature recorded at Waco was 111°F on August 12, 1936. Summers are warm and maximum temperatures above 90°F occur an average of 110 days during the warm season.

Table 1. Annual temperature, precipitation, and snowfall, Waco, Texas.

AVERAGE TEMPERATURE

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	An'l.
1900	49.0	48.0	57.0	65.4	73.8	84.2	84.5	84.1	82.5	71.7	59.2	51.1	67.5
1901	51.0	47.3	58.7	61.6	74.6	83.4	88.2	87.8	79.3	69.8	58.8	45.9	67.2
1902	46.3	49.8	61.8	71.7	80.0	86.3	85.1	87.6	76.4	66.8	63.2	49.4	68.7
1903	51.7	50.8	57.8	67.0	73.0	76.8	84.8	84.6	77.0	65.4	56.3	50.8	66.3
1904	46.4	54.0	64.4	66.4	74.7	82.4	84.5	84.2	81.7	71.9	57.6	51.4	68.3
1905	46.2	40.2	63.9	66.6	78.4	84.8	84.6	87.1	83.2	71.2	64.0	50.2	68.4
1906	51.2	50.8	57.0	68.9	76.6	84.2	83.4	83.2	80.0	64.4	57.9	56.6	67.8
1907	58.4	54.0	68.4	65.9	69.8	83.4	86.5	87.8	79.1	67.9	53.6	50.6	68.8
1908	49.6	50.5	65.9	68.3	74.6	84.1	84.4	84.2	78.0	66.4	58.4	52.3	68.1
1909	52.2	51.4	59.6	65.0	73.0	83.6	89.6	87.6	79.6	69.4	63.7	41.0	68.0
1910	48.4	43.2	63.2	65.3	72.6	82.0	87.2	89.3	83.5	68.6	60.0	49.4	67.7
1911	54.6	55.2	61.0	65.8	75.1	86.8	85.8	87.4	85.4	67.3	53.0	46.8	68.7
1912	41.1	47.8	52.8	67.2	76.8	79.2	88.0	87.0	79.6	69.9	54.7	48.4	66.0
1913	50.8	45.8	53.0	65.2	75.7	82.3	88.4	86.6	74.4	63.4	63.2	45.2	66.2
1914	51.3	45.1	54.6	64.2	73.4	84.8	89.0	83.2	79.0	67.6	56.8	41.1	65.8
1915	45.3	52.8	48.1	66.8	75.4	83.9	85.0	81.6	79.3	67.9	59.8	50.6	66.4
1916	48.8	50.0	62.5	64.1	74.5	83.0	86.4	84.6	78.3	68.5	54.2	48.4	66.9
1917	48.9	50.8	58.2	65.2	68.6	84.0	87.6	86.8	77.2	63.2	55.8	43.6	65.8
1918	38.5	51.2	62.2	65.4	76.9	86.8	88.1	88.2	75.2	70.2	55.4	51.8	67.5
1919	47.0	50.0	58.8	68.6	72.8	79.3	84.5	84.2	78.4	72.0	56.8	47.8	66.7
1920	45.2	53.0	59.8	68.7	77.0	81.2	85.4	81.4	80.1	69.0	54.2	50.8	67.2
1921	55.2	55.0	66.8	65.3	76.2	81.6	85.1	87.0	82.9	68.1	63.2	55.4	70.2
1922	47.2	55.4	59.0	69.4	77.2	83.8	87.3	87.6	80.8	68.8	60.3	55.8	60.4
1923	58.5	49.5	56.0	68.4	77.4	85.0	87.7	87.6	80.6	66.4	57.3	53.6	69.0
1924	44.6	50.4	54.4	68.6	72.5	85.0	85.4	89.3	77.7	69.2	61.8	50.2	67.4
1925	45.3	59.4	66.0	75.0	77.4	88.8	90.8	86.6	83.2	66.7	57.4	47.5	70.3
1926	45.6	57.9	56.6	62.8	74.6	82.4	83.7	85.5	82.4	73.3	56.4	50.6	67.6
1927	50.5	58.0	60.6	71.2	79.2	81.2	85.4	86.6	80.7	70.6	66.8	47.9	69.9
1928	50.4	51.6	62.8	64.7	76.6	82.2	86.2	86.7	77.2	72.6	56.6	49.4	68.1
1929	49.1	42.2	62.8	71.7	74.8	83.4	85.0	87.2	79.4	70.2	51.0	49.9	67.2
1930	37.0	59.0	57.2	71.9	74.2	82.2	87.8	87.2	79.9	67.6	57.8	47.8	67.5
1931	50.4	55.2	54.6	64.8	73.2	84.1	87.2	83.8	83.8	75.0	64.0	51.8	69.0
1932	50.0	58.6	55.1	69.6	74.9	83.9	87.6	87.2	77.4	66.3	53.2	46.1	67.5
1933	55.8	48.2	63.2	69.0	79.4	83.4	88.1	86.4	85.2	72.2	61.0	58.1	70.8
1934	52.6	52.6	56.9	71.2	76.4	87.4	89.4	88.9	78.7	73.7	61.2	49.3	69.9
1935	49.8	50.4	64.0	67.0	72.0	81.6	86.9	86.8	75.5	70.2	53.8	46.0	67.0
1936	44.9	42.8	62.8	64.3	73.3	82.6	82.7	85.1	80.0	62.6	52.4	50.0	65.3
1937	42.3	50.2	51.4	65.9	76.2	81.8	84.4	86.8	79.0	67.6	52.7	47.8	65.5
1938	49.2	55.6	63.6	63.8	72.9	80.3	81.8	83.8	78.2	70.7	53.8	49.1	66.9
1939	49.3	46.4	59.6	66.0	74.5	80.1	84.8	83.2	80.9	69.2	52.9	51.6	66.5
1940	35.1	48.2	59.4	64.4	73.2	77.2	81.4	82.8	76.0	68.9	53.7	49.3	64.1
1941	50.7	48.2	52.8	66.0	75.1	78.8	83.4	84.2	80.2	72.4	56.1	51.2	66.6
1942	45.0	49.4	57.6	65.7	72.1	81.0	83.2	83.7	74.6	66.9	61.4	51.1	66.0
1943	47.4	55.8	53.4	70.6	75.4	83.0	85.1	86.5	76.7	67.0	56.2	47.3	67.0
1944	47.0	54.0	56.9	66.0	72.0	82.8	86.2	85.5	78.4	69.2	59.3	46.1	67.0
1945	47.9	51.8	64.0	65.2	73.5	80.6	83.2	84.0	79.1	65.7	61.9	46.5	67.0
1946	47.2	53.5	61.8	69.6	73.2	79.6	84.9	85.3	77.6	70.2	57.6	53.5	67.8
1947	46.9	45.3	52.3	66.0	72.6	82.2	84.4	85.6	79.4	75.4	53.7	50.3	66.2
1948	41.2	49.0	55.7	71.3	75.6	84.2	85.2	86.3	77.7	67.6	57.0	52.9	67.0
1949	41.8	51.0	58.0	63.2	77.1	81.6	84.8	83.0	79.0	68.0	60.6	51.8	66.7
1950	51.8	54.7	57.5	64.7	75.1	80.4	83.1	84.2	77.0	72.2	56.6	48.6	67.2
1951	47.7	51.7	60.4	66.1	73.8	81.6	88.1	90.0	79.7	70.3	54.1	51.4	67.9
1952	56.8	55.9	57.0	63.1	72.4	82.8	84.6	88.8	79.0	64.2	56.1	47.9	67.4
1953	53.7	51.5	62.8	64.6	73.3	85.6	84.8	83.7	78.6	69.8	55.6	46.8	67.6
1954	48.5	56.7	57.1	72.0	71.3	83.1	88.8	87.7	82.2	71.5	57.3	52.2	69.1
1955	48.6	51.2	60.0	70.4	76.2	78.8	84.9	83.0	80.9	68.7	57.2	49.7	67.4
1956	47.4	52.5	59.8	66.4	78.2	83.8	87.5	87.0	81.3	72.6	54.9	53.1	68.7
1957	46.6	57.3	56.3	64.2	73.6	81.2	87.4	86.4	76.7	64.5	54.1	54.3	66.9
1958	46.8	46.5	51.9	64.2	75.0	82.4	85.8	85.1	78.4	66.7	59.3	46.0	65.7
1959	45.3	50.2	58.1	63.8	76.4	80.7	83.4	83.9	79.4	67.4	50.4	52.1	65.9
1960	46.9	45.7	52.5	69.1	73.3	82.7	84.8	84.0	79.8	71.1	59.3	46.0	66.3
1961	43.3	53.2	61.6	66.1	75.0	78.3	81.4	82.3	78.0	68.6	54.5	49.2	66.0
1962	43.0	57.1	56.1	66.5	77.1	79.9	86.0	88.0	80.4	72.3	57.8	49.1	67.8
1963	40.9	48.7	63.1	72.0	76.2	83.7	87.5	87.4	80.8	74.9	59.5	41.2	68.0
1964	46.7	45.5	57.4	68.7	75.5	82.6	87.9	86.8	78.7	65.8	60.9	50.6	67.3
1965	51.4	48.2	51.2	71.9	75.6	82.6	87.2	86.0	79.9	66.0	63.2	52.4	68.0
RECORD MEAN TEMP	47.9	50.2	58.7	67.1	74.9	82.6	85.8	85.8	79.4	69.0	57.5	49.5	67.4
MAX	58.4	60.3	70.1	77.9	85.1	92.9	96.3	96.5	90.0	80.3	68.3	59.8	78.0
MIN	37.4	40.1	47.3	56.2	64.7	72.3	75.3	75.1	68.7	57.6	46.7	39.1	56.7

TOTAL PRECIPITATION

WACO, TEXAS
MUNICIPAL AIRPORT
1953

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1900	3.00	0.00	5.00	9.50	7.00	2.62	2.85	2.83	4.48	1.15	0.60	1.24	40.27
1901	0.00	3.10	3.71	2.89	4.50	1.89	T	0.65	4.99	0.50	2.08	1.50	25.81
1902	0.76	0.65	2.35	4.02	5.57	3.15	8.95	0.00	6.23	3.40	10.36	1.95	47.39
1903	2.55	6.19	2.90	0.20	2.18	5.46	8.63	0.40	1.68	2.68	0.00	0.18	33.05
1904	1.60	2.99	1.17	4.97	7.11	4.19	3.99	1.06	1.48	6.43	0.06	0.29	35.34
1905	1.61	3.93	8.38	13.01	8.39	5.40	3.19	2.22	2.74	2.39	3.33	5.61	60.20
1906	1.38	2.65	2.95	3.46	5.15	5.97	5.88	4.34	5.77	1.66	2.00	5.02	46.23
1907	1.54	0.83	0.82	3.92	8.44	1.85	0.20	0.25	1.61	6.23	6.54	4.03	36.26
1908	1.02	4.43	3.14	8.90	10.51	1.54	2.66	3.06	3.72	1.74	2.46	3.04	46.22
1909	T	1.90	1.00	2.02	3.78	4.20	0.46	3.16	0.38	4.38	2.26	4.69	28.23
1910	1.12	3.14	3.54	1.36	8.18	2.94	1.67	T	0.12	0.88	0.72	3.70	27.37
1911	0.26	2.88	2.46	6.82	1.62	1.42	6.61	0.94	1.32	4.49	2.30	5.54	36.66
1912	0.00	4.30	8.02	5.38	3.28	4.40	0.32	1.38	2.70	5.82	1.51	2.74	39.85
1913	1.78	2.47	0.78	3.40	1.20	1.16	0.15	4.07	11.17	3.52	5.32	11.76	46.78
1914	0.20	1.66	3.78	5.46	7.88	0.49	0.93	9.98	1.33	0.45	3.53	3.51	39.20
1915	1.56	1.49	2.06	6.28	3.21	2.12	1.04	6.40	1.22	1.07	2.04	1.88	30.37
1916	4.74	T	0.28	4.45	4.99	3.12	2.80	1.44	0.94	2.39	2.61	T	27.76
1917	0.49	0.36	1.11	2.47	4.04	0.45	1.46	0.11	1.55	0.06	1.29	T	13.39
1918	1.06	0.16	1.91	5.69	0.64	0.72	0.43	0.72	2.35	4.76	3.97	4.88	28.29
1919	2.29	1.58	5.49	2.44	3.07	9.89	4.58	5.38	3.22	7.13	6.00	1.00	52.07
1920	4.72	0.88	1.27	0.37	5.75	3.07	2.53	6.29	2.88	2.66	5.02	1.08	36.52
1921	1.60	1.24	3.16	4.10	2.92	4.81	2.14	0.33	1.40	0.58	0.18	3.91	26.37
1922	2.97	1.77	5.32	10.72	5.56	2.73	0.55	1.77	0.44	0.87	2.33	T	35.03
1923	0.37	5.81	2.53	5.05	0.38	2.46	0.49	0.89	3.26	3.83	2.59	8.63	36.29
1924	1.93	3.39	3.60	1.90	3.80	0.93	T	T	4.33	0.14	1.18	0.55	21.75
1925	1.46	0.21	T	1.99	1.49	0.30	0.89	3.48	5.72	4.46	3.08	0.45	23.53
1926	4.78	T	6.51	4.21	2.18	4.67	3.55	0.28	1.40	3.22	1.33	4.92	37.05
1927	1.10	2.91	4.73	5.27	3.03	10.55	1.75	0.12	1.77	6.98	0.43	1.87	40.51
1928	T	5.08	1.46	2.71	1.04	6.19	1.91	1.35	2.19	1.15	1.47	3.32	27.87
1929	2.45	2.18	2.50	3.87	9.70	0.15	1.88	T	3.82	1.58	3.68	1.10	32.91
1930	1.50	2.46	2.08	4.78	9.68	2.49	0.00	2.44	2.50	6.22	3.30	2.69	40.14
1931	3.19	2.82	4.36	3.25	1.59	1.14	0.70	2.49	0.03	0.88	1.39	2.84	24.68
1932	6.56	5.58	2.13	1.92	9.70	2.36	2.55	0.60	6.43	0.34	0.07	3.39	41.63
1933	2.61	1.74	2.90	1.30	6.40	T	4.63	0.44	3.73	1.31	1.32	2.72	29.10
1934	4.18	2.23	5.50	3.24	0.08	T	1.42	0.89	0.98	0.06	4.95	0.50	24.03
1935	1.51	3.67	1.70	2.23	7.15	5.11	0.94	0.75	9.11	4.15	3.41	4.18	43.91
1936	0.39	0.86	0.88	3.11	7.15	0.02	2.93	0.03	10.39	3.49	2.30	4.15	35.70
1937	2.92	0.69	3.39	0.84	0.69	3.76	1.55	0.23	0.93	3.95	2.00	5.60	27.15
1938	3.92	2.31	3.37	5.78	3.29	10.21	3.61	0.74	0.85	0.18	1.23	1.45	36.94
1939	4.23	3.77	1.93	1.83	6.20	3.08	0.70	3.27	0.60	2.00	2.25	1.45	31.31
1940	1.24	2.39	0.33	3.98	1.13	4.14	1.58	1.86	0.69	1.61	9.85	4.46	33.26
1941	1.97	5.95	4.77	3.77	4.41	4.01	4.23	3.62	1.00	3.06	1.26	1.67	39.72
1942	0.55	1.84	1.02	10.40	3.84	4.47	0.27	3.47	9.37	3.85	3.63	2.43	45.14
1943	0.63	0.48	1.50	0.76	4.55	0.27	4.51	0.68	4.69	3.63	1.32	2.42	25.44
1944	3.29	4.55	2.67	6.93	8.01	1.19	0.43	2.17	1.05	1.15	4.50	4.26	40.20
1945	3.39	3.38	6.84	5.80	0.72	2.71	0.74	2.77	1.46	2.62	1.73	3.30	35.46
1946	3.38	3.08	4.41	2.35	7.75	1.82	0.46	0.72	2.84	1.47	3.36	2.86	34.50
1947	3.36	0.85	4.03	5.23	3.71	4.31	2.89	2.11	0.86	0.69	2.09	3.66	33.79
1948	1.56	1.21	2.08	3.34	2.92	1.33	5.02	1.02	1.85	1.37	0.97	1.74	24.41
1949	3.66	2.31	2.39	4.30	0.86	6.97	3.32	0.89	0.61	4.51	0.19	1.48	31.49
1950	1.35	4.24	0.16	3.72	4.54	2.96	2.59	0.85	4.92	2.00	0.31	0.04	27.68
1951	1.30	2.07	2.02	2.76	3.35	2.21	0.33	0.59	3.60	0.89	0.56	0.44	20.12
1952	0.59	1.46	2.05	5.49	4.68	1.10	0.77	T	0.73	0.00	6.24	4.14	27.25
1953	0.53	2.37	3.21	2.04	9.72	0.27	1.72	3.15	1.65	3.37	0.82	3.18	32.03
1954	0.79	0.44	0.86	2.50	3.87	0.79	0.37	0.17	0.56	2.48	2.02	0.07	14.92
1955	1.58	3.59	3.20	1.30	7.61	2.01	0.39	3.14	2.42	2.38	1.13	0.43	29.18
1956	2.75	1.25	0.04	0.65	4.25	0.37	0.34	0.14	0.00	1.08	2.34	1.94	15.15
1957	1.53	2.41	5.58	13.37	7.60	1.03	0.61	0.50	5.69	5.40	4.77	0.42	48.91
1958	2.49	3.27	0.96	3.60	5.58	2.72	0.68	7.34	4.68	1.24	1.81	0.94	35.31
1959	0.29	2.72	0.22	2.74	1.96	5.74	1.84	2.14	3.49	7.36	1.25	4.06	33.81
1960	1.79	1.91	0.69	1.67	2.38	2.73	1.20	3.00	1.12	5.25	0.86	7.03	29.63
1961	5.83	3.86	1.76	1.05	1.34	12.06	7.68	0.90	2.28	1.28	3.53	1.14	42.71
1962	0.65	1.41	0.81	2.95	2.19	4.69	0.07	0.72	3.92	2.37	1.48	1.34	22.60
1963	0.49	0.51	0.76	2.76	5.70	1.83	T	1.28	0.83	1.09	3.22	1.10	19.57
1964	3.15	1.29	2.85	2.85	1.48	4.32	0.23	2.30	5.49	0.79	3.67	0.90	29.32
1965	2.97	4.41	3.13	1.35	15.00	0.82	0.12	0.64	3.80	2.91	4.64	2.31	42.10
RECORD MEAN	2.14	2.34	2.75	4.02	4.62	3.12	1.96	2.16	2.86	2.55	2.58	2.63	33.73

Record mean values above (not adjusted for instrument location changes listed in the Station Location table) are means for the period beginning in 1897.

MONTHLY AND SEASONAL SNOWFALL

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1899-1900							T						T
1900-1901								1.0					1.0
1901-1902								1.5					1.5
1902-1903								1.0					1.0
1903-1904													0.0
1904-1905													0.0
1905-1906							2.0	1.1					3.1
1906-1907						T							T
1907-1908													0.0
1908-1909							T						T
1909-1910						1.5		3.0					4.5
1910-1911													0.0
1911-1912													0.0
1912-1913													0.0
1913-1914													0.0
1914-1915							1.0		2.5				3.5
1915-1916						0.5							0.5
1916-1917									0.9				0.9
1917-1918							3.5						3.5
1918-1919					T		T						T
1919-1920													0.0
1920-1921					T								T
1921-1922													0.0
1922-1923								4.0					4.0
1923-1924								13.0					13.0
1924-1925													0.0
1925-1926							8.0						8.0
1926-1927													0.0
1927-1928						0.5							0.5
1928-1929													0.0
1929-1930						13.0	2.0						15.0
1930-1931									0.4				0.4
1931-1932									0.8				0.8
1932-1933						1.1		T					1.1
1933-1934													0.0
1934-1935													0.0
1935-1936							1.5						1.5
1936-1937													0.0
1937-1938					6.5								6.5
1938-1939													0.0
1939-1940						T	5.8	3.0					8.8
1940-1941													0.0
1941-1942							T	0.2					0.2
1942-1943						T							T
1943-1944							3.0						3.0
1944-1945						T							T
1945-1946						T	0.5	T					0.5
1946-1947						2.0		T	T				2.0
1947-1948							1.0	T	1.0	T			2.0
1948-1949							7.0		T				7.0
1949-1950						T	T	T	T			T	T
1950-1951							0.8	1.0	T				1.8
1951-1952					T						T		T
1952-1953							1.5			T	T		1.5
1953						T							

Data from U.S. Weather Bureau Station, Waco, Texas.

RAINFALL

Waco has a mean annual precipitation of about 33 to 34 inches (table 1). The maximum annual recorded precipitation was 60.20 inches in 1905 and the minimum was 13.39 inches in 1917. April and May are months of heaviest precipitation which is produced when warm, moist air moves inland from the Gulf of Mexico (fig. 3). The maximum observed monthly precipitation, 15.00 inches, was recorded in May 1965.

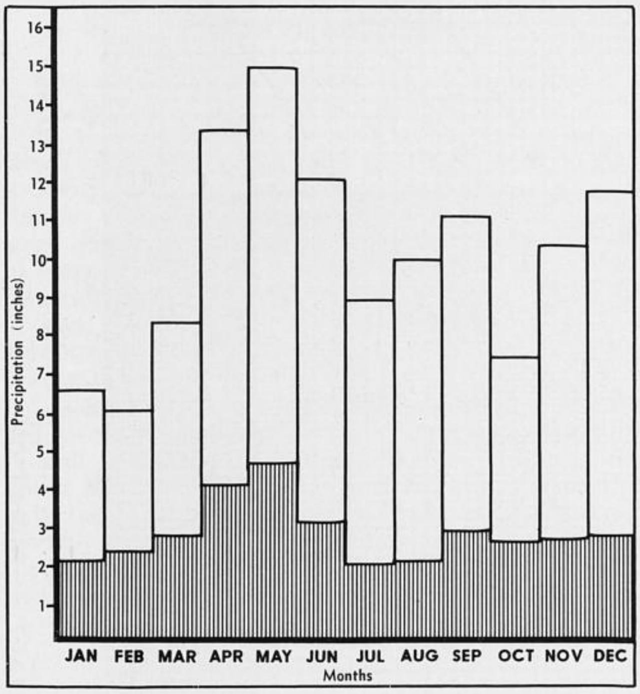

Fig. 3. Monthly mean (1897-1965) and maximum (1900-1965) precipitation, Waco, Texas.

Rainfall varies in drainage basins of the rivers which flow through the Waco area. The Brazos River drainage basin averages about 33 inches annually; about 17 inches fall at the headwaters and about 48 inches at the mouth (Texas Water Development Board, 1966, p. 3). The Bosque drainage basin, which is a part of the Brazos River drainage basin, varies only slightly in amount of rainfall from that of the Waco area.

Rainfall intensity-duration curves for Waco are shown in figure 4. The largest recorded 24 hour rainfall at Waco, 7.18 inches, fell May 11, 1953 when Waco was hit by the first tornado ever reported in the immediate vicinity.

Several maximum observed rainfall records in the United States were established less than 100 miles from Waco and should be considered indicative of rainfall potentials in the Waco area. Selected maximum rainfalls in Texas are shown in table 2. Many of these records were set within a 100 mile radius of Waco. The largest recorded 24 hour rainfall in the United States occurred September 9-10, 1921 at Thrall, Williamson County, Texas when a total of 38.21 inches was recorded—an unofficial measurement of 32 inches in 12 hours was made 2 miles north of Thrall during the same period. During this storm Taylor, Williamson County received 23.11 inches of rain in 24 hours, 18.96 inches in 12 hours, and 8.02 inches in 40 minutes. On June 28, 1899 Hearne, Robertson County received 24 inches of rain in 24 hours and an estimated total rainfall of 30 inches during this storm. The Taylor, Texas storm of April 29, 1905 deposited 2 inches of rain in 10 minutes and more than 2.5 inches in 15 minutes. It should be noted that these records were not established in a single storm period but in three successive storm periods in 22 years (1899-1921) of record within a 70 mile radius of Waco.

Tropical storms originating in the Gulf of Mexico, Caribbean, or South Atlantic frequently bear westward and strike inland into Texas. When these storms reach the Balcones escarpment in Central Texas the warm moisture-laden air is forced to rise. Cooling of the air due to the elevation increase causes precipitation and can produce heavy rainfall along the escarpment. Generally, these tropical storms occur during late summer and autumn.

Masses of cool air moving through Texas from the northwest also elevate warm, moisture-laden air from the Gulf of Mexico and produce rain. This condition frequently is responsible for heavy spring rains.

Table 2. Selected maximum rainfalls in Texas.

Site	Date	Duration (time)*	Amount (inches)	Authority
Thrall	Sept. 9-10, 1921	24 h	38.2	U. S. Weather Bureau
Hearne	June 28, 1899	24 h	24.0	U. S. Weather Bureau
Taylor	Sept. 9, 1921	24 h	23.11	U. S. Weather Bureau
San Antonio	Sept. 9-10, 1946	24 h	21.0	U. S. Geol. Survey
Austin	Sept. 9, 1921	24 h	19.03	U. S. Weather Bureau
Moulton	June 30, 1940	24 h	17.98	U. S. Weather Bureau
San Antonio (near)	Sept. 9, 1921	24 h	17.0	U. S. Geol. Survey
Smithville	June 30, 1940	15 h	16.0	U. S. Weather Bureau
Thrall	Sept. 9-10, 1921	12 h	29.8	U. S. Weather Bureau
Taylor	Sept. 9, 1921	12 h	18.96	U. S. Weather Bureau
San Antonio (11 mi SE)	Sept. 27, 1946	11 h	16.67	U. S. Geol. Survey
De Leon (5.5 mi E)	May 23, 1952	9 h	20.0	U. S. Geol. Survey
Fort Worth	May 16-17, 1949	9 h	11.0	U. S. Geol. Survey
Frisco	Sept. 21, 1964	8 h	14.0	U. S. Geol. Survey
Thrall	Sept. 9-10, 1921	6 h	19.6	U. S. Weather Bureau
Taylor	Sept. 9, 1921	6 h	14.16	U. S. Weather Bureau
Fort Worth	Sept. 7, 1962	5 h	11.5	U. S. Geol. Survey
Taylor	Sept. 9, 1921	3 h	10.72	U. S. Weather Bureau
Dallas	Oct. 8, 1962	3 h	7.46	U. S. Geol. Survey
Taylor	Sept. 9, 1921	2 h	7.51	U. S. Weather Bureau
Taylor	Sept. 9, 1921	1 h	4.25	U. S. Weather Bureau
Dallas	Oct. 8, 1962	1 h	3.95	U. S. Geol. Survey
Taylor	Sept. 9, 1921	30 m	2.89	U. S. Weather Bureau
Taylor	Sept. 9, 1921	15 m	2.53	U. S. Weather Bureau
Taylor	Sept. 9, 1921	10 m	2.00	U. S. Weather Bureau
Taylor	Sept. 9, 1921	5 m	1.30	U. S. Weather Bureau

* h-hour; m-minute

From Ruggles, Frederick H., Jr. (1966) Floods on small streams in Texas: U. S. Geological Survey-Water Resources Division, Open File Report No. 89, p. 5.

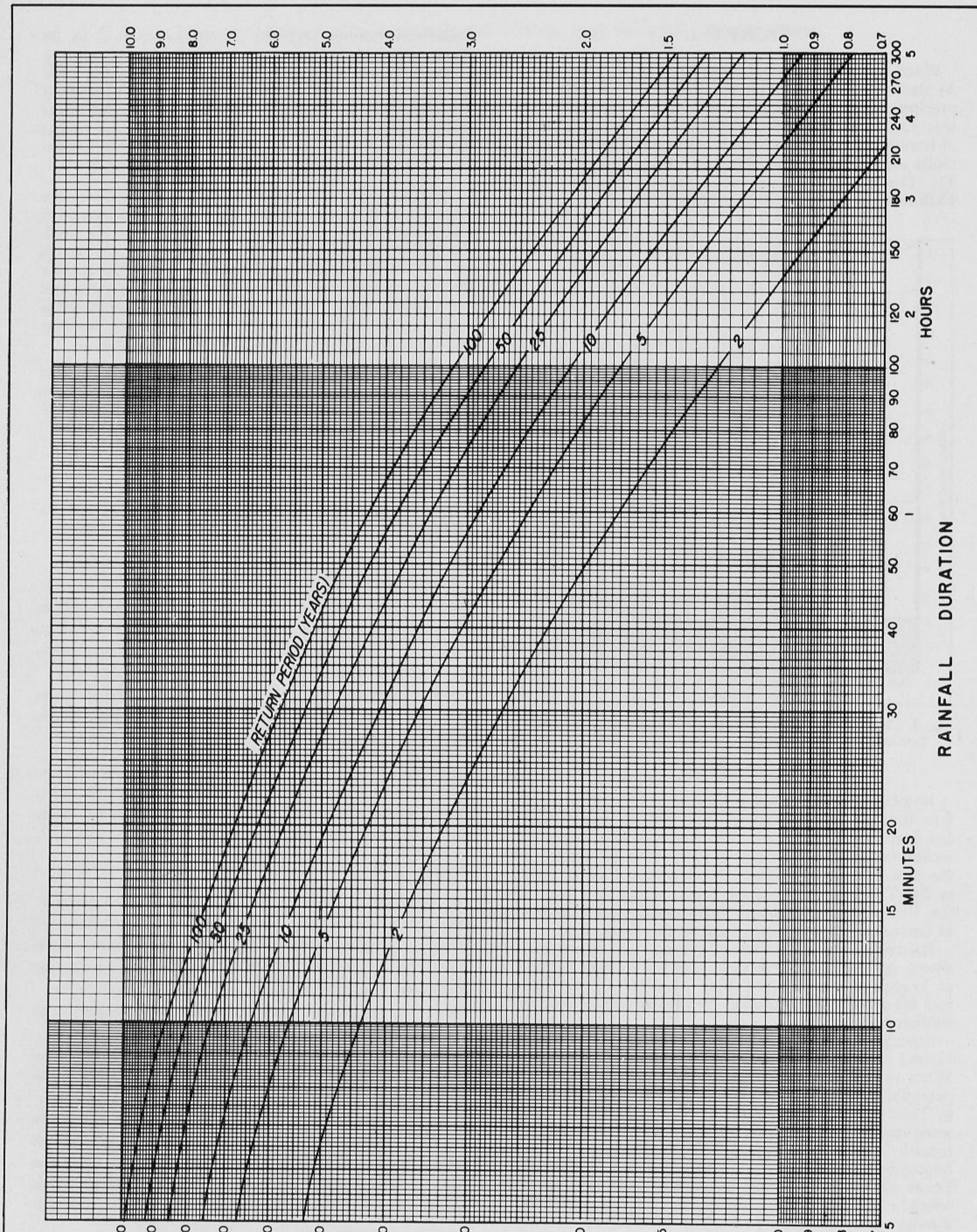

Fig. 4. Rainfall intensity-duration curves, Waco, Texas. *From* Waco City Engineering Department.

SNOW

Hail, snow, and sleet, although rare, also occur in Waco (table 1). Most snowfalls in the area are between one and two inches. The largest monthly snowfalls recorded in Waco, both 13 inches, occurred during February 1924 and December 1929. Because the temperature may not reach much below 32°F, potentially large snowfalls in the Waco area may fall partly as rain as the temperature fluctuates around the freezing point.

EVAPORATION

Evaporation is the process by which moisture is taken up from a source at one location and carried as vapor to other locations by wind action. Among factors which affect evaporation rates are temperature, humidity, wind, and sunshine. The principal source of moisture for evaporation is open bodies of water; however, large quantities of water are consumed by the process of evapo-transpiration. Measurements are usually taken by observing the lowering of a water surface in a tank or pan. Monthly coefficients are applied to the pan evaporation rates to convert them to gross lake-surface evaporation rates.

Gross lake surface evaporation minus effective rainfall gives the net reservoir evaporation rates. Effective rainfall is defined as rainfall over the reservoir site minus that which becomes runoff (Lowry, 1960, p. 1).

In the Waco area August normally has the greatest monthly evaporation rate; January and February have the lowest evaporation rates. Appendix I lists evaporation rates (1940-1957) for an area (lat 31° to 32°N; long 97° to 98°W) which includes Waco in the east-central section.

During the general Texas drought of 1954 to 1956, the gross lake surface evaporation for the Waco area as determined by the Texas Board of Water Engineers was: 1954—83.0 inches, 1955—67.0 inches, and 1956—85.0 inches (Lowry, 1960, p. F-10). The average annual gross lake surface evaporation rate (1940 through 1957) was 69.0 inches. During its first 10 months of operation (March-December, 1965) the enlarged Lake Waco had a gross evaporation rate of approximately 77.57 inches.

DROUGHTS

A drought may be defined as dryness due to lack of rain. However, not all periods of rainfall deficiency are classed as droughts. It is only when these deficiencies are great or prolonged that a drought is in progress.

A drought also may be defined as a period when annual precipitation averages are at least 15 percent below normal. In this case with an average annual precipitation of 33 to 34 inches, a drought period in Waco would be a year in which less than 28 or 29 inches of moisture were received. Annual precipitation departures from the mean at Waco are shown in figure 5.

Texas has experienced 11 major droughts during the 70 years of reliable records. Some of these drought periods have affected different sections of the state. A comparison of the state-wide drought periods with figure 5 shows how Waco was affected. In order of statewide severity these droughts were: 1954-56, 1916-18, 1909-12, 1901, 1953, 1933-34, 1950-52, 1924-25, 1891-93, 1937-39, and 1896-99 (Lowry, 1959, p. 20).

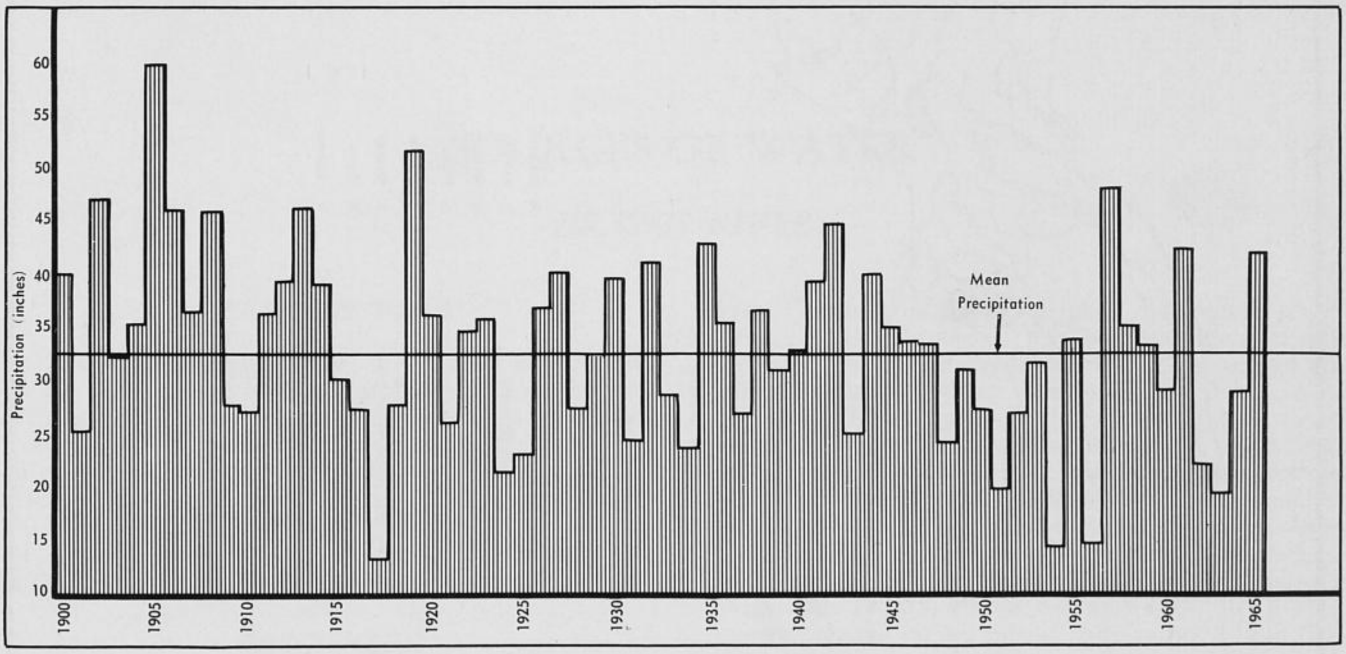

Fig. 5. Annual precipitation departures from mean, Waco, Texas.

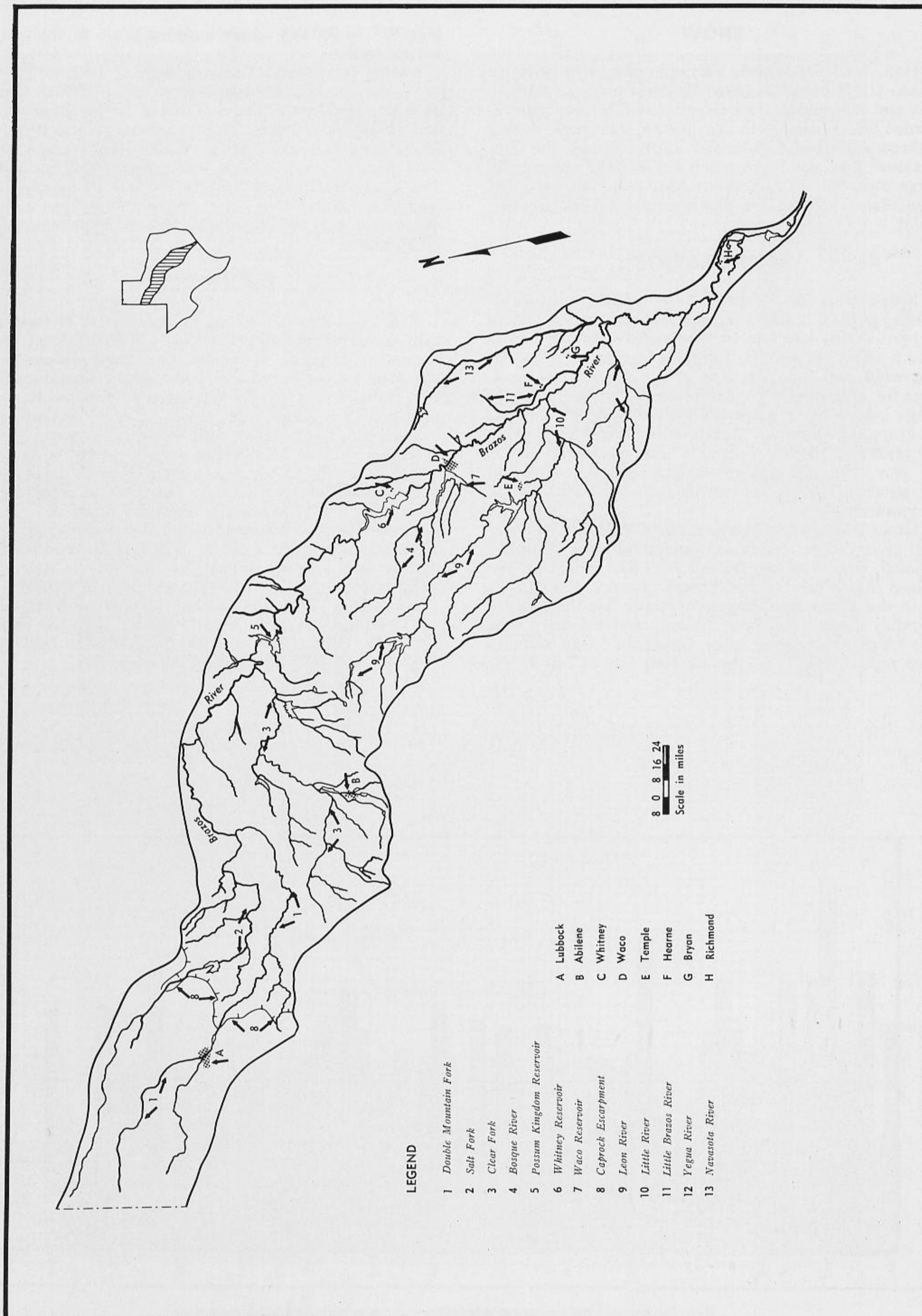

Fig. 6. Brazos River drainage basin.

GEOLOGY

Waco lies in the Brazos River basin which has a total area of 44,640 square miles. About 28,500 square miles of drainage basin lie above Waco. Although the drainage basin begins in eastern New Mexico, the main stem of the Brazos River is formed by the confluence of the Double Mountain Fork and the Salt Fork about 60 miles northwest of Abilene (fig. 6). The Clear Fork of the Brazos River joins the main stem about 135 miles northwest of Waco in Young County. From Waco southward, major Brazos River tributaries include the Bosque, Little, Little Brazos, Navasota, and Yegua rivers. Total river length from the source of the Double Mountain Fork, the longest originating branch, to the river mouth at the Gulf of Mexico is approximately 900 miles.

The Brazos River enters the Waco area from the north about 30 miles downstream from Lake Whitney. It is in the Waco area that the river leaves the rolling and hilly country of the Grand Prairie of Central Texas and enters the flatlying Blackland Prairie and upper Gulf Coastal Plain (figs. 1, 6).

The Brazos River drains sedimentary rocks which vary in age from Ordovician to Recent. Above the Caprock escarpment in far West Texas its tributaries flow across Cenozoic formations. Below the Caprock escarpment in West Texas and above Waco the Brazos River and its tributaries drain in succession Triassic, Permian, Pennsylvanian, and Cretaceous age rocks. Below Waco it drains upper Cretaceous, Tertiary, and Quaternary age rocks. One tributary below Waco drains an area containing Ordovician rocks.

In many places, including Central Texas, the Brazos River has left large terraces of sand and gravel. These terraces produce water from shallow wells and also provide commercial quantities of sand and gravel.

The Bosque River system has a drainage basin of about 1670 square miles and consists of three main tributaries—North, Middle and South (figs. 2, 10). The Middle Bosque joins the South Bosque west of Waco Reservoir; they continue together as the South Bosque River which joins the North Bosque at Waco Reservoir to form the Bosque River. The Bosque River flows from Waco Reservoir to join the Brazos River at the northern edge of Waco.

The Bosque rivers drain sedimentary rocks of Cretaceous age in Central Texas. The North Bosque River heads in the lower Cretaceous Glen Rose Formation in Erath County (fig. 10). It and its tributaries also drain formations of the Fredericksburg Group including the Walnut Clay, Comanche Peak Limestone and Edwards Limestone. Formations of the Washita Group drained by the North Bosque River and its tributaries include the Kiamichi Shale, Georgetown Limestone, Del Rio Clay, and Buda Limestone. In the immediate area of Lake Waco it flows across rocks of the Eagle Ford Group—the Lake Waco Formation and the South Bosque Shale. The Middle Bosque River heads in the Edwards Limestone in Coryell County. It drains formations of the Washita and Eagle Ford groups. The South Bosque River heads in southwestern McLennan County and drains formations of the Fredericksburg, Washita, and Eagle Ford groups.

SOURCES OF WATER

BRAZOS RIVER

DRAINAGE BASIN

Of the 28,500 square miles of drainage basin above Waco, 9,240 square miles are probably noncontributing. This area includes most of the river basin in eastern New Mexico and above the Caprock escarpment in West Texas. The basin reaches its maximum width of 110 miles south of Waco, increasing from a width of 70 miles in far West Texas and decreasing to a width of 10 miles near Richmond at the Gulf of Mexico (Texas Water Development Board, 1966, p. 2).

DISCHARGE

The drainage area above the Caprock escarpment in West Texas contributes virtually no runoff to the Brazos River. Throughout the basin runoff varies from an annual average of about 75 acre-feet per square mile above Possum Kingdom Dam to about 225 acre-feet per square mile between Whitney Dam and the mouth of the Navasota River which includes the Waco area. Most runoff of the Brazos River basin occurs between Whitney Dam and the mouth of the Navasota River.

Average discharge for the Brazos River at Waco (1898-1965) was 2,504 cfs or 1,813,000 acre-feet per year (Appendix II). Maximum observed discharge at Waco was 246,000 cfs on September 27, 1936. Minimum discharge for periods of daily record (1898-1911, 1914-1965) was no flow August 20-21, 1918 and probably no flow for several days in August 1923.

SEDIMENTATION

Sediment load records of the Brazos River at Waco are available from June 1, 1924 to August 31, 1933 when the Waco station was discontinued (Appendix III). Annual sediment production rate above Waco for this period was 0.536 acre-feet of sediment per square mile of the 19,260 square mile contributing area—10,323.4 acre-feet annually above Waco (table 3).

Between Possum Kingdom Reservoir and Waco, it is estimated that 14,000 acres of alluvial plain have been damaged by sediment in the last 60 years. Between Waco and Hearne, about 40,000 acres of alluvial land have been severely damaged by sediment during the past 45 years (Texas Board of Water Engineers, *et al.*, 1958, p. 94).

WATER QUALITY

Average 1963 water quality data for stations along the Brazos River and its headward tributaries the Salt Fork, Double Mountain Fork and Clear Fork are shown in Appendix IV. Extreme water quality data for the same stations are listed in Appendix V. It can be noted that the Brazos River has an unusually high total dissolved solids content which is caused principally by water from the Salt and Double Mountain forks. Brazos River water is poorest in the upper part of the basin and best about 800 miles downstream from its origin after it has been diluted by tributary waters. In this respect, the Brazos River differs from most other rivers which have the best water at the headwaters.

The Salt Fork has a drainage area of about 4,830 square miles, of which approximately 2,770 square miles are probably noncontributing. It drains an area of salt seeps and springs and is, therefore, high in chlorides. Near Aspermont a total dissolved solids content of the water ranging from 1,230 ppm to 114,000 ppm has been recorded (Appendix V). This maximum total dissolved solids content is more than three times the salinity of "normal" sea water, which averages about 35,000 ppm, and over 100 times the maximum total dissolved solids recommended by the U. S. Public Health Service for drinking water (Appendix VI).

Table 4. Chemical analysis of Brazos River water at Waco, Texas during high and low mean discharge rates.

	3,560 cfs[1]	478 cfs[2]
Substance	Concentration in ppm	
Silica	7.8	6.8
Calcium	127	108
Magnesium	28	14
Sodium-Potassium	274	160
Bicarbonate	67	181
Sulfate	325	182
Chloride	450	235
Fluoride	—	0.3
Nitrate	0.0	4.2
Total dissolved solids	1,240	859*
Hardness as $CaCO_3$		
Total	432	327
Noncarbonate	377	178
Percent Sodium	58	51
Specific conductance (micromhos at 25°C)	2,200	1,330
Hydrogen ion concentration (pH)	8.0	7.4

*Residue on evaporation at 180°C. (calculated)

[1]Analysis June 7, 1949. Texas Board of Water Engineers (1950) Chemical composition of Texas surface waters, 1949: Texas Board of Water Engineers, Austin, p. 114.

[2]Analysis March 30, 1962. Texas Water Commission (1965) Chemical composition of Texas surface water, 1962: Texas Water Comm., Bull. 6501, Austin, p. 40.

Water from the Double Mountain Fork has a high sulfate content reflecting gypsum (calcium sulfate) deposits in the drainage basin. Near Aspermont, a total dissolved solids content of the water ranging from 599 ppm to 6,450 ppm has been recorded (Appendix V).

Brazos River water quality at Waco during high and low discharge rates is illustrated in table 4. Most rivers, with increased discharge, have a corresponding decrease in total dissolved solids. However, a comparison of these analyses indicates an anomalous total dissolved solids increase with increased discharge. This increase probably reflects contamination by runoff from salt springs and seeps in the drainage basin or increased inflow of oil field brines depending upon the origin of the discharge within the drainage basin.

Table 3. Brazos River sediment load.

(1) Drainage basin and stream	(2) Location	(3) Sediment contrib. area (sq mi)	(4) Length of record (yrs.)	(5) Measured annual sed. production rate: Per sq. mi. (ac-ft)	(6) Est. vol. weight (lbs/cu ft)	(7) Volume wt. adj. factors*	(8) Bed load adj. factors	(9) Adj. ann. sediment prod. rate (ac-ft/sq mi)
Salt Fork	Aspermont	2,216	1.238	1.272	70	0.875	1.30	1.45
Double Mountain Fork	Aspermont	1,510	9.244	1.765	70	0.875	1.30	2.01
Clear Fork	Eliasville	5,740	1.244	0.092	70	1.00	1.15	0.105
Brazos River	Mineral Wells	13,910	10.332	0.468	70	1.00	1.15	0.54
Brazos River	Glen Rose	15,600	4.588	0.537	70	1.00	1.15	0.62
Brazos River	Waco	19,260	9.254	0.536	70	1.00	1.15	0.62
Brazos River	Richmond	34,810	33.306	0.538	70	1.40	1.05	0.79

*The sediment cubic foot dry weight values used in computing the column weight adjustment factors in column 7 can be determined by dividing column 6 by column 7.

From U. S. Soil Conservation Service (1959) Inventory of sedimentation data in Texas: Texas Board of Water Engineers, Bull. 5912, Austin, pp. 8-9.

FLOODS

Large flood-producing storms are more frequent along the Balcones escarpment than any other region of the United States. "The large number [of floods] along the Balcones Front of the Edwards Plateau in Texas marks that area as one of high flood potentiality" (Hoyt and Langbein, 1955, pp. 74, 76). "When moist, unstable air blows in from the Gulf of Mexico and releases as much as 20 to 30 inches of rain in a matter of hours, the resulting flood-peak discharges often exceed those recorded elsewhere in the United States for watersheds of equivalent area" (*idem,* p. 296).

"The greatest [Brazos River] floods experienced have been generated in the central portion of the basin generally between Kopperl and Navasota, where the basin attains its greatest width" (Texas Board of Water Engineers, *et al.,* 1958, pp. 86-87). Brazos River flood damage has been greatest below Waco after the river enters the relatively flatlying coastal plain where it can more easily overflow its banks.

In Texas the most severe floods have occurred frequently from April to October. Seasonal occurrences of Brazos River floods at Waco indicate that April, May, and June have the highest percentage of floods. Of 166 Brazos River floods at Waco in 62 years, 30 percent occurred in May (Jarvis, *et al.,* 1936, pp. 333-334; Patterson, 1963, p. B-71). A second slight increase in floods occurs in September and October (fig. 7).

Yearly maximum elevations of the Brazos River at Waco are shown in figure 8. Peak stages and discharges of record for the Brazos River at Waco are given in Appendix VII. Flood water, during the maximum recorded discharge at Waco of 246,000 cfs overtopped and broke the 40.90 foot levee on the east bank of the river. The December 1-5, 1913 Brazos River flood produced a maximum discharge of 211,000 cfs and a

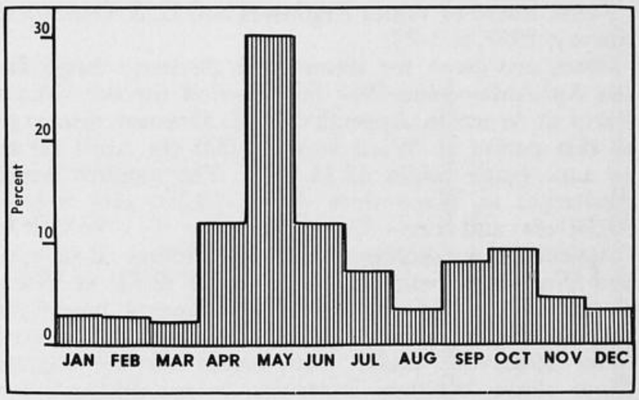

Fig. 7. Seasonal occurrence of Brazos River floods, Waco, Texas.

gage height of 39.7 feet. Maximum stages on all points on the Brazos River below Waco were recorded during this flood. A gage height of 36.7 feet was recorded at Waco May 25, 1908 and April 22, 1945 with discharges of 142,000 cfs and 144,000 cfs respectively.

It has been estimated that flood control improvements which existed prior to the 1957 floods prevented higher discharges on many of the larger rivers and streams in Texas including the Brazos. From April to June 1957, the Brazos River basin, along with the Trinity and lower Colorado basins, had the greatest recorded runoff for any comparable period of record.

The drought preceding the 1957 floods resulted in relatively dry soil and reservoirs at very low stages. Much of the early runoff was caught and held by soil and reservoirs. Continuing runoff saturated soil and filled reservoirs resulting in "floods comparable in

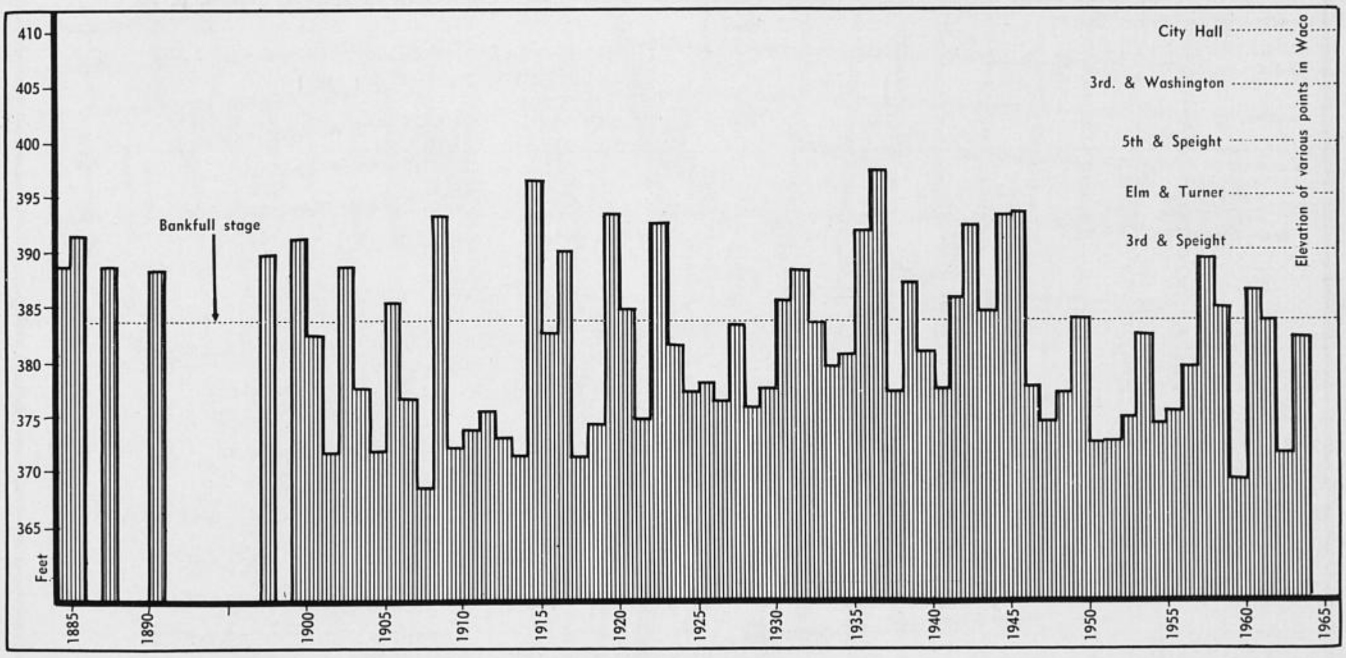

Fig. 8. Yearly maximum elevation of Brazos River, Waco, Texas.

magnitude and areal extent to the greatest known in the history of recorded stream flow records for the area" (Texas Board of Water Engineers and U. S. Geological Survey, 1957, p. 1-2).

Data are given for mean daily discharge rates for the April-May-June 1957 flood period for the Brazos River at Waco in Appendix VIII. Greatest discharge of this period at Waco was 101,000 cfs April 20 at 10 a.m. (gage height 32.33 feet). The monthly mean discharges at Waco were April—10,360 cfs; May—36,340 cfs; and June—37,140 cfs.

Calculated modifying effects of Whitney Reservoir and Waco Reservoir on Brazos River floods at Waco are shown in table 5. These flood control reservoirs provide 2,183,800 acre-feet of flood storage. DeCordova Bend Reservoir, under construction on the Brazos River above Whitney Reservoir, is not designed for flood control but will provide 105,400 acre-feet of water storage (Texas Water Development Board, 1966, p. 16).

LOW WATER DAM

A low water dam to create a lake at Waco is planned for the Brazos River (fig. 9). Land along the shore of the proposed Lake Brazos will be landscaped and developed to provide various cultural, educational, recreational, and civic facilities.

The proposed dam will probably be located about 1800 feet downstream from the LaSalle Avenue bridge just upstream from the Waco sewage treatment plant. Suggested water level would reach elevation 375.0 feet. This elevation will raise the water level on the Brazos River as far upstream as Steinbeck Bend and on the Bosque River to Waco dam.

The mouths of creeks and streams which enter the area of Lake Brazos will be inundated which could, to some extent, affect their function of internal city drainage. Water level of river terraces will rise and the resulting decrease in terrace permeability will increase surface runoff after rainfall.

Table 5. Observed maximum stage and discharge during seven major floods in Brazos River at Waco, Texas, and calculated modifying effect of Whitney Reservoir alone, and of Whitney and Waco reservoirs combined.

	Natural			Modified by Whitney Only			Modified by Whitney & Waco		
Flood Period	Discharge C. F. S.	Stage at Clay Ave.	Stage at Waco Crk.	Discharge C. F. S.	Stage at Clay Ave.	Stage at Waco Crk.	Discharge C. F. S.	Stage at Clay Ave.	Stage at Waco Crk.
Apr-May 1922	122,000*	392.3	391.2	55,000	381.8	380.7	47,000	380.0	378.9
May-June 1935	112,000*	391.3	390.2	54,000	381.6	380.5	51,000	380.9	379.8
Sept-Oct 1936	246,000*	397.3	396.2	185,000	395.1	394.0	80,000	386.4	385.3
Apr-May 1942	126,000*	392.1	391.0	60,800	382.9	381.8	56,000	382.0	380.9
Apr-May 1944	137,000*	393.0	391.9	97,000	388.3	387.2	58,000	382.4	381.3
Apr-June 1945	144,000*	393.1	392.0	144,000	393.1	392.0	55,000	381.9	380.3
Apr-June 1957	170,000	394.7	393.6	101,000*	388.7	387.6	50,000	380.7	379.6

*Observed—all other discharges calculated.

From Forrest, T. Carr and Cotton, James A. (1960) Report on criteria and basic design of storm drainage and flood control system for lower Waco Creek basin City of Waco, Texas: Forrest and Cotton, Inc., Consulting Engineers, Dallas, p. 70.

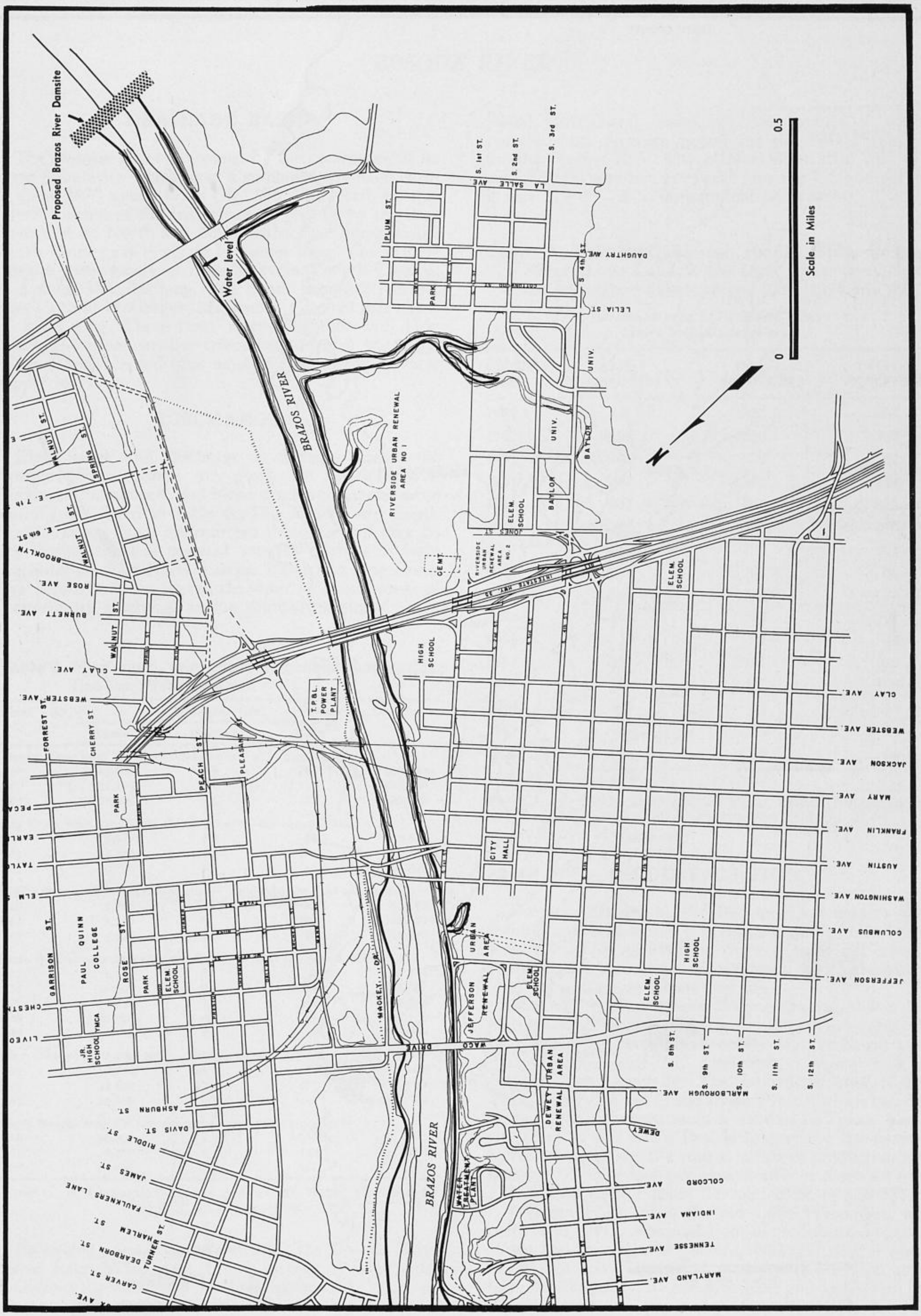

Fig. 9. Proposed low water dam and Lake Brazos, Waco, Texas.

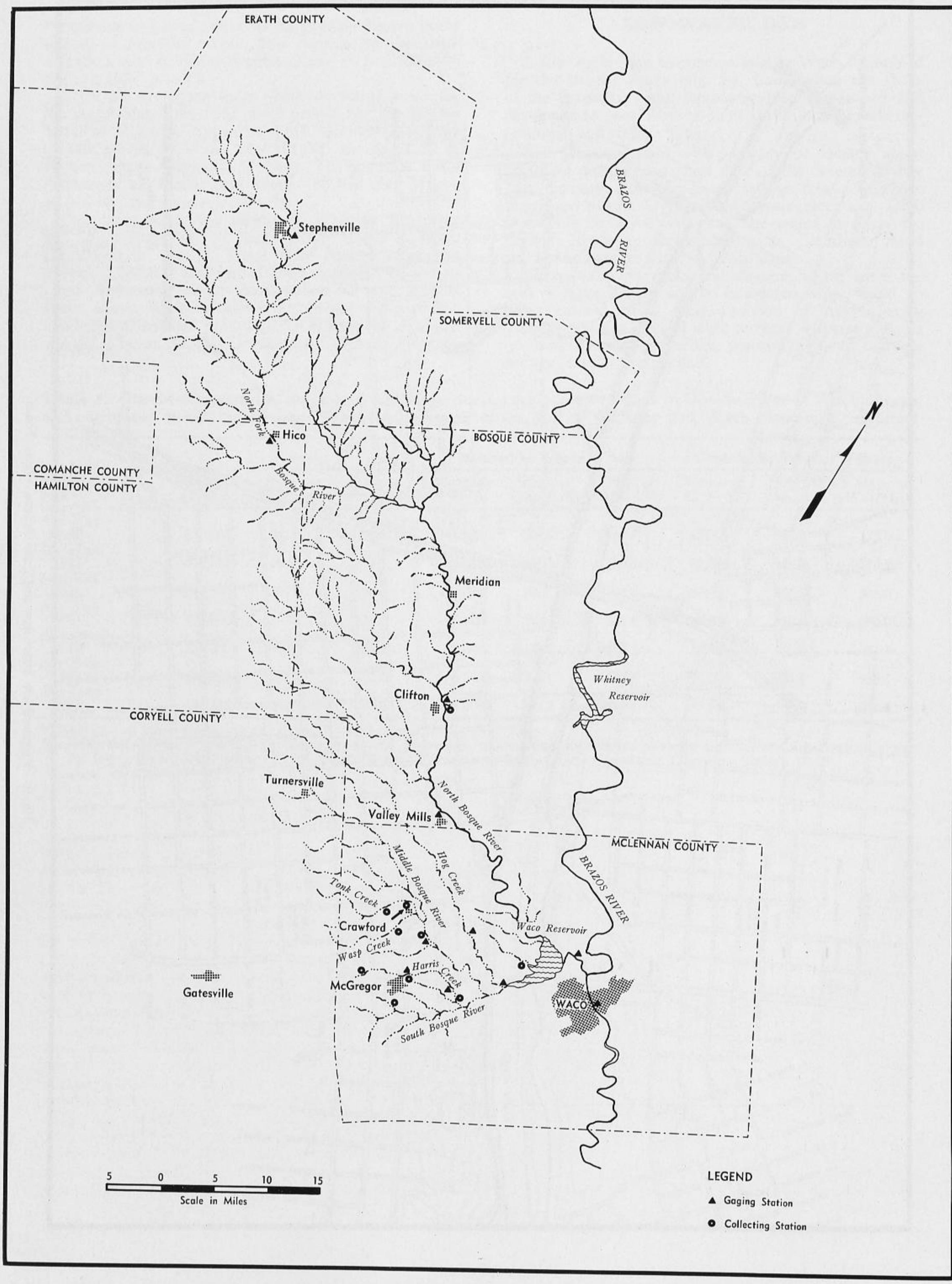

Fig. 10. Bosque River drainage basin.

BOSQUE RIVER

DRAINAGE BASIN

The Bosque River is formed by the confluence of its three tributaries which have a combined drainage basin of about 1670 square miles (fig. 10). The North Bosque River, longest of the tributaries, is formed by the confluence of its North and South forks near Stephenville, Erath County; it is about 147 miles long. The Middle Bosque River heads near Turnersville, Coryell County; it is about 35 miles long. The South Bosque River begins south of McGregor, McLennan County; it is about 26 miles long. These three rivers, together with Hog Creek and other smaller tributaries, furnish water for Waco Reservoir and thus most of the municipal water supply for Waco.

DISCHARGE

River stage and discharge at stations within the Bosque River system are given in Appendix IX. Maximum, minimum, and mean discharges at the same stations are listed in table 6. The Middle and South Bosque rivers have intermittent drainage and may be dry during the late summer months if there is little precipitation. The North Bosque River and Hog Creek flow throughout the year in the lower reaches because of groundwater discharge in the drainage basins.

Table 6. Maximum, minimum, and mean discharges, Bosque River system.

Water Year	Discharge (cfs)			(acre-feet)
	Maximum	Minimum	Mean	
Bosque River near Waco—Drainage area 1655 square miles				
1960	45,600	0.9	783	532,100
1961	32,300	6.3	1,164	843,000
1962	24,600	1.6	317	229,600
Hog Creek near Crawford—Drainage area 78.3 square miles				
1960	5,930	0.2	49.3	35,810
1961	3,080	0.2	101	72,840
1962	2,720	0.1	36.9	26,690
Middle Bosque River near McGregor—Drainage area 182 square miles				
1960	4,810	0	92.4	67,050
1961	5,340	0	260	188,100
1962	3,330	0	52.6	38,070
South Bosque near Speegleville—Drainage area 388 square miles				
1925	1,520	0	2.91	2,100
1926	38,400	0	223	161,000
1927	54,500	1.3	225	163,000
1928	20,900	0	81.4	59,100
1929	5,480	0	——	——
North Bosque at Valley Mills—Drainage area 1,149 square miles				
1960	53,600	10	468	339,600
1961	15,500	13	471	341,000
1962	28,400	9.7	243	176,100
North Bosque near Clifton—Drainage area 972 square miles				
1960	30,000	4.1	297	215,400
1961	9,370	5.3	334	241,700
1962	16,100	2.9	151	109,400

From U. S. Geological Survey and Texas Water Commission.

Estimated annual runoff rates for the Bosque River above Lake Waco dam (1941 through 1956) under conditions for watershed development in 1958, 1975, and 2010 are given in table 7. These data are based on projected agricultural, municipal, and industrial water requirements. Average runoff for the 1941-56 period for the Bosque River above Lake Waco dam was 413 cfs (299,000 acre-feet per year); for the 1959-65 period it was 519 cfs (375,700 acre-feet per year).

Table 7. Estimated annual runoff rates, Bosque River above Lake Waco Dam under conditions for watershed development 1958, 1975 and 2010.

Drainage area 1,670 square miles
(rates in 1,000 acre-feet)

Calendar Year	1958 conditions	1975 conditions	2010 conditions
1941	881	872	854
1942	895	886	868
1943	74	70	62
1944	482	472	458
1945	903	894	875
1946	325	318	298
1947	213	206	191
1948	104	98	88
1949	205	199	184
1950	106	100	91
1951	39	37	31
1952	129	122	112
1953	208	201	184
1954	65	62	54
1955	83	79	71
1956	78	75	66
average	299	293	281

From U. S. Study Commission—Texas (1962) Report to the President and to the Congress. Part III, pp. 92-94.

SEDIMENTATION

The area drained by the Bosque River system contributes sediment which is eventually carried into Waco Reservoir. This sediment is derived from soil erosion of the Grand and Black prairies upon which the rivers originate and across which they flow.

About 81 percent of the Bosque drainage basin lies in the Grand Prairie physiographic province (fig. 2) which does not have an especially high sediment production rate—about 0.47 acre-foot per square mile of drainage area annually. The immediate area of the Waco Reservoir lies in the Black Prairie which has one of the highest average rates of erosion in Texas. Marls and clays of the Black Prairie are readily transported by runoff water and the annual sediment production rate is about 0.9 acre-foot per square mile of drainage area (U. S. Soil Conservation Service, 1959, pp. 30-32).

Between 1930, when the old Lake Waco dam was built, and 1947, accumulation of sediment in Lake Waco had caused a 44 percent reduction of the water storage capacity. The 1930 capacity was 39,378 acre-feet; 1936 capacity, 31,588 acre-feet; and 1947 capacity, 22,026 acre-feet (Jones and Rogers, 1952, p. 22).

Soil conservation practices are now in effect in the upper North Bosque drainage basin in Erath, Hamilton, and Bosque counties. The loss of storage capacity in old Lake Waco from sediment derived from this part of the drainage basin averaged about 157 acre-feet annually (U. S. Soil Conservation Service, 1963, p. 10). Soil conservation measures in the upper North Bosque drainage basin will benefit conservation structures in the drainage basin as well as Waco Reservoir. It is estimated that of the 13,560 acres of flood plain between the watershed and Clifton, an average of 28 percent of the drainage area will be controlled and of the 7,353 acres of flood plain between Clifton and Waco Reservoir, an average of 16 percent of the contributing drainage area will be controlled by flood retarding structures. It is calculated that these projects should reduce sedimentation in Waco Reservoir by about 67 acre-feet annually; 45 acre-feet of which is attributed to 28 planned flood water retarding structures.

Primary cause of this high rate of storage capacity loss from sediment was excessive size of the drainage area, 1670 square miles, compared to the original (1930) capacity of the reservoir, 39,378 acre-feet—23.6 acre-feet of reservoir per square mile of drainage basin (Jones and Rogers, 1952, pp. 42, 44). By 1947 sedimentation had reduced this capacity to 13.2 acre-feet per square mile.

An annual sediment production rate of 0.81 acre-foot per square mile of Lake Waco drainage basin has been estimated (table 8). Based on this figure, capacity loss due to sedimentation would be 1,353 acre-feet annually.

Table 8. Lake Waco Reservoir sedimentation survey.

Sediment contributing area (sq mi)	1,662	[1670]
Length of record (yrs)	17.7	
Type of record	D*	
Average dry weight of sediment (lbs/cu ft)	58.5	
Average annual sediment production rate (acre-ft/sq mi)	0.81	

*Detail sedimentation survey.
From U. S. Soil Conservation Service (1959) Inventory of sedimentation data in Texas: Texas Board of Water Engineers, Bull. 5912, Austin, p. 14.

Most sediment is carried into Waco Reservoir during periods of increased river discharge. The water is eventually used by Waco, discharged through the dam, or lost through evaporation while most of the sediment remains in the lake to deplete the water storage capacity. Sediment trap efficiency of the old reservoir to 1947 was approximately 71 percent (Jones and Rogers, p. 42).

Table 9 shows the controlled storage capacity of Waco Reservoir. Total capacity of Waco Reservoir is 726,400 acre-feet—435 acre-feet per square mile of drainage basin. The enlarged lake is, therefore, better able to accommodate sediment carried into it than was the old lake.

Soil and water conservation measures are undertaken by individual landowners on the South and Middle Bosque drainage basins. Conservation measures are being studied for Hog Creek. More such conservation efforts are needed, especially in the drainage basin nearest the lake to control erosion from the Black Prairie.

Table 9. Controlled storage capacity, Waco Reservoir. (acre-feet)

Water conservation	104,100
Flood control	553,300
Sediment	69,000
Total	726,400

U. S. Army Corps of Engineers.

Clays of the Black Prairie may be a natural source of water purification. Clays, especially montmorillonite, are abundantly present in the Eagle Ford Group of the Black Prairie and present to a lesser extent in other shale formations in the drainage basin. These clays have a marked adsorptive capacity and can remove ions from solution. Various complex ions such as those containing arsenic, molybdenum, and metal ions, some of which may be detrimental to human health, are adsorbed by these clays. During periods when these clays are carried into the lake they may be sweeping the water clean of potentially harmful ions.

WATER QUALITY

The Bosque rivers and their tributaries drain an area of sedimentary rocks, principally limestone and shale formations. Chemistry of the water reflects this geologic terrain. Appendix X shows Bosque River water quality.

Potable water standards as recommended by the U. S. Public Health Service are given in Appendix VI. Because of the relatively low mineral content of Bosque River water, treatment by the Waco City Water Department consists primarily of the destruction and removal of organisms and flocculation and removal of suspended particles. Chemical composition of the water remains essentially the same as when it is withdrawn from the lake (table 10). Raw water is pre-chlorinated

Table 10. Chemical analysis of municipal water at Waco, Texas.

Substance	Concentration in ppm			
	untreated*	treated		
		average	maximum	minimum
Silica	7.4	6.6	11.1	4.7
Calcium	52.9	56.6	63.4	49
Magnesium	4.5	5.8	6.9	5.0
Sodium and Potassium	31.4	20	42	8.0
Bicarbonate	180	162	180	152
Sulfate	37.5	43	68.6	20.6
Chloride	23.8	22.3	43.6	12.0
Fluoride	0.31	0.25	0.3	0.2
Total dissolved solids	267.4	246	333	194
Total hardness as $CaCO_3$	150.6	151	170	142
Hydrogen ion concentration (pH)	8.0	7.6	8.1	7.3

*Analysis April 9, 1962. Waco City Water Department.
Water temperature: max. 85° F, min. 34° F.

and aluminum sulfate (alum) is added for the flocculation process. The processed water is rechlorinated before distribution. Occasionally copper sulfate is used to eliminate algae in the settling basins and activated carbon (processed powdered charcoal) is added to eliminate unpleasant taste and odor.

Comparisons of several chemical characteristics of Bosque and Brazos River water are shown in figure 11. Brazos River water has a higher total dissolved solids content than Bosque River water, due primarily to the high sodium, chloride, and sulfate content. Bicarbonate and nitrate concentrations are higher in Bosque River water than in Brazos water. Bicarbonate is derived from limestone formations in the Bosque drainage basin while nitrate is normally caused by the introduction of organic material (sewage, agricultural chemicals, or decaying biologic material) into the water.

Brazos River water is used to supplement Bosque River water when the latter supply is inadequate to meet Waco's needs. Dilution of the saline Brazos River water makes it more palatable and only that amount of Brazos River water which is absolutely required is used. Generally, not more than 35 percent Brazos River water is combined with Waco Reservoir (Bosque River) water (table 11, fig. 12).

Table 11 lists an actual tap composite of Brazos River and Lake Waco water. Figure 12 illustrates the rise in salinity when Brazos water is mixed with Lake Waco water in proportions of 35 and 65 percent.

Since completion of the enlarged Waco Reservoir in 1965, Brazos River water has not been required to supplement the municipal supply.

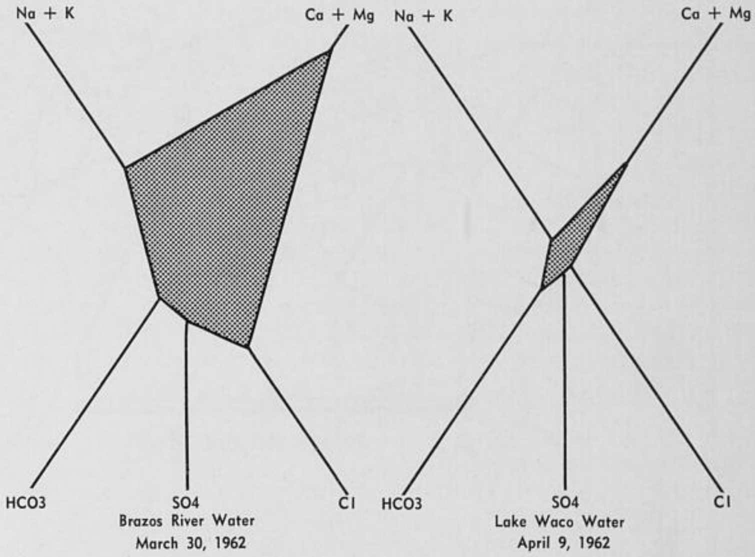

Fig. 11. Water comparison, Brazos River and Lake Waco.

Table 11. Tap composite Brazos River and Lake Waco water, Waco, Texas.*

Substance	Concentration in ppm
Silica	8.0
Iron and Aluminum Oxides	5.4
Aluminum	3.8
Iron	0.3
Calcium	51.7
Magnesium	6.1
Sodium and Potassium	32.7
Bicarbonate	168.0
Sulfate	42.6
Chloride	30.0
Fluoride	0.4
Nitrate	0.4
Total dissolved solids	244.6
Total alkalinity as $CaCO_3$	138.0
Total hardness, E.D.T.A. as $CaCO_3$	164
as $CaCO_3$	154.1
Hydrogen ion concentration (pH)	8.1

*Analysis June 1-14, 1962, Waco City Water Department.

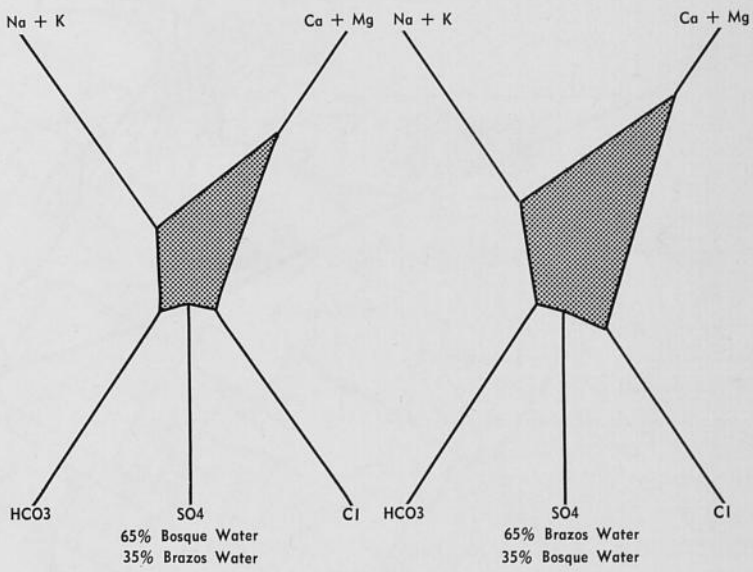

Fig. 12. Combined water comparison, Brazos River and Lake Waco.

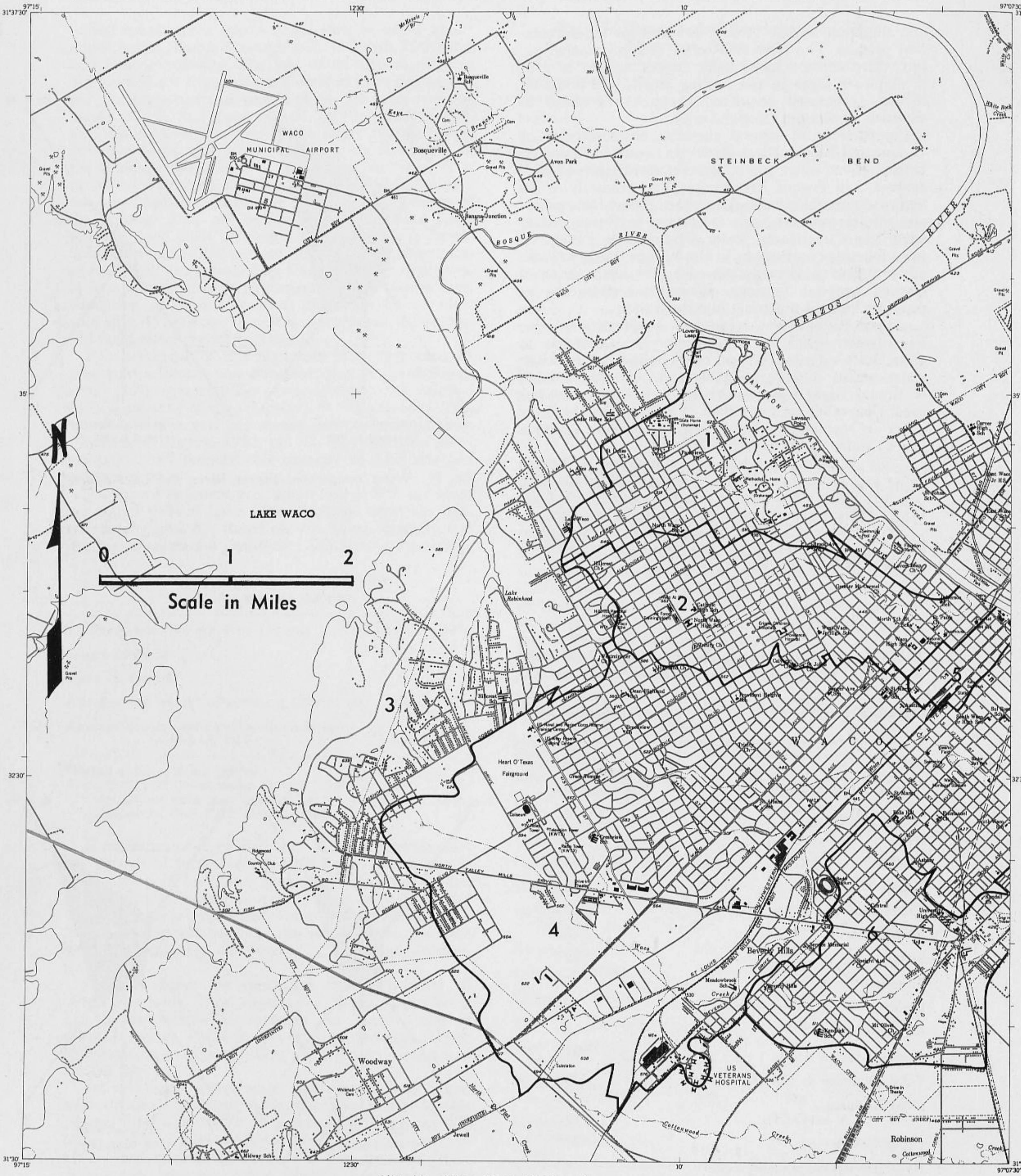

Fig. 13. Waco West Quadrangle.

Major basin divides: (1) Wilson Creek; (2) Barron Branch; (3) Bosque River Watershed; (4) Waco Creek; (5) Business District; (6) Primrose Creek; and (7) East Waco.

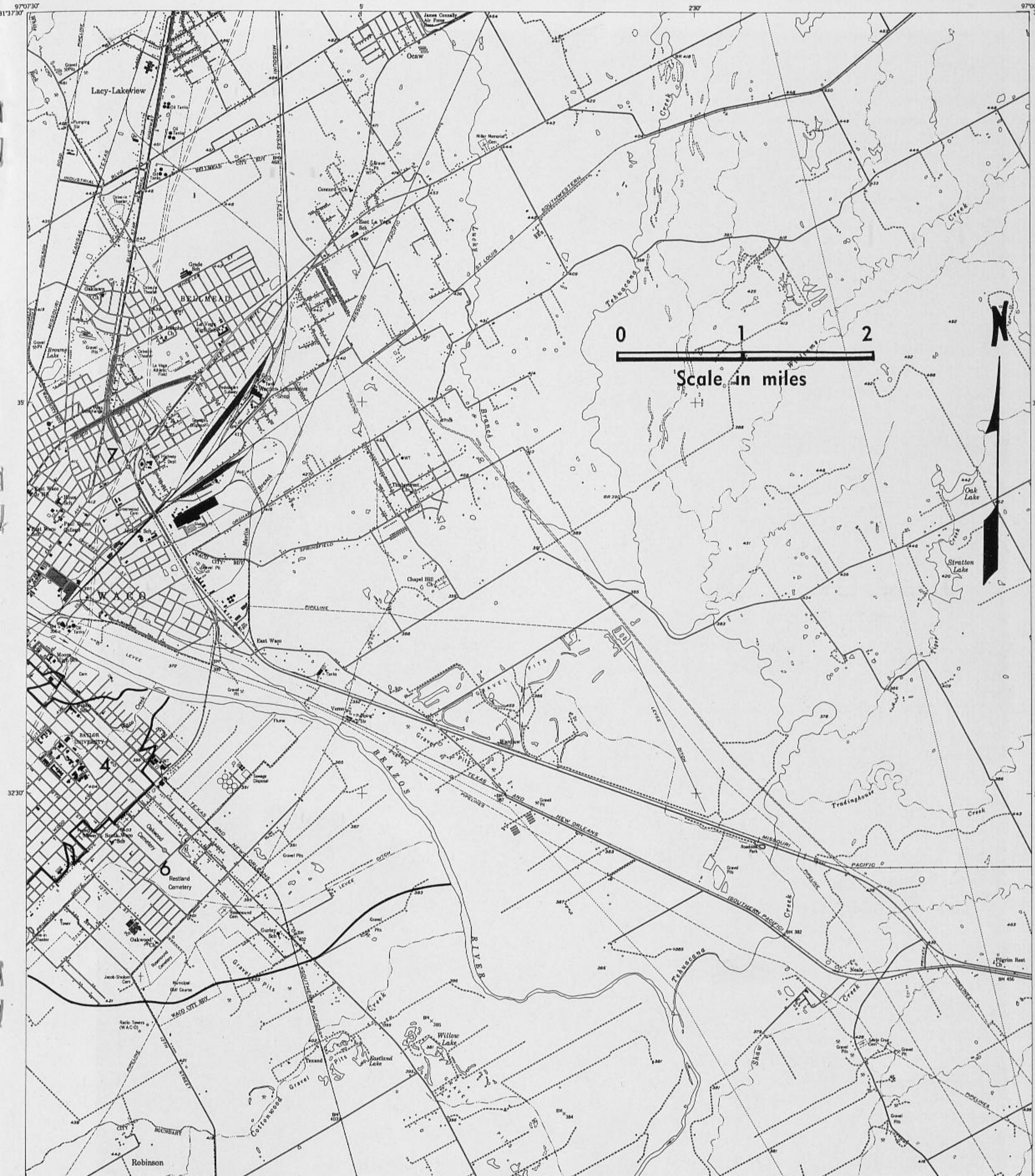

Fig. 14. Waco East Quadrangle.

Major basin divides: (1) Wilson Creek; (2) Barron Branch; (3) Bosque River Watershed; (4) Waco Creek; (5) Business District; (6) Primrose Creek; and (7) East Waco.

Plate I. Lake Waco Reservoir. U. S. Army Corps of Engineers photograph.

FLOODS

The Bosque rivers and tributaries do not flood in the Waco metropolitan area but do so upstream bringing large amounts of water into Waco Reservoir. The flood of September 26-27, 1936 on the Bosque rivers helped contribute to the maximum recorded Brazos River flood at Waco. Maximum recorded discharge of the Bosque River near Waco since 1880 was 140,000 cfs April 22, 1945 and 103,000 cfs April 20, 1957. Peak recorded discharge at miscellaneous sites in the Bosque drainage basin are given in table 12. Continuous runoff records, except at a few stations, are not available over the entire Bosque drainage basin. Maximum recorded discharges and gage heights at two stations are given in Appendix XI.

Extremely high runoff rates have been recorded on Harris Creek, a tributary of the South Bosque River (table 12). Peak discharges of 1,220 cfs per sq. mi. (cubic feet per second per square mile) and 1,060 cfs per sq. mi. on Harris Creek east of McGregor have been recorded (Ruggles, 1966, p. 24). The South Bosque River, near old Speegleville, had a discharge rate of 140.4 cfs per sq. mi. June 14, 1927.

LAKE WACO RESERVOIR

Lake Waco Reservoir eventually receives all Bosque runoff except that lost to evaporation and ground infiltration (Pl. I). The dam consists of an earthen embankment with concrete outlet works. It is 24,618 feet long, rises 140 feet above the stream bed, and tapers from a thickness of 990 feet at the base to 20 feet at the crest. Berms, designed to reduce lateral stress by increasing the width of the dam, have been constructed midway along the dam on both the upstream and downstream sides. The dam is located on the Bosque River at river mile 4.6 above its confluence with the Brazos River and adjacent to the northwestern edge of Waco.

Dual purpose of the reservoir is water conservation and flood control. The normal conservation pool has a capacity of 104,100 acre-feet at an altitude of 455 feet above mean sea level. The lake covers 7,270 acres with a shoreline of 60 miles. The flood control pool has a capacity of 553,300 acre-feet at an altitude of 500 feet above mean sea level. This pool is that interval between the top of the conservation pool and the top of the flood gates and has an area of 19,440 to 21,000 acres. The normal conservation pool accommodates the equivalent of 1.2 inches of runoff from the Bosque watershed. The flood control pool will accommodate the equivalent of an additional 6.2 inches of runoff from the entire basin.

Annual net evaporation (1941-1956) for Lake Waco was 33.36 inches (U. S. Study Commission—Texas, Pt. II, p. 50). Net evaporation (1940-1957) for the Waco area is about 40.32 inches (3.36 ft.) as determined by the Texas Board of Water Engineers (Appendix I). Using these loss rates, it is calculated that Waco Reservoir would lose from 20,200 to 24,400 acre-feet of water per year or 19 to 23 percent of the normal conservation pool capacity through evaporation. Therefore, this amount of annual runoff is unavailable for use by Waco.

Construction on the dam embankment by the U. S. Army Corps of Engineers began in 1957 and was completed in the spring of 1965. Gates on the new lake were closed February 27, 1965. In 10 hours between May 14 and 15, 1965 the lake rose the final 10 feet to full conservation pool level as the result of heavy spring rains in the drainage basin.

Table 12. Peak discharge at miscellaneous sites and unusual floods at short term gaging stations, Bosque River system.

Stream and place of determination	Drainage area sq mi	Peak discharge Date	cfs	cfs/sq mi
North Bosque River at U. S. Highway 377, in Stephenville[1]	93.3	May 23, 1952	40,000	429
North Bosque River at Stephenville[1]	92.4	May 19, 1955	49,000	530
North Bosque River at Hico[1]	358	May 23, 1952	87,800	245
North Bosque River near Clifton[2]	971	Oct. 4, 1959	92,800	95.5
North Bosque River at Valley Mills[1]	1,149	Oct. 4, 1959	107,000	93.1
South Bosque River near Speegleville[3]	388	June 14, 1927	54,500	140.4
Harris Creek near McGregor, 1.5 miles east[4]	8.85	June 16, 1964	10,800	1,220
Harris Creek near McGregor, 5.8 miles east[4]	20.9	June 16, 1964	22,100	1,060
Hog Creek near Crawford[2]	78.3	Oct. 4, 1959	15,400	196.6
Bosque River at Lake Waco dam, near Waco[2]	1,655	Sept. 27, 1936	96,000	57.8
	1,655	April 22, 1945	140,000	84.5
	1,655	April 20, 1957	103,000	62.2

[1]Patterson, James L. (1963) Floods in Texas: Texas Water Commission, Bull. 6311, Austin, p. A-11.
[2]U. S. Geological Survey (1962) Surface water records of Texas, 1962: U. S. Geological Survey—Water Resources Division, Austin, pp. 206, 209, 210.
[3]Texas Board of Water Engineers (1958) Compilation of surface water records in Texas through September 1957: Texas Board of Water Engineers, Bull. 5807 A, Austin, p. 225.
[4]Ruggles, Frederick H., Jr. (1966) Floods on small streams in Texas: U. S. Geological Survey—Water Resources Division, open file report No. 89, Austin, p. 24.

LOCAL CREEKS AND STREAMS

Various creeks and streams drain the Waco area. Those drainage basins outside of the city include Cottonwood Creek and Tehuacana Creek with its tributaries, Lucky Branch, Williams Creek, and Tradinghouse Creek. Cottonwood Creek drains the southeastern part of Waco and empties into the Brazos River below Waco. Tehuacana Creek flows east of Waco and enters the Brazos River below Waco. Because of their relatively flat drainage basins, both of these creeks can easily flood.

Seven major basins drain the City of Waco. One empties into the Bosque system and six empty into the Brazos River. The six drainage basins include Primrose Creek, Waco Creek, Business District, Barron's Branch, Wilson's Creek, and East Waco (figs. 13, 14). Waco Creek, which has the largest drainage basin, drains intensively developed sections of the city including residential, industrial, and commercial districts.

Waco Creek has a drainage basin of about 10.5 square miles. The altitude drops from a maximum of about 625 feet in the western part of town to about 358 feet at its confluence with the Brazos River. Channel gradient is steeper in the upper reaches of the drainage basin and nearly level in the lower reaches. In its lower reaches Waco Creek has been responsible for considerable flooding within Waco when rainfall runoff accumulated in this part of the channel.

The most common soil type in the Waco Creek drainage basin is the Houston Black clay which underlies approximately 5 square miles of the drainage basin. This soil has only a fair natural drainage with permeability rates of 0.05 to 0.15 inch per hour (Elder, 1965, p. 37). Another soil type the Austin silty clay, which lies in the central portion of the drainage basin and in scattered patches in the western section, has good natural soil drainage with permeability rates of 0.2 to 1.0 inch per hour. Soil types in the one square mile lower reach of Waco Creek have permeability rates from 0.05 to 2.0 inches per hour. An average infiltration rate for the entire drainage basin is approximately 0.4 inch per hour, after which excess moisture becomes runoff.

A relief sewer for Waco Creek has been constructed beneath Clay Avenue from Webster Avenue to the Brazos River. This diversion channels stream flow from higher elevations directly into the Brazos River bypassing lower reaches of the channel. This relief sewer has helped alleviate flood problems in the lower reaches of Waco Creek.

Other drainage facilities in the lower elevations of Waco include the underground diversion of Waco Creek beneath the Baylor University campus from Fifth to Third streets and a trunk sewer constructed along Interstate 35 Crosstown Freeway. The trunk sewer was constructed under an agreement between the City of Waco and the Texas Highway Department and carries storm water from connected city lateral systems as well as from the right-of-way.

MUNICIPAL AND INDUSTRIAL RETURN FLOWS

SOURCES

In addition to natural sources of water such as precipitation and ground water discharge, rivers receive water from waste disposal plants along their courses. Many of these plants obtain their water from other surface water sources or from groundwater. At Waco, water originating primarily in Waco Reservoir passes through the city water mains, is treated at the Waco waste disposal plant, and returned to the Brazos River as treated effluent.

Elm Mott and Bellmead also use the Brazos River or its tributaries for municipal waste disposal. The City of McGregor and the Rocketdyne Corporation at McGregor release treated sewage effluent into tributaries of the South Bosque River. The cities of Valley Mills and Clifton release treated sewage effluent into the North Bosque River. The City of Meridian has recently begun operating a system of oxidation ponds into which its treated sewage effluent is pumped; at present none of this water enters the North Bosque River.

At present, neither Hog Creek nor the Middle Bosque River is used for waste water disposal.

DISCHARGE

Waco discharges over 10 mgd (million gallons per day) of treated sewage effluent into the Brazos River or about 300 million gallons monthly. The treated effluent, originating principally from Waco Reservoir as municipal water to the Waco water system, is an excellent potential source of water for various industrial or agricultural uses. A complete analysis of this effluent is given in table 13.

The McGregor waste treatment plant discharges about 175,000 gpd of treated sewage effluent into Harris Creek, a tributary of the South Bosque River. Industrial waste from the McGregor area is treated at the Rocketdyne Corporation waste disposal plant and is released into a branch of the South Bosque River south of McGregor at a rate of about 200,000 gpd. Effluent from both of these treatment plants eventually enters Waco Reservoir via the South Bosque River.

Valley Mills and Clifton release treated sewage effluent into the North Bosque River at rates of 50,000-70,000 gpd and about 198,900 gpd, respectively. Meridian releases about 46,000 gpd of treated sewage effluent into its oxidation ponds.

QUALITY

Chemical analysis of the final sewage effluent from the Waco waste treatment plant is listed in table 13.

Some industries within Waco and the communities surrounding Waco obtain their water supplies from deep wells (Holloway, 1966). Total pumpage in the Waco area, from these wells for 1965, as reported to the Texas Water Development Board, was 2,006,775,000 gallons. A major portion of this water enters the Brazos system in the immediate vicinity of Waco as sewage effluent discharged from these industries and communities.

McGregor, Rocketdyne Corporation, Valley Mills, and Clifton (fig. 10) all use municipal water obtained from wells drilled into the Trinity Sand; this water eventually enters the Bosque rivers after treatment at their waste treatment plants. Meridian also obtains its municipal water supply from deep wells drilled into the Trinity Sand.

Quality of Trinity water is high throughout McLennan County except in some local areas where brackish water is found (Holloway, 1966). Therefore, the addition of Trinity water to the Bosque system does not reduce the quality of the latter supply.

Table 13. Chemical analysis of final sewage effluent, Waco, Texas.

Substance	Concentration in ppm
Specific conductance (micromhos)	960
Total dissolved solids	574
Chloride	72
Sulfate	65
Chlorine demand	1.5
Dissolved Oxygen	0*
River above outfall	9.6
River below outfall	9.3
B. O. D.	26
River above outfall	2.1
River below outfall	2.3
Ammonia	14
Nitrate Nitrogen	0.1
Nitrite Nitrogen	0.4
P. alkalinity	0.0
Total alkalinity	262
Total suspended solids	34
Volatile suspended solids	33
Fixed suspended solids	1

*Analysis made several hours after collection.
Analysis November 18, 1965, Texas State Department of Health and Waco Water Department.

POTENTIAL USES

Treated sewage effluent is an excellent source of water for various agricultural and industrial purposes. Treated effluent is a source of irrigation water for nonedible crops and is used for this purpose in other areas. Various industries use treated sewage effluent for their process water. Industrial problems, however, are diverse and require individual study. Treated sewage effluent also may be used to water parks and golf courses. An annotated bibliography of the re-use of effluent is given by Whetstone (1965).

POLLUTION HAZARD

Of more concern than effluent from monitored waste disposal plants are the unmonitored sources of pollutants that can enter Waco Reservoir. These include the addition through runoff of agricultural chemicals such as insecticides, herbicides, and fertilizers in the Bosque drainage basin as well as runoff from septic tanks and livestock pens.

Rain-saturated ground increases runoff of chemicals and pollutants into streams and subsequently into Waco Reservoir. Under saturated ground conditions septic tank fluids cannot be absorbed by the soil and are carried as runoff into creeks around the lake and eventually into the lake. As the density of homes with septic tanks increases in the areas surrounding Waco Reservoir, less land will be available for absorption of septic tank fluids. These fluids will contribute effluent to surface streams flowing into the lake.

PROPOSED REGIONAL SEWAGE TREATMENT PLANT

The Brazos River Authority is currently studying the possibility of construction and operation of a regional waste treatment system to serve the Waco metropolitan area which includes Bellmead, Beverly Hills, Hewitt, Lacy-Lakeview, Northcrest, Robinson, Waco, and Woodway. This area covers approximately 248 square miles of McLennan County.

Waco, Bellmead, and Robinson have waste treatment plants. The other towns either discharge sewage into the Waco waste treatment system or individuals must dispose of this waste water by septic tanks. In areas of high population density, the latter may constitute a definite source of serious pollution.

The proposed regional waste treatment plant would be built at the confluence of Flat Creek and the Brazos River south of Waco, a site which would allow for later expansion of treatment facilities. Existing treatment plants would continue operating until their capacity is surpassed or the regional plant is sufficiently enlarged to accommodate the additional waste.

Interceptor sewers would receive sewage from each city to carry it to the regional treatment plant. Sewage collection within each city would be a municipal responsibility. Treated sewage effluent, monitored for pollution control standards, would be returned to the Brazos River as useful raw water.

FUTURE REQUIREMENTS AND SUPPLY

PRESENT DEMAND

In 1931 Waco used over one billion gallons of water and in 1950, 3 billion gallons. By 1960 the population in Waco was 97,808 and the total water requirement was over 7 billion gallons (195 million gallons ground water and over 6 billion gallons surface water). These data include water supplied by the municipal water plant as well as ground water withdrawals by industries which maintain their own wells.

Additional water is withdrawn from the Brazos River or pumped from wells drilled into Brazos alluvium. This water is used to irrigate alluvial land along the Brazos River in the Waco area and southward.

PROJECTED REQUIREMENTS

Projected population increase and resultant water needs for Waco have been made by the Texas Water Development Board (1966, pp. 17, 42). Projected water requirements are based on population projections, industrial change, and related elements of the economy (fig. 15). It is estimated that by 1990 Waco's population will be 247,700 and the annual water requirements will be over 20 billion gallons. By the year 2020, the population is expected to reach 496,000 with an annual water requirement of more than 42 billion gallons. Ground water was not included as a projected water supply source. It is proposed that all municipal and industrial water will be supplied from surface sources.

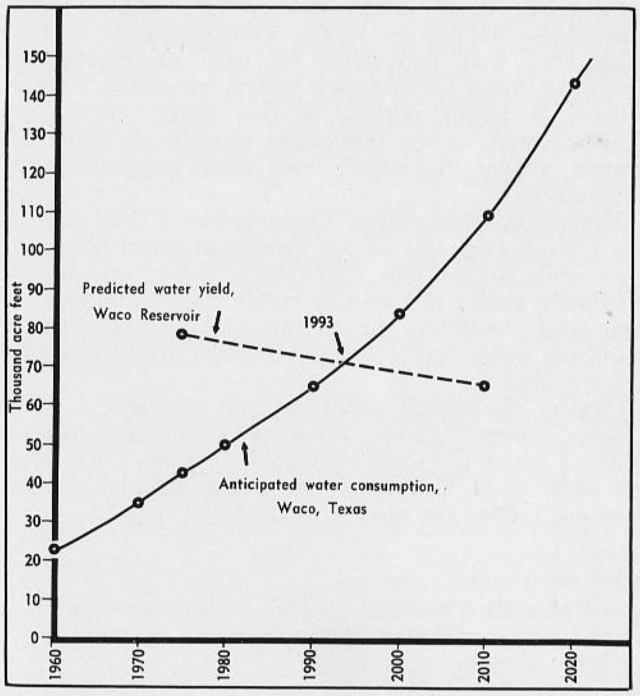

Fig. 15. Predicted water yield, Waco Reservoir; anticipated water consumption, Waco, Texas.

Table 14. Surface-water supply projects necessary to meet central basin requirements in 2020, Brazos River basin, Texas.

Reservoir	Status	Requirement supplied (acre-feet)		Usable return flow (acre-feet)	Remaining yield (acre-feet)
Possum Kingdom	Existing	Graham	2,100	—	—
		Waco	40,100	—	—
		Other cities	20,000	—	—
			62,200	4,700	28,500
Whitney	Existing	Cleburne	9,200	—	—
		Waco	20,000	—	—
		Marlin	3,500	—	—
		Other cities	9,000	—	—
			41,700	7,700	13,100
Waco	Existing	Bellmead	11,800	—	—
		Waco	45,500	—	—
			57,300	—	—
Belton	Existing	Waco	25,000	—	—
		Belton	5,900	—	—
		Killeen	12,300	—	—
		Temple	22,400	—	—
		Irrigation (NP)	5,000	—	—
			70,600	—	33,100

NP—Non project, water supplied directly to individual fields and farms adjacent to streams.
From Texas Water Development Board (1966) Proposed water resources development in the Brazos River Basin, pp. 52-53.

SOURCES OF SUPPLY

It is estimated that Waco's present water resources will be inadequate to meet the requirements of its population and industrial increase. Future use of ground water will be limited and projected requirements must be met from surface water sources.

The preliminary Texas water plan indicates that storage reservoirs in other parts of the Brazos River basin will be used to augment Waco's water supply. Surface water supply projects proposed to meet Waco's requirements in the year 2020 are shown in table 14. These reservoir sources include Possum Kingdom Reservoir, Whitney Reservoir, Waco Reservoir, and Belton Reservoir. The plan suggests that they can provide 130,500 acre-feet of water to Waco.

Water from Possum Kingdom Reservoir and Whitney Reservoir has a higher salinity or total dissolved solids content under present conditions than water from Waco Reservoir or Belton Reservoir. This saline water will require dilution before it becomes suitable for municipal use but may, however, be adequate for some industrial purposes.

The water program suggested by the Texas Water Development Board in the preliminary Texas water program provides only water from in-State sources to Central Texas. At present there are no plans to divert water from out-of-State sources to Central Texas.

Economic studies on the potential of desalination are presently underway in some areas of Texas to determine whether or not such plants are practical for various areas of the State. Although possibly useful at Possum Kingdom and Whitney reservoirs, none, however, is presently planned for the Central Texas area.

CONCLUSIONS

1. The municipal water supply for Waco, Texas is obtained primarily from Waco Reservoir which was enlarged in 1965. Water yield from this reservoir, however, is projected to be inadequate for long range needs of the city and plans are being developed to keep the city adequately supplied with water from additional reservoirs. Of the four reservoirs which could supply Waco, two (Waco Reservoir and Belton Reservoir) have water with low enough salinity to make it suitable for municipal purposes. The other two reservoirs (Whitney Reservoir and Possum Kingdom Reservoir) have water of rather high salinity (under present conditions) which will need desalination or extensive dilution before the water is acceptable for municipal use. This saline water, however, in an untreated state might be useful for some industrial purposes.
2. Irrigation and industrial water can be supplied from different sources than municipal water. Water from the Brazos River at Waco, though saline, can be used for irrigation purposes on permeable terraces along the river. Irrigation of terraces will prevent accumulation of salt such as would occur if this water were used for irrigation on nonpermeable soils. Treated effluent from the Waco waste treatment plant is an excellent source of water for nonedible crops. This effluent provides a relatively constant year round supply of water which also could be an inexpensive source of water for some industrial purposes. The planned regional waste treatment plant will increase the amount of treated effluent since it will process waste water from surrounding towns as well as from Waco.
3. When the Brazos River floods at Waco, it normally floods its east bank inundating low areas of East Waco. Waco Reservoir and Whitney Reservoir, as well as other reservoirs upstream on the Brazos River, have considerably reduced floods on the Brazos River at Waco. However, it should be noted that once these reservoirs reach their flood storage capacities all additional water must be released. Therefore, while the number of small floods is reduced by dams, there can be no complete protection against larger floods. This fact is especially important to remember in the Waco area because of the influence on rainfall of the Balcones escarpment. Several national rainfall records were observed less than 100 miles from Waco and geographic conditions are favorable for such high rainfall rates in the Waco area.
4. In West Waco, on the western side of the Brazos River, the principal flood problem is caused by Waco Creek. Because of its relatively flat drainage basin as it approaches its confluence with the Brazos River, Waco Creek has frequently overflowed its banks and, at times, caused major flooding. The Clay Avenue relief channel diverts much of the water derived from higher elevations of the city away from the lower Waco Creek channel and carries this water directly to the Brazos River. This diversion reduces the percentage of floods in the lower Waco Creek basin. Nevertheless, when the Brazos River is at a high stage, backwater at the mouth of Waco Creek can prevent drainage into the Brazos River and cause the creek to overflow its banks. High Brazos River water elevation at the Clay Avenue relief sewer outlet can prevent discharge from this source until the Brazos River reaches a lower stage.
5. The proposed low water dam on the Brazos River will raise the water level to an elevation of 375.0 feet. This maximum elevation is over 15 feet above the present confluence of Waco Creek and the Brazos River. Water will saturate river terraces at least as high as water level. Saturated river terraces will reduce infiltration of surface water such as that from rainfall and will increase surface runoff from this source. Sedimentation will take place upstream in both the Clay Avenue relief sewer and in Waco Creek when the water level at their mouths is raised. Such sedimentation in a channel reduces the cross section of the channel and thereby reduces its water-carrying capacity. Normal flushing of this sediment during periods of increased discharge is hampered by high water at the mouths.
6. Snow is relatively infrequent in the Central Texas area. However, within a 71 year period of record, 13-inch snowfalls have occurred twice. The weight of this type of load should be considered when broad flat roofs are contemplated. The potential effect of ice on supporting structures, although not a frequent problem in the Central Texas area, is also a factor which should be considered.

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APPENDIX I

EVAPORATION RATES*

Waco lies in the east-central section of an area designated as quadrangle F-10 (lat 31° to 32°N; long 97° to 98°W). Blacklands Experiment Station in McLennan County (lat 31°29'; long 96°53') is the evaporation station for this quadrangle.

Gross lake surface evaporation rates were determined by pan evaporation. Monthly coefficients for each evaporation station were used to convert these figures to gross lake surface evaporation rates which are indicated in inches.

Net reservoir evaporation rates were derived by subtracting effective rainfall for each quadrangle from gross lake surface evaporation. These values were then converted to feet.

"In order to determine the monthly evaporation loss from a proposed reservoir it is only necessary to multiply the net monthly evaporation rate as given by the average reservoir surface area in acres during the month. The loss indicated will then be in terms of acre-feet.

"When a study is to be made of an existing reservoir the gross reservoir evaporation rates contained at the top of the tables . . . should be used. THESE MONTHLY GROSS RATES WILL HAVE TO BE REDUCED BY 100 PERCENT OF THE RAINFALL *FOR AN EXISTING RESERVOIR* FOR EACH MONTH OF THE PERIOD WHEN THE RESERVOIR WAS IN OPERATION. . . . In this type study all the monthly rainfall is subtracted from the monthly gross evaporation rate to determine the net evaporation rate. The net evaporation rate, after it is obtained by this method, is used in the same manner described above" (Lowry, 1960, p. 11).

*Lowry, Robert L., Jr. (1960) Monthly reservoir evaporation rates for Texas 1940 through 1957: Texas Board of Water Engineers, Bull. 6006, Austin.

QUADRANGLE F—10

Lat. 31° to 32° N. Long. 97° to 98° W.

GROSS LAKE SURFACE EVAPORATION RATES IN INCHES

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	2.4	2.9	4.5	4.4	6.3	6.6	7.5	9.7	9.2	6.5	4.3	3.7	68.0
1941	3.2	2.5	3.2	4.0	4.7	6.0	8.7	10.3	8.8	5.9	4.5	3.2	65.0
1942	3.3	3.0	5.0	3.2	4.3	6.7	8.4	8.8	.64	5.1	4.7	3.1	62.0
1943	2.6	4.0	3.6	6.0	5.4	6.6	8.0	9.8	7.9	6.1	4.5	2.5	67.0
1944	2.0	2.2	2.9	5.4	4.4	7.6	9.9	11.0	8.6	7.3	3.8	2.9	68.0
1945	2.5	2.3	3.1	3.4	6.5	6.8	7.6	9.1	9.4	5.3	5.4	3.6	65.0
1946	2.6	3.0	4.5	5.1	4.9	6.9	10.1	11.9	5.8	5.4	4.4	3.4	68.0
1947	1.9	3.4	3.4	3.4	5.0	8.0	9.5	9.6	9.6	7.7	4.8	2.7	69.0
1948	2.0	1.6	3.6	5.4	5.0	8.2	8.5	10.4	8.5	7.4	5.5	3.9	70.0
1949	2.3	1.7	3.3	3.2	5.4	6.6	9.2	9.0	8.6	5.6	5.5	2.6	63.0
1950	2.1	2.3	5.1	3.7	4.8	6.0	8.8	11.2	7.2	7.5	6.4	3.9	69.0
1951	3.6	2.6	5.2	5.4	5.1	6.2	9.9	12.7	8.2	6.3	4.2	3.6	73.0
1952	3.2	4.0	3.8	4.4	5.3	6.6	8.3	12.2	9.9	9.7	4.8	2.8	75.0
1953	3.7	3.0	3.4	4.7	4.9	8.1	8.5	9.7	7.6	5.8	4.0	3.6	67.0
1954	2.5	4.8	4.3	4.7	5.5	8.7	12.4	11.9	10.2	8.2	5.4	4.4	83.0
1955	2.6	2.5	3.8	4.6	5.9	6.7	8.6	7.3	6.8	8.2	6.2	3.8	67.0
1956	3.4	2.9	5.2	5.5	7.0	8.9	11.8	11.8	10.9	7.8	5.3	4.0	85.0
1957	2.7	2.1	3.1	2.6	3.8	5.8	9.2	10.3	7.5	4.5	3.4	3.0	58.0

NET RESERVOIR EVAPORATION RATES IN FEET

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1940	.12	.04	.35	.02	.40	—.02	.47	.70	.71	.43	—.38	—.05	2.79
1941	.12	—.13	.02	—.06	.08	.08	.45	.53	.66	.12	.27	.14	2.28
1942	.23	.17	.34	—.47	.01	.20	.62	.47	.10	.08	.28	.12	2.15
1943	.18	.32	.16	.35	.12	.48	.49	.80	.37	.39	.30	.01	3.97
1944	—.13	—.13	.06	.14	—.30	.56	.75	.71	.59	.51	.03	—.08	2.71
1945	—.01	—.11	—.15	—.19	.42	.28	.44	.57	.62	.24	.33	.15	2.59
1946	—.05	.06	.09	.21	—.04	.43	.79	.87	.14	.36	.14	.08	3.08
1947	—.13	.21	.03	.05	.12	.52	.72	.55	.71	.56	.25	—.01	3.58
1948	.06	—.07	.18	.22	.10	.49	.49	.82	.59	.55	.39	.21	4.03
1949	—.13	—.04	.08	—.12	.32	.19	.64	.62	.67	.17	.45	.08	2.93
1950	.02	—.13	.39	.01	.09	.24	.52	.82	.27	.51	.48	.32	3.54
1951	.22	.01	.31	.24	.11	.20	.77	1.03	.38	.42	.29	.27	4.25
1952	.23	.13	.13	—.12	.01	.48	.63	.99	.74	.81	—.12	—.16	3.75
1953	.27	.13	.04	.18	—.09	.62	.51	.57	.48	.09	.22	.13	3.15
1954	.10	.37	.29	.16	.24	.68	.99	.97	.78	.44	.25	.34	5.61
1955	.10	—.06	.19	.18	—.06	.25	.57	.33	.28	.58	.47	.24	3.07
1956	.08	.10	.42	.34	.23	.69	.95	.91	.90	.53	.28	.16	5.59
1957	.13	.01	—.04	—.55	—.17	.34	.67	.83	.33	—.13	—.05	.19	1.56

NOTE: Negative values indicate effective rainfall exceeds gross lake surface evaporation rate.

Lowry, Robert L., Jr. (1960) monthly reservoir evaporation rates for Texas 1940 through 1957: Texas Board of Water Engineers, Bull. 6006, Austin, p. F-10.

APPENDIX II

BRAZOS RIVER DISCHARGE AND RUNOFF, WACO, TEXAS*

Location. --Lat 31°33'40", long 97°07'45", at Washington Avenue Bridge in Waco, McLennan County, 2½ miles downstream from Bosque River, and at mile 404.

Drainage area. --28, 500 sq mi, approximately, of which 9, 240 sq mi is probably noncontributing.

Gage. --Water-stage recorder. Datum of gage is 356. 80 ft above mean sea level, datum of 1929, supplementary adjustment of 1942. Sept. 14, 1898, to Mar. 28, 1918, and May 6, 1922, to Feb. 12, 1934, staff or chain gages at several sites within about 350 ft of present site and at same datum. Mar. 28, 1918, to May 5, 1922, and Feb. 13, 1925, to Sept. 29, 1934, water-stage recorder at site about 300 ft downstream at same datum.

Average discharge. --59 years (1898-1957), 2, 550 cfs (1, 846, 000 acre-ft per year).

Extremes. --1898-1957: Maximum discharge, 246, 000 cfs Sept. 27, 1936 (gage height, 40. 90 ft, levee on left bank was overtopped and broken by flood); minimum discharge for periods of daily record, 1898-1911, 1914-57, no flow Aug. 20, 21, 1918, and probably for several days in August 1923.

Maximum stage 1854-97, 34. 6 ft May 28, 1885, from floodmark near gage. A stage of 39. 7 ft was reached Dec. 3, 1913 (discharge, 211, 000 cfs), when levee on left bank was broken by flood; from information by the U. S. Weather Bureau.

Remarks. --Flow regulated by Possum Kingdom and Whitney Reservoirs on Brazos River, several small reservoirs in Clear Fork and other basins (combined capacity, 221, 800 acre-ft), and Lake Waco on Bosque River (capacity, 22, 000 acre-ft); total combined capacity of all reservoirs, about 2, 986, 000 acre-ft, of which 1, 630, 500 acre-ft is flood-control storage in Whitney Reservoir. A siltation survey of Lake Waco by the Soil Conservation Service of the U. S. Department of Agriculture in December 1947 indicates a 44. 07 percent capacity loss from siltation since storage began in April 1930. Many small diversions above station for municipal supply, irrigation, and oilfield operation do not appreciably affect flow. The city of Waco discharges sewage effluent into river 2¼ mi below gage.

Monthly and yearly mean discharge, in cubic feet per second

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1899	389	105	166	141	103	42. 7	174	1, 580	11, 500	10, 900	597	90. 1	2, 160
1900	924	5, 670	3, 000	2, 320	885	1, 090	11, 000	7, 300	4, 990	3, 020	2, 140	15, 300	4, 780
1901	4, 370	1, 942	634	352	408	256	631	2, 992	2, 711	127	490	752	1, 310
1902	257	260	110	48. 3	46. 7	1, 012	1, 031	4, 329	2, 152	15, 380	2, 349	1, 661	2, 418
1903	1, 214	4, 625	1, 639	1, 083	6, 188	6, 610	1, 140	708	1, 620	1, 405	745	557	2, 266
1904	3, 767	450	149	112	259	369	484	2, 153	3, 409	1, 764	1, 707	1, 100	1, 316
1905	1, 877	462	195	349	545	1, 607	7, 317	18, 250	3, 859	5, 710	2, 238	1, 857	3, 718
1906	1, 560	718	931	548	733	352	547	3, 970	8, 610	3, 090	4, 020	3, 020	2, 350
1907	1, 400	640	1, 270	827	580	557	351	3, 180	3, 700	3, 400	858	376	1, 440
1908	2, 560	2, 590	3, 440	1, 220	1, 500	1, 310	19, 100	22, 000	3, 120	1, 060	777	926	4, 970
1909	444	218	367	32. 0	22. 0	31. 8	26. 9	354	4, 610	359	1, 410	113	665
1910	230	437	2, 750	114	192	41. 7	1, 500	3, 290	620	170	18. 6	616	836
1911	270	78. 6	56. 1	12. 3	1, 120	240	443	187	33. 3	3, 100	1, 720	5, 110	1, 030
1912	177	79. 2	2, 310	263	367	899	732	767	990	262	3, 510	431	905
1913	1, 000	137	40. 3	10. 6	90. 4	232	536	3, 980	1, 340	1, 050	351	2, 690	960
1914	5, 150	5, 620	24, 700	868	327	712	7, 290	19, 400	7, 410	1, 430	10, 900	3, 450	7, 340
1915	1, 129	1, 220	1, 871	1, 268	924	1, 372	14, 090	7, 892	11, 420	3, 005	2, 304	2, 176	4, 047
1916	3, 220	509	415	1, 490	1, 500	476	13, 800	6, 470	2, 480	523	172	383	2, 610
1917	1, 650	281	136	117	85. 8	95. 3	267	846	1, 180	479	391	1, 310	572
1918	175	41. 7	52. 3	44. 2	26. 4	21. 0	3, 320	2, 730	3, 000	228	2. 72	2, 680	1, 020
1919	4, 580	11, 300	6, 230	5, 840	3, 990	3, 490	4, 390	9, 450	9, 470	5, 270	4, 430	5, 360	6, 150
1920	12, 400	11, 800	2, 940	6, 180	2, 640	2, 030	1, 000	14, 800	5, 550	1, 420	7, 810	10, 200	6, 580
1921	2, 340	2, 860	1, 460	2, 270	2, 310	2, 020	1, 480	530	6, 080	808	155	606	1, 900
1922	173	67. 1	90. 4	79. 1	87. 3	291	19, 000	23, 700	3, 860	775	118	143	4, 040
1923	114	226	138	146	772	183	6, 950	2, 980	5, 750	241	16. 9	885	1, 520
1924	4, 340	4, 140	5, 670	992	895	5, 730	2, 880	3, 580	2, 190	91. 3	74. 6	1, 930	2, 720
1925	303	174	148	146	63. 1	33. 9	1, 330	8, 120	311	75. 7	702	6, 050	1, 460
1926	2, 690	1, 250	153	1, 540	352	1, 810	6, 840	2, 990	5, 820	3, 580	2, 700	4, 800	2, 880
1927	5, 400	650	1, 660	555	1, 230	1, 830	4, 550	2, 040	7, 200	1, 710	636	331	2, 320
1928	2, 100	133	207	182	999	407	1, 720	4, 940	5, 340	2, 340	3, 400	1, 030	1, 900
1929	83. 6	167	750	744	445	849	2, 190	5, 150	2, 930	677	164	5, 370	1, 630
1930	821	411	260	124	518	269	443	15, 000	6, 030	668	235	1, 060	2, 170
1931	10, 300	1, 180	4, 520	1, 920	4, 570	2, 590	1, 780	1, 860	1, 400	475	202	150	2, 580
1932	4, 480	1, 520	1, 380	5, 550	8, 210	3, 520	896	6, 760	4, 280	8, 200	691	10, 400	4, 640
1933	917	357	1, 650	1, 540	406	2, 150	931	6, 980	1, 530	1, 060	1, 340	1, 700	1, 730
1934	415	311	389	1, 140	631	2, 850	4, 800	649	112	16. 6	15. 6	236	962
1935	118	1, 465	393	812	1, 346	651	1, 902	22, 110	11, 130	4, 361	1, 005	5, 286	4, 230
1936	1, 764	1, 519	1, 614	515	283	155	195	4, 678	1, 759	1, 044	93. 2	19, 540	2, 744
1937	7, 063	1, 755	3, 555	2, 156	1, 437	2, 299	710	515	2, 519	406	1, 270	843	2, 055
1938	1, 231	208	2, 718	6, 719	8, 156	4, 420	6, 028	4, 991	4, 757	3, 715	1, 424	244	3, 691
1939	71. 7	68. 3	81. 1	891	812	343	476	4, 453	5, 958	954	560	189	1, 237
1940	30. 4	254	80. 3	63. 6	152	107	1, 659	1, 958	7, 527	2, 703	4, 062	1, 205	1, 647
1941	196	6, 921	6, 599	2, 160	8, 855	4, 631	5, 431	21, 020	14, 840	3, 357	3, 275	1, 744	6, 560
1942	11, 970	4, 431	754	1, 272	468	357	22, 470	10, 840	9, 574	834	782	5, 432	5, 757
1943	8, 644	1, 773	1, 186	1, 069	1, 454	1, 935	2, 114	1, 700	1, 206	924	717	600	1, 953
1944	275	116	179	637	2, 155	1, 988	1, 470	12, 330	1, 558	551	434	903	1, 891
1945	473	640	1, 087	2, 971	5, 512	9, 055	14, 410	2, 720	2, 785	4, 695	969	501	3, 796

Monthly and yearly mean discharge, in cubic feet per second, of Brazos River at Waco, Tex.--Continued

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1946	1,883	618	946	2,150	3,327	3,435	1,669	3,919	2,150	594	821	2,037	1,955
1947	3,177	3,474	3,278	2,670	1,624	2,575	2,651	6,365	2,173	849	723	706	2,532
1948	465	352	1,342	892	2,238	1,331	719	1,926	1,198	1,646	795	769	1,138
1949	238	221	260	387	1,308	1,597	1,837	8,133	5,581	1,462	917	1,273	1,936
1950	1,725	866	399	509	2,229	584	1,597	1,587	1,729	3,378	2,637	3,528	1,724
1951	1,292	398	453	624	612	255	267	894	3,167	1,319	1,184	890	947
1952	378	324	227	196	204	140	1,021	1,477	392	752	1,109	427	556
1953	57.7	226	789	216	113	826	517	3,416	422	466	556	199	658
1954	127	89.3	137	95.5	78.3	146	631	6,043	2,529	1,230	846	324	1,032
1955	412	133	40.8	44.6	145	155	160	3,501	4,029	1,031	655	3,135	1,120
1956	9,679	455	444	557	581	528	627	4,014	664	1,532	722	581	1,717
1957	420	132	59.7	585	717	887	10,360	36,340	37,140	3,869	687	595	7,658

Monthly and yearly runoff, in acre-feet

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1899	23,900	6,250	10,200	8,640	5,710	2,620	10,400	96,900	682,000	672,000	36,700	5,360	1,560,000
1900	56,800	338,000	184,000	143,000	49,200	67,000	654,000	449,000	297,000	186,000	132,000	908,000	3,460,000
1901	268,700	115,500	38,970	21,630	22,680	15,720	37,560	184,000	161,300	7,800	30,130	44,740	948,700
1902	15,810	15,480	6,770	2,970	2,590	62,230	61,330	266,200	128,000	945,900	144,500	98,840	1,751,000
1903	74,640	275,200	100,800	66,620	343,600	406,400	67,850	43,560	96,370	86,400	45,810	33,160	1,640,000
1904	231,600	26,810	9,150	6,880	14,900	22,700	28,770	132,400	202,900	108,500	105,000	65,470	955,100
1905	115,400	27,460	12,010	21,480	30,280	48,790	435,400	1,122,000	229,600	351,100	137,600	110,500	2,692,000
1906	95,900	42,700	57,200	33,700	40,700	21,600	32,500	244,000	512,000	190,000	247,000	180,000	1,700,000
1907	86,100	38,100	78,100	50,800	32,200	34,200	20,900	196,000	220,000	209,000	52,800	22,400	1,040,000
1908	157,000	154,000	212,000	75,000	86,300	80,600	1,140,000	1,350,000	186,000	65,200	47,800	55,100	3,610,000
1909	27,300	13,000	22,600	1,970	1,220	1,960	1,600	21,800	274,000	22,100	86,700	6,720	481,000
1910	14,100	26,000	169,000	7,010	10,700	2,560	89,200	202,000	36,900	10,500	1,140	36,700	606,000
1911	16,600	4,680	3,450	756	62,200	14,800	26,400	11,500	1,980	191,000	106,000	304,000	743,000
1912	10,900	4,710	142,000	16,200	21,100	55,300	43,600	47,200	58,900	16,100	216,000	25,700	657,000
1913	61,800	8,170	2,480	655	5,020	14,300	31,900	245,000	79,900	64,700	21,600	160,000	695,000
1914	317,000	334,000	1,520,000	53,400	18,100	43,800	434,000	1,190,000	442,000	88,000	670,000	205,000	5,320,000
1915	69,420	72,610	115,100	77,970	51,340	84,370	838,400	485,300	679,600	184,800	141,700	129,500	2,930,000
1916	198,000	30,300	25,500	91,600	86,300	29,300	821,000	398,000	148,000	32,200	10,600	22,800	1,890,000
1917	101,000	16,700	8,360	7,190	4,770	5,860	15,900	52,000	70,200	29,500	24,000	78,000	413,000
1918	10,800	2,480	3,220	2,720	1,470	1,290	198,000	168,000	179,000	14,000	167	159,000	740,000
1919	282,000	672,000	383,000	359,000	222,000	215,000	261,000	581,000	564,000	324,000	272,000	319,000	4,450,000
1920	762,000	702,000	181,000	380,000	152,000	125,000	59,500	910,000	330,000	87,300	480,000	607,000	4,780,000
1921	144,000	170,000	89,800	140,000	128,000	124,000	88,100	32,600	362,000	49,700	9,530	36,100	1,370,000
1922	10,700	3,990	5,560	4,860	4,850	17,900	1,130,000	1,460,000	230,000	47,700	7,250	8,520	2,930,000
1923	6,980	13,500	8,490	9,000	42,900	11,300	414,000	183,000	342,000	14,800	1,040	52,600	1,100,000
1924	267,000	246,000	348,000	61,000	51,500	352,000	171,000	220,000	130,000	5,610	4,590	115,000	1,970,000
1925	18,600	10,400	9,070	8,980	3,500	2,080	79,300	499,000	18,500	4,660	43,200	360,000	1,060,000
1926	166,000	74,200	9,390	94,800	19,600	111,000	407,000	184,000	346,000	220,000	166,000	286,000	2,080,000
1927	332,000	38,700	102,000	34,100	68,400	112,000	271,000	126,000	428,000	105,000	39,100	19,700	1,680,000
1928	129,000	7,910	12,700	11,200	57,500	25,000	102,000	304,000	318,000	144,000	209,000	61,300	1,380,000
1929	5,140	9,940	46,100	45,700	24,700	52,200	131,000	317,000	174,000	41,600	10,100	319,000	1,180,000
1930	50.500	24,500	16,000	7,620	28,800	16,500	26,400	922,000	359,000	41,100	14,400	63,100	1,570,000
1931	633,000	70,200	278,000	118,000	254,000	159,000	106,000	114,000	83,300	29,200	12,400	8,930	1,870,000
1932	275,000	90,400	84,800	341,000	472,000	216,000	53,300	416,000	255,000	504,000	42,500	619,000	3,370,000
1933	56,400	21,200	101,000	94,700	22,500	132,000	55,400	429,000	91,000	65,200	82,400	101,000	1,250,000
1934	25,500	18,500	23,900	70,100	35,000	175,000	286,000	39,900	6,660	1,020	959	14,000	697,000
1935	7,290	87,190	24,160	49,950	74,740	40,020	113,200	1,359,000	662,000	268,100	61,790	314,600	3,062,000
1936	108,500	90,390	99,220	31,670	16,250	9,550	11,620	287,700	104,600	64,180	5,730	1,162,000	1,991,000
1937	434,300	104,400	218,600	132,600	79,790	141,400	42,280	31,700	149,900	24,960	78,080	50,170	1,488,000
1938	75,690	12,370	167,100	413,100	453,000	271,800	358,700	306,900	283,100	228,400	87,560	14,510	2,672,000
1939	4,410	5,060	4,990	54,820	45,070	21,080	28,330	273,800	354,600	58,640	34,410	11,220	895,400
1940	1,870	15,110	4,930	3,910	8,730	6,570	98,710	120,400	447,900	166,200	249,800	71,700	1,196,000
1941	12,050	411,800	405,800	132,800	491,800	284,700	323,200	1,293,000	882,900	206,400	201,300	103,800	4,750,000
1942	735,700	263,700	46,360	78,190	26,000	21,950	1,337,000	666,200	569,700	51,290	48,110	323,200	4,167,000
1943	531,500	105,500	72,910	65,720	80,730	119,000	125,800	104,500	71,790	56,790	44,100	35,680	1,414,000
1944	16,900	6,880	11,030	39,170	123,900	122,200	87,500	758,200	92,720	33,850	26,680	53,760	1,373,000
1945	29,100	38,080	66,860	182,700	306,100	556,800	857,600	167,300	165,700	288,700	59,570	29,820	2,748,000
1946	115,800	36,780	58,160	132,200	184,800	211,200	99,310	241,000	127,900	36,550	50,500	121,200	1,415,000
1947	195,300	206,700	201,500	164,200	90,170	158,300	157,700	391,400	129,300	52,210	44,490	41,980	1,833,000
1948	28,570	20,930	82,490	54,870	128,700	81,810	42,780	118,400	71,290	101,200	48,900	45,760	825,700
1949	14,640	13,140	15,980	23,800	72,640	98,180	109,300	500,100	332,100	89,890	56,380	75,750	1,402,000
1950	106,100	51,540	24,520	31,270	123,800	35,910	95,050	97,580	102,900	207,700	162,200	210,000	1,249,000
1951	79,460	23,680	27,880	38,400	33,970	15,690	15,870	54,980	188,400	81,130	72,810	52,950	685,200
1952	23,220	19,270	13,990	12,080	11,740	8,580	60,760	90,820	23,340	46,250	68,190	25,390	403,600
1953	3,550	13,440	48,510	13,280	6,260	50,810	30,780	210,100	25,100	28,660	34,180	11,830	476,500
1954	7,790	5,310	8,410	5,870	4,350	8,970	37,530	371,500	150,500	75,620	52,030	19,250	747,100
1955	25,350	7,940	2,510	2,740	8,030	9,540	9,520	215,200	239,700	63,370	40,280	186,600	810,800
1956	595,100	27,100	27,330	34,280	33,430	32,470	37,300	246,800	39,510	94,210	44,380	34,560	1,246,000
1957	25,820	7,830	3,670	35,960	39,800	54,530	616,700	2,234,000	2,210,000	237,900	42,220	35,420	5,544,000

*Texas Board of Water Engineers (1958) Compilation of surface water records in Texas through Sept. 1957, Bull. 5807A, Austin, pp. 225-226.

APPENDIX III

BRAZOS RIVER SILT LOAD, WACO

"All summary values are reported as tons of silt for a water-year, which extends from October 1 through September 30 of the following calendar year.

"Tons of silt were calculated and converted to acre-feet of silt. The [Texas] Board of Water Engineers uses 1,524.6 tons per acre-foot for this conversion on streams for which it has gathered records; the [U. S.] Boundary Commission uses 1,452 tons per acre-foot for this conversion on records for the Rio Grande and Pecos River. Rounding to the nearest acre-foot was done for each month. The summary values for acre-feet of silt are the totals of the rounded monthly values and do not correspond to a direct conversion from the summary value for tons of silt.

"Zero values were not printed in this compilation but are indicated where blanks appear in a column having a summary value. No summary values are shown for columns that had missing data." Stout, *et al.* (1961) Silt load of Texas streams (June 1889-Sept. 1959): Texas Board of Water Engineers, Bull. 6108, Austin, pp. 4, 77-79.

BRAZOS RIVER WATERSHED

WACO STATION ON THE BRAZOS RIVER

Net Drainage Area: 19,260 sq. mi.
Location: Texas Electric Company bridge in Waco
Records Available: June 1, 1924 to August 31, 1933

WATER YEAR 1924

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	267,000			
NOVEMBER	246,000			
DECEMBER	348,000			
JANUARY	61,000			
FEBRUARY	51,500			
MARCH	352,000			
APRIL	171,000			
MAY	220,000			
JUNE 1/	130,000	776,880	510	.439
JULY	5,610	460		.006
AUGUST	4,590	2,090	1	.033
SEPTEMBER	115,000	1,154,760	757	.738
SUMMARY	1,972,000			

WATER YEAR 1925

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	18,600	21,980	14	.087
NOVEMBER	10,400	2,420	2	.017
DECEMBER	9,070	1,010	1	.008
JANUARY	8,980			
FEBRUARY	3,500			
MARCH	2,080			
APRIL	79,300	1,843,960	1,210	1.708
MAY	499,000	7,657,020	5,022	1.127
JUNE	18,500	5,530	4	.022
JULY	4,660	860	1	.014
AUGUST	43,200	876,980	575	1.491
SEPTEMBER	360,000	7,001,770	4,592	1.429
SUMMARY	1,057,000	17,411,530	11,421	1.210

1/ Station was established May 31, 1924 but sampling did not begin until June 1, 1924

WATER YEAR 1926

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	166,000	1,265,840	830	.560
NOVEMBER	74,200	205,570	135	.240
DECEMBER	9,390	1,390	1	.011
JANUARY	94,800	387,950	255	.301
FEBRUARY	19,600	3,920	3	.015
MARCH	111,000	669,550	439	.443
APRIL	407,000	4,418,640	2,898	.798
MAY	184,000	1,768,300	1,160	.706
JUNE	346,000	4,384,480	2,876	.931
JULY	220,000	2,019,260	1,324	.674
AUGUST	166,000	3,189,260	2,092	1.411
SEPTEMBER	286,000	3,985,940	2,614	1.024
SUMMARY	2,084,000	22,300,100	14,627	.786

WATER YEAR 1927

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	332,000	6,979,080	4,578	1.544
NOVEMBER	38,700	53,460	35	.101
DECEMBER	102,000	690,500	453	.497
JANUARY	34,100	22,620	15	.049
FEBRUARY	68,400	74,240	49	.080
MARCH	112,000	509,300	334	.334
APRIL	271,000	1,998,030	1,311	.542
MAY	126,000	772,190	506	.450
JUNE	428,000	4,818,226	3,160	.827
JULY	105,000	477,370	313	.334
AUGUST	39,100	134,690	88	.253
SEPTEMBER	19,700	16,210	11	.060
SUMMARY	1,676,000	16,545,916	10,853	.725

BRAZOS RIVER WATERSHED

WACO STATION ON THE BRAZOS RIVER - CONTINUED

WATER YEAR 1928

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	129,000	947,742	622	.540
NOVEMBER	7,910	510		.005
DECEMBER	12,700	9,470	6	.055
JANUARY	11,200	4,280	3	.028
FEBRUARY	57,500	181,670	119	.232
MARCH	25,000	18,600	12	.055
APRIL	102,000	816,875	536	.588
MAY	304,000	5,350,431	3,509	1.293
JUNE	318,000	3,276,964	2,149	.757
JULY	144,000	2,242,469	1,471	1.144
AUGUST	209,000	1,882,270	1,235	.662
SEPTEMBER	61,300	308,970	203	.370
SUMMARY	1,382,000	15,040,251	9,865	.799

WATER YEAR 1930

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	50,500	220,670	145	.321
NOVEMBER	24,500	10,290	7	.031
DECEMBER	16,000	3,980	3	.018
JANUARY	7,520	680		.007
FEBRUARY	28,900	89,180	58	.227
MARCH	16,500	42,360	28	.191
APRIL	26,400	250,180	164	.696
MAY	922,000	12,511,440	8,206	.997
JUNE	359,000	2,752,210	1,305	.563
JULY	41,100	8,360	6	.015
AUGUST	14,400	5,680	4	.029
SEPTEMBER	63,100	164,940	108	.192
SUMMARY	1,570,000	16,060,470	10,534	.751

WATER YEAR 1929

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	5,140	630		.009
NOVEMBER	9,940	4,690	3	.035
DECEMBER	46,100	167,760	110	.267
JANUARY	45,700	251,310	165	.404
FEBRUARY	24,700	113,320	74	.337
MARCH	52,200	134,280	88	.189
APRIL	131,000	666,931	437	.374
MAY	317,000	3,693,779	2,423	.856
JUNE	174,000	1,404,565	921	.593
JULY	41,600	163,120	107	.288
AUGUST	10,100	28,540	19	.208
SEPTEMBER	319,000	5,276,001	3,461	1.215
SUMMARY	1,176,000	11,904,926	7,808	.744

WATER YEAR 1931

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	633,000	6,198,480	4,066	.719
NOVEMBER	70,200	170,060	112	.178
DECEMBER	278,000	1,953,460	1,281	.516
JANUARY	118,000	184,900	121	.115
FEBRUARY	254,000	589,410	387	.170
MARCH	159,000	219,420	144	.101
APRIL	106,000	96,990	64	.067
MAY	114,000	266,510	175	.172
JUNE	83,300	440,600	289	.389
JULY	29,200	29,100	19	.073
AUGUST	12,400	7,480	5	.044
SEPTEMBER	8,930	1,270	1	.010
SUMMARY	1,866,000	10,157,680	6,664	.400

WATER YEAR 1932

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	275,000	2,866,240	1,880	.766
NOVEMBER	90,400	605,210	397	.492
DECEMBER	84,800	315,160	207	.273
JANUARY	341,000	1,672,660	1,097	.360
FEBRUARY	472,000	1,099,160	721	.171
MARCH	216,000	283,560	186	.096
APRIL	53,300	49,970	33	.069
MAY	416,000	2,734,410	1,794	.483
JUNE	255,000	1,571,090	1,030	.453
JULY	504,000	4,625,840	3,034	.674
AUGUST	42,500	128,480	84	.222
SEPTEMBER	619,000	6,255,530	4,103	.742
SUMMARY	3,369,000	22,207,310	14,566	.484

WATER YEAR 1933

MONTH	STREAM DISCHARGE ACRE-FEET	SILT LOAD OF STREAM TONS	SILT LOAD OF STREAM ACRE-FEET	DRY SILT PCT. BY WT.
OCTOBER	56,400	17,760	12	.023
NOVEMBER	21,200	1,800	1	.006
DECEMBER	101,000	970,020	636	.706
JANUARY	94,700	268,320	176	.208
FEBRUARY	22,500	2,900	2	.009
MARCH	132,000	402,430	264	.224
APRIL	55,400	103,120	68	.137
MAY	429,000	4,361,260	2,861	.747
JUNE	91,000	484,900	318	.391
JULY	65,200	449,260	295	.506
AUGUST	82,400	922,440	605	.822
SEPTEMBER	101,000			
SUMMARY	1,252,000			

APPENDIX IV

BRAZOS RIVER WATER QUALITY
(parts per million)

Water Year	Mean discharge (cfs)	SiO_2	Ca	Mg	Na	HCO_3	SO_4	Cl	NO_3	Total dissolved solids (calculated)	Hardness as $CaCO_3$ Ca, Mg	Hardness as $CaCO_3$ Non-carbonate	Specific conductance (Micromhos at 25°C)	pH
Salt Fork, Brazos River near Aspermont, Texas														
1963	80.8	17	319	61	1,850	116	854	2,900	—	6070	1050	955	8770	7.4
Double Mountain Fork, Brazos River near Aspermont, Texas														
1963	164*	17	159	24	182	124	457	220	3.0	1120	496	394	1640	7.4
Clear Fork, Brazos River at Eliasville, Texas														
1963	194	9.3	80	26	117	141	149	203	2.9	661	307	191	1110	7.1
Brazos River at Possum Kingdom Dam near Graford, Texas (immediately below dam)														
1963	867	11	126	25	314	124	286	496	0.6	1320	417	315	2230	7.2
Brazos River at Whitney Dam near Whitney, Texas (immediately below dam)														
1963	1,215	7.9	95	18	197	129	189	309	0.8	896	310	204	1520	7.1
Brazos River at State Highway 21, near Bryan, Texas														
1963	1,896	7.9	84	16	143	153	146	217	1.3	703	274	150	1200	7.1
Brazos River at Richmond, at gaging station at bridge on U. S. Highway 59														
1963	2,759	11	66	12	97	140	100	145	1.3	513	215	100	871	7.2

*Mean discharge based on 365 days; mean discharge for 360 days of actual flow, 166 cfs.
From Hughes and Leifeste (1965) Chemical composition of Texas surface waters, 1963: Texas Water Development Board, Report 7, Austin, 168 pp.

APPENDIX V

BRAZOS RIVER WATER QUALITY EXTREMES

Drainage area (sq. mi.)	Period of record	Total dissolved solids (ppm) max.	Total dissolved solids (ppm) min.	Hardness (ppm) max.	Hardness (ppm) min.	Specific conductance (micromhos) max. daily	Specific conductance (micromhos) min. daily	Water temperature °F max.	Water temperature °F min.
Salt Fork Brazos River near Aspermont, Texas									
4,830	1948-51 1956-63	114,000	1,230	6,200	334	125,000	1,690	96°	32°
Double Mountain Fork, Brazos River near Aspermont, Texas									
7,980	1948-51 1956-63	6,450	599	2,720	193	10,400	735	99°	32°
Clear Fork, Brazos River at Eliasville, Texas									
5,721	1961-63	3,020	218	1,290	128	5,350	300	98°	32°
Brazos River at Possum Kingdom Dam near Graford, Texas									
22,550	1942-63	3,770	331	928	135	6,110	494	--	--
Brazos River near Whitney, Texas									
26,170	1947-63	1,560	183	542	96	2,660	203	92°	32°
Brazos River at State Highway 21, near Bryan, Texas									
38,400	1961-63	1,200	186	488	110	1,890	319	89°	38°
Brazos River at Richmond at gaging station at bridge on U. S. Highway 59									
44,020	1945-63	1,400	133	446	74	2,540	187	91°	39°

From Hughes and Leifeste (1965) Chemical composition of Texas surface waters, 1963: Texas Water Development Board, Report 7, Austin, 168 pp.

APPENDIX VI

QUALITY OF WATER*

The suitability of a water supply depends upon the chemical quality of the water and the limitations imposed by the contemplated use of the water. Various criteria of water quality requirements have been developed and include physical characteristics, such as turbidity, color, odor, and temperature; chemical substances; bacterial content; and radioactivity. Usually water quality problems of bacteria and physical characteristics can be alleviated economically, but the removal or neutralization of undesirable chemical constituents can be difficult and expensive.

CHEMICAL QUALITY

All surface water contains dissolved minerals carried in solution. The kinds and concentrations of these minerals depend on the environmental history, movement, and source of the water. Water derived from precipitation is relatively free of mineral matter until it comes into contact with the soil and rocks of the earth's crust. Chemical substances in surface water originate principally from the soil and rocks over and through which the water has moved. Consequently, the differences in chemical character of the water reflect in a general way the character of the rock formations that have been in contact with the water. As the water, which has some solvent power, comes into contact with the rock it begins to dissolve minerals and carry them in solution. The length of time the water is in contact with the rock, the solubility of the minerals, and the amount of free carbon dioxide in the water control the amount of minerals dissolved.

Chemical quality of surface water is affected in some areas by artificial or man-made conditions as well as by natural conditions. Highly mineralized water, generally encountered in oil wells and commonly produced with oil, can enter fresh water streams by seepage from waste disposal ponds or from direct discharge of the mineralized water to the streams. Disposal of sewage waste into surface streams can also cause pollution of fresh water.

Chemical quality criteria.

The principal chemical constituents found in water are calcium, magnesium, sodium, potassium, iron, silica, sulfate, chloride and minor amounts of manganese, nitrate, fluoride, and boron. Concentrations of these ions or chemical constituents are commonly reported by weight in parts per million (ppm). One part per million defines one part by weight of the ion to a million parts by weight of water.

Various criteria have been developed for ascertaining water quality requirements. For many purposes, the chemical suitability of water is determined by the total dissolved mineral content of the water. A general classification of water, based on dissolved solids content, presented by Winslow and Kister (1966, p. 50) is given below:

Description	Dissolved solids content (ppm)
Fresh	less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	more than 35,000

However, the criteria used to determine the water quality suitability for public supply, industrial and agricultural uses are more specific.

Public supply.

The quality of water required for public supply can be simply stated in general terms—the water furnished to the consumer must be free of harmful chemical substances which adversely affect health; it must be free of turbidity, odor, and color to the extent that it is not objectional to the user; and must not be excessively corrosive to the water supply system. To produce such water with practical treatment the quality of the raw water prior to treatment must not be below certain standards.

The U. S. Public Health Service has established and periodically revises standards of drinking water to be used on common carriers engaged in interstate commerce. The standards are designed to protect the traveling public and are used to evaluate public supplies. According to the standards, chemical substances should not be present in a water supply in excess of the listed concentrations whenever more suitable supplies are or can be made available at reasonable cost. These limits apply to water at the free-flowing outlet of the consumer. The major chemical standards adopted by the U.S. Public Health Service (1962, pp. 7-8) are as follows:

Substance	Concentration (ppm)
Chloride	250
Fluoride	0.8-1.0*
Iron	0.3
Manganese	0.05
Nitrate	45
Sulfate	250
Total dissolved solids	500

*Optimum and upper limits for Waco based on approximate annual average of maximum daily air temperature of 78.1°F.

Water having a chloride content in excess of 250 ppm is objectionable because with an equivalent amount of sodium it has a salty taste and also may be excessively corrosive to the water supply system.

Water with a sulfate content in excess of 250 ppm may have a laxative effect on people not acclimated to the use of water high in sulfate.

Water containing optimum fluoride content reduces the incidence of tooth decay, especially in children, when the water is used during the period of enamel calcification. However, in excessive concentrations, it may cause mottling of the teeth, depending upon the age of the child, amount of drinking water consumed, and the susceptibility of the individual (Maier, 1950, pp. 1120-1132). Water with a high fluoride content reduces bone decalcification (osteoporosis) in elderly persons (Burnstein, *et al.*, 1966), especially women, and may play a significant role in preventing calcification of the aorta in men. The optimum fluoride level for a given area depends on climatic conditions because the amount of drinking water (and consequently the amount of fluoride) consumed is influenced primarily by air temperature.

Water containing iron in excess of 0.3 ppm and manganese in excess of 0.05 ppm may cause reddish brown or dark gray stains on laundry goods, utensils, and plumbing fixtures, and iron in large amounts imparts an objectionable taste.

Water with a nitrate content above 45 ppm is potentially dangerous for infant feeding and can produce infant cyanosis or "blue baby" disease (Maxcy, 1950, p. 271). More than several parts per million of nitrate may indicate contamination by sewage (Lohr and Love, 1954, p. 10), decaying organic matter, fertilizers, or nitrates in the soil.

Water with a dissolved solids content (degree of mineralization or "total solids") in excess of 500 ppm is not recommended for public supply if other less mineralized supplies are or can be made available at a reasonable cost. Water with less than 500 ppm dissolved solids is not always available, and it is recognized that a considerable number of supplies with dissolved solids in excess of the recommended limit are used without any obvious ill effect. Usually, water containing more than 1,000 ppm dissolved solids is unsuitable for many purposes.

The hardness of water, caused principally by calcium and magnesium is important in water supply, although no limits of rejection have been established by the U. S. Public Health Service. As the hardness of water increases, the desirability of the water decreases for most household purposes, especially cleaning and heating, because of increased soap consumption and increased formation of scale in hot water heaters and water pipes. Water used for ordinary household purposes does not become particularly objectionable until it reaches the level of about 100 ppm (Hem, 1959, p. 147). The commonly accepted classification of water hardness is given in the following table:

Classification	Hardness range (ppm)
Soft	60 or less
Moderately hard	61 to 120
Hard	121 to 180
Very hard	More than 180

Industrial Use.

The quality requirements for industrial water range widely and almost every industrial application has different standards. Because of the wide variations of chemical-quality standards for industrial water, only facts and interpretations of a general nature that can be further studied by those who have special requirements are discussed. Water used by industry can be classified into three principal categories—cooling, boiler, and process.

Cooling water is usually selected for its temperature and source of supply, although its chemical quality also is significant. Hardness, iron, and silica may cause a scale which adversely affects the heat exchange surfaces in the cooling process. Corrosiveness is another objectionable feature. Sodium chloride, acids, oxygen, and carbon dioxide are among substances that make water corrosive.

Boiler water for the production of steam must meet rigid chemical-quality requirements. Here the problems of corrosion and incrustation are paramount. The calcium and magnesium content, which causes hardness, greatly affects the industrial value of the water by contributing to the formation of boiler scale. Silica in boiler water also is undesirable because it too forms a hard scale, the scale-forming tendency increasing with pressure in the boiler (Moore, 1940, p. 236).

Process water, that is incorporated into the manufactured product, usually is subject to rigid quality requirements. Quality approaching that of distilled water is required for processes such as the manufacture of textiles, high-grade paper, beverages, and pharmaceuticals, where impurities in the water would seriously affect the quality of the product. Water that is low in dissolved solids and contains little or no iron and manganese, which cause staining, is highly desirable for use as process water.

Irrigation Use.

The suitability of water for irrigation depends on the chemical quality of the water and other factors such as soil texture and composition, types of crops, irrigation practices, and climate. From chemical analysis, it is possible to classify water in terms of suitability for irrigation and to anticipate with some assurance the effect of the water on crops and soil. The most important chemical characteristics pertinent to the evaluation of water for irrigation are the sodium concentration, an index of the sodium or alkali hazards; total concentration of soluble salts, an index of the salinity hazard; residual sodium bicarbonate; and concentration of boron or other elements that may be toxic.

Treatment of Water

Water that does not meet the requirements of a municipal or industrial user commonly can be treated by various methods so that it will become useable. Treatment methods include softening, aeriation, filtration, cooling, diluting, or blending of poor and good quality waters, and addition of chemicals. The limiting factor in treatment is economy. Each water type may require different treatment practices and the treatment should be designed for that particular water. However, once a treatment is established it probably will not have to be changed as the chemical characteristics of uncontaminated water remain fairly constant.

Bacteriological Quality

Surface water generally is considered bacteriologically polluted. Standards for the bacteriological quality of water used for public water supply generally are based on the presence of the coliform group of bacteria in the water.

Coliform organisms are non-pathogenic (not disease-producing) bacteria that are characteristic of human or animal intestinal origin, and are therefore used as indicators of the presence of sewage contaminants. Pathogenic organisms are not easily detected by normal bacteriological laboratory techniques; hence, indicator organisms such as the coliform group, which can be rather easily identified, must be relied upon to detect bacteriological pollution.

The Texas State Department of Health uses the multiple-tube fermentation technique (presumptive and confirmed tests) in bacteriological analysis as an indication of the sanitary quality of water. This technique consists of ascertaining the incidence of coliform organisms in water samples. Water of satisfactory bacteriological quality should be free of coliform organisms.

Compliance with the bacteriological requirements of the U. S. Public Health Service standards is based on examination of samples collected at representative points throughout the distribution system. The minimum number of samples to be collected from the distribution system and examined each month is based on the population served by the system. Limits on the presence of organisms of the coliform group, as indicated by samples examined, are based on the standard portion of sample examined and number of samples examined per month.

*This discussion has been extracted primarily from the following sources: U. S. Public Health Service, 1962; Dillard, 1963; Holloway, 1965; Baker, 1965.

APPENDIX VII

MAXIMUM DISCHARGE AND STAGES, BRAZOS RIVER, WACO, TEXAS

BRAZOS RIVER BASIN

Brazos River at Waco, Tex.

Location.--Lat 31°33'40", long 97°07'45", at Washington Avenue Bridge in Waco, McLennan County, 2½ miles downstream from Bosque River, and at mile 404.

Drainage area.--28,500 sq mi, approximately, of which about 19,260 sq mi contributes directly to surface runoff.

Gage.--Nonrecording September 1898 to March 1918 and May 1922 to February 1925; recording March 1918 to May 1922 and after Feb. 13, 1925. Datum of gage is 356.80 ft above mean sea level, datum of 1929, supplementary adjustment of 1942.

Stage-discharge relation.--Defined by current-meter measurements.

Bankfull stage.--27 ft (U.S. Weather Bureau).

Historical data.--Maximum stage since at least 1847, that of Sept. 27, 1936.

Remarks.--Gage heights for periods Jan. 1, 1912, to Sept. 30, 1912, and May 6, 1922, to Feb. 12, 1925, obtained from U.S. Weather Bureau. Flow partly regulated by reservoirs above station. Only annual peaks are shown.

Peak stages and discharges

Water year	Date	Gage height (feet)	Discharge (cfs)
1884	May 22, 1884	32.03	-
1885	May 28, 1885	34.63	-
1887	May 31, 1887	32.13	-
1890	Apr. 26, 1890	31.43	-
1897	Mar. 29, 1897	32.93	-
1899	June 30, 1899	34.38	117,000
1900	Sept.28, 1900	25.70	69,800
1901	May 19, 1901	14.75	22,600
1902	July 26, 1902	32.1	106,000
1903	Feb. 27, 1903	20.45	43,600
1904	Oct. 1, 1903	14.7	22,400
1905	May 14, 1905	28.6	85,800
1906	June 6, 1906	19.8	40,900
1907	July 15, 1907	11.4	13,500
1908	May 25, 1908	36.7	142,000
1909	June 18, 1909	15.1	23,500
1910	Dec. 2, 1909	16.8	29,200
1911	July 18, 1911	18.5	35,400
1912	Aug. 7, 1912	16.2	24,900
1913	May 7, 1913	14.5	19,000
1914	Dec. 3, 1913	39.7	211,000
1915	Apr. 26, 1915	26.0	73,300
1916	Apr. 2, 1916	33.8	113,000
1917	Oct. 19, 1916	14.32	17,600
1918	Apr. 15, 1918	17.5	30,000
1919	Nov. 9, 1918	36.4	125,000
1920	Oct. 23, 1919	27.9	78,100
1921	June 11, 1921	18.0	31,100
1922	May 10, 1922	35.9	122,000
1923	Apr. 27, 1923	24.6	66,900
1924	Dec. 13, 1923	20.2	41,900
1925	May 9, 1925	21.1	49,300
1926	June 22, 1926	19.30	40,500
1927	June 14, 1927	26.4	62,000
1928	Apr. 4, 1928	18.95	24,800
1929	Sept.13, 1929	20.66	31,300
1930	May 18, 1930	28.90	74,800
1931	Oct. 7, 1930	31.4	93,500
1932	Feb. 19, 1932	26.95	62,500
1933	July 30, 1933	23.05	41,100
1934	Apr. 6, 1934	24.00	45,400
1935	May 19, 1935	34.90	112,000
1936	Sept.27, 1936	40.9	246,000
1937	Oct. 26, 1936	20.3	26,600
1938	Jan. 24, 1938	30.75	88,400
1939	June 20, 1939	24.10	43,500
1940	June 29, 1940	20.78	38,500
1941	May 5, 1941	29.24	68,800
1942	Apr. 25, 1942	35.70	126,000
1943	Oct. 18, 1942	27.68	67,400
1944	May 2, 1944	36.60	137,000
1945	Apr. 22, 1945	36.70	144,000
1946	Mar. 13, 1946	20.73	37,600
1947	Nov. 4, 1946	17.78	29,600
1948	Feb. 26, 1948	20.48	36,800
1949	May 18, 1949	27.27	71,400
1950	Feb. 13, 1950	15.67	16,700
1951	June 13, 1951	15.88	18,300
1952	May 25, 1952	18.13	25,500
1953	May 12, 1953	25.97	61,100
1954	May 17, 1954	17.54	22,600
1955	May 19, 1955	18.68	23,600
1956	May 2, 1956	22.94	46,100
1957	Apr. 20, 1957	32.33	101,000
1958	May 3, 1958	28.10	70,600
1959	June 25, 1959	12.32	10,600
1960	Oct. 5, 1959	29.73	80,900
1961	Jan. 8, 1961	26.82	62,800

Patterson, James L. (1963) Floods in Texas: Texas Water Commission, Bull. 6311, p. B-71.

APPENDIX VIII

MEAN DISCHARGE, BRAZOS RIVER, WACO, TEXAS APRIL-MAY-JUNE 1957

Brazos River at Waco, Tex.

Location.--Lat 31°33'40", long 97°07'45", on right bank at downstream side of pier of Washington Avenue Bridge in Waco, McLennan County, 2-1/2 miles downstream from Bosque River, and at mile 404. Datum of gage is 356.80 ft above mean sea level, datum of 1929, supplementary adjustment of 1942.

Drainage area.--28,500 sq mi, approximately, of which 9,240 sq mi is probably noncontributing.

Gage-height record.--Water-stage recorder graph except for Apr. 1-12 when graph was drawn on basis of gage readings furnished by the U. S. Weather Bureau.

Discharge record.--Stage-discharge relation defined by current-meter measurements. Shifting control method used Apr. 19 to June 30.

Maxima.--April-June 1957: Discharge, 101,000 cfs 10 a.m. Apr. 20 (gage height, 32.33 ft).
1898 to March 1957: Discharge, 246,000 cfs Sept. 27, 1936 (gage height, 40.90 ft, levee on left bank was overtopped and broken by flood).
Maximum stage 1854-97, 34.6 ft May 28, 1885. A stage of 39.7 ft was reached Dec. 3, 1913, when levee on left bank was broken by flood, from information by U. S. Weather Bureau.

Remarks.--Flow largely regulated by Possum Kingdom and Whitney Reservoirs on Brazos River, several small reservoirs in Clear Fork and other basins (combined capacity, 221,800 acre-ft), and Lake Waco on Bosque River (capacity, 22,000 acre-ft); total combined capacity of all reservoirs, about 2,986,000 acre-ft, of which 1,630,500 acre-ft is flood-control storage in Whitney Reservoir. Many small diversions above station for municipal supply, irrigation, and oil field operation do not appreciably affect flow.

Mean discharge, in cubic feet per second, 1957

Day	April	May	June	Day	April	May	June	Day	April	May	June
1	2,080	18,700	54,800	11	1,680	35,300	37,800	21	8,460	38,200	39,200
2	1,900	23,800	39,700	12	1,130	49,000	35,300	22	6,570	36,200	39,200
3	2,380	31,100	36,900	13	1,160	65,500	35,200	23	39,900	39,000	38,500
4	3,100	32,400	39,900	14	444	39,100	27,800	24	37,400	46,300	39,200
5	1,930	17,400	40,500	15	225	11,500	29,500	25	29,300	41,300	39,200
6	365	23,100	38,500	16	1,310	18,200	35,000	26	10,200	45,300	40,500
7	320	25,200	41,200	17	1,310	25,200	37,200	27	50,300	51,100	39,700
8	182	24,900	40,200	18	736	40,900	39,200	28	22,700	56,000	34,700
9	265	26,700	39,300	19	1,630	39,100	35,900	29	21,200	54,000	22,400
10	1,230	27,800	38,900	20	48,000	39,300	38,700	30	13,500	52,500	20,100
								31		52,300	
Monthly mean discharge, in cubic feet per second.									10,360	36,340	37,140
Runoff, in acre-feet.									616,700	2,234,000	2,210,000

Texas Board of Water Engineers (1957) Texas Floods: April-May-June, p. II-32.

APPENDIX IX

STAGE AND DISCHARGE, BOSQUE RIVER SYSTEM

Bosque River near Waco
Location. Lat 31°36'04", long 97°11'36", on downstream side of bridge on Farm Road 1637, 2.8 miles upstream from mouth and 4.7 miles northwest of courthouse in Waco, McLennan County.
Drainage area. 1,655 sq mi.
Average discharge. (6 years) 519 cfs (375,700 acre-ft per year).
Extremes. (1959-65)
Maximum discharge, 69,000 cfs Oct. 4, 1959 (gage height, 39.8 ft, from floodmark), from rating curve extended above 51,000 cfs on basis of computation of peak flow thru gates at old Lake Waco; no flow at times in 1963 and 1964.
Maximum stage since at least 1880, 44.5 ft Sept. 27, 1936, from information by local resident (discharge, 96,000 cfs). Maximum stage is probably the result of backwater from Brazos River because the discharge on Apr. 22, 1945 (140,000 cfs) and Apr. 20, 1957 (103,000 cfs) exceed the discharge corresponding to the maximum stage. The discharge for the 1936, 1945 and 1957 floods obtained from rating curve for taintor gates at old Lake Waco.

South Bosque River near Speegleville, Texas
Location. Lat 31°31', long 97°15', at highway bridge about half a mile downstream from Hog Creek, 2 miles south of Speegleville, McLennan County, about 3 miles upstream from confluence with North Bosque River, and about 6 miles west of Waco.
Drainage area. 388 sq mi.
Extremes. (1924-30)
Maximum discharge, 54,500 cfs June 14, 1927 (gage height 29.37 ft), from rating curve extended above 3,000 cfs on the basis of slope-area measurement of peak flow; no flow at times.

Hog Creek near Crawford, Texas
Location. Lat 31°33'20", long 97°21'22", on downstream side of bridge on Farm Road 185, 5.6 miles east of Crawford, McLennan County, and 9.8 miles upstream from confluence with South Bosque River.
Drainage area. 78.2 sq mi.
Average discharge. (6 years) 47.4 cfs (34,320 acre-ft per year).
Extremes. (1959-65)
Maximum discharge, 15,400 cfs Oct. 4, 1959 (gage height 14.31 ft); no flow Sept. 1, 1959 and days each year 1963-64.
Maximum stage since 1900, 17.5 ft Sept. 26, 1936. Flood in April or May 1957 reached a stage of 15.7 ft (from information by local residents).

Middle Bosque River near McGregor, Texas
Location. Lat 31°30'33", long 97°21'56", on downstream side of bridge on county road, 1,100 ft downstream from Pecan Creek, 5.2 miles northeast of McGregor, McLennan County, and 8.2 miles upstream from confluence with South Bosque River.
Drainage area. 182 sq mi.
Average discharge. (6 years) 105 cfs (76,020 acre-ft per year).
Extremes. (1959-65)
Maximum discharge, 32,600 cfs June 16, 1964; no flow at times in 1960-64.
Historical flood information begins with flood in 1889 which reached a stage of 28.5 ft. Flood in 1957 reached a stage of 28.2 ft, and floods in 1913 and 1942 or 1943 reached a stage of about 28 ft (from information by local residents).

North Bosque River at Valley Mills, Texas
Location. Lat 31°40'10", long 97°28'09", on right bank at downstream side of bridge on Farm Road 56, about 0.8 mile downstream from Thompson Hollow and 0.8 mile north of intersection of State Highway 6 and Farm Road 56 in Valley Mills, Bosque County.
Drainage area. 1, 150 sq mi.
Average discharge. (6 years) 235 cfs (170,100 acre-ft per year).
Extremes. (1959-65)
Maximum discharge 107,000 cfs Oct. 4, 1959 (gage height, 40.22 ft, from flood mark), from rating curve extended above 28,200 cfs on basis of slope-area measurement of 107,000 cfs; no flow Oct. 5-12, 1963.
Maximum stage since at least 1868, 43 ft in May 1908, and floods in Sept. 1936 and Apr. 1945 reached a stage of about 38 ft (from information by local residents).

North Bosque River near Clifton, Texas
Location. Lat 31°47'10", long 97°34'00", at bridge on Farm Road 219, 0.5 mile northeast of Clifton, Bosque County, and 2.9 miles downstream from Meridian Creek.
Drainage area. 972 sq mi.
Average discharge. (42 years) 199 cfs (144,000 acre-ft per year).
Extremes. (1923-65)
Maximum discharge, 92,800 cfs Oct. 4, 1959 (gage height, 34.88 ft) from rating curve extended above 34,000 cfs on basis of contracted-opening measurement of 92,800 cfs; no flow at times.
Maximum stage since at least 1854, that of Oct. 4, 1959. Flood of May 9, 1922, reached a stage of about 32 ft (from information by local residents).
*U. S. Geological Survey and Texas Water Development Board.

APPENDIX X

BOSQUE RIVER WATER QUALITY
(parts per million)

Discharge (cfs)	SiO_2	Fe	Ca	Mg	Na & K	HCO_3	SO_4	Cl	F	NO_3	Total dissolved solids	Hardness as $CaCO_3$ CaMg	Specific conductance (micromhos at 25°C)	pH	Date
Lake Waco water, untreated[1]															
—	7.4	0.3	52.9	4.5	31.3	180	37.5	23.0	0.31	0.31	267.4	150.6[2]	—	8.0	4/9/62
North Bosque River near Clifton, Bosque County[3]															
4.12	14.0	—	68	7.2	24	228	22	26	0.4	4.8	278	199	462	7.0	8/29/62
181	6.2	—	64	22	63	252	57	85	0.4	0.2	422	250	741	7.2	4/30/63
Middle Bosque River near McGregor, McLennan County[3]															
96.0	8.9	—	70	2.8	9.8	199	19	12	0.3	8.6	229	186	398	7.0	12/1/61
0.5	14.0	—	44	2.5	12	132	19	12	0.3	0.0	169	120	281	7.1	7/31/62
Tonk Creek west of Crawford, Highway 185[1]															
—	6.3	0.05	68.0	8.1	37.15	208.6	62	25	—	2.5	205.4	202	—	8.3	2/25/64
Tonk Creek below falls, Tonk Park[1]															
—	5.9	0.03	46.4	6.8	43.59	138.1	72	22	—	1.37	171.2	134	—	8.4	2/25/64
Wasp Creek south of Crawford, Highway 317[1]															
—	6.1	0.06	72.0	7.6	34	170.8	58	27	—	5.5	212.6	220	—	8.5	2/25/64
Harris Creek west of McGregor[1]															
—	8.8	0.02	80.0	3	39.45	225.7	74	23	—	4.1	239.7	210	—	8.1	2/25/64
Harris Creek east of McGregor[1]															
—	7.7	0.03	80.0	7.35	58.84	274.5	67	41	—	6.5	342.4	230	—	8.2	2/25/64
Harris Creek above junction with South Bosque River[1]															
—	6.0	0.02	79.2	5.4	64.87	239.1	58	43	—	7.0	333.3	220	—	8.5	2/25/64
A branch of the South Bosque River south of McGregor, Highway 317[1]															
—	—	—	—	—	—	290.3	—	43	—	—	376.2	—	—	8.5	2/29/64

[1] Analysis by Waco City Water Department.
[2] Hardness calculated.
[3] Analysis from Texas Water Development Board.

APPENDIX XI

MAXIMUM DISCHARGE AND GAGE HEIGHTS, BOSQUE WATERSHED

South Bosque River near Speegleville, Texas

Location. Lat 31°31', long 97°15', at halfway bridge half a mile downstream from Hog Creek, 2 miles south of Speegleville, McLennan County, 3 miles upstream from confluence with North Bosque River, and 6 miles west of Waco, Tex.
Drainage area. 388 sq mi.
Gage. Nonrecording. Altitude of gage is 420 ft (from topographic map).
Stage-discharge relation. Defined by current-meter measurements below 6,000 cfs and by slope-area measurement at 54,500 cfs.
Remarks. Only annual peaks are shown.

Peak stages and discharges

Water year	Date	Gage height (feet)	Discharge (cfs)	Water year	Date	Gage height (feet)	Discharge (cfs)
1900	—	31.5	—	1927	June 14, 1927	29.37	54,500
1924	May 26, 1924	a17.75	15,600	1928	June 4, 1928	20.26	20,900
1925	Sept 12, 1925	7.37	1,520	1929	May 28, 1929	11.10	5,480
1926	Apr. 21, 1926	26.0	38,400	1930	May 10, 1930	b11.80	6,350

a Maximum observed during period March to September 1924.
b Maximum observed during period October 1929 to May 1930.

North Bosque River near Clifton, Texas

Location. Lat 31°47'10", long 97°34'00", near left bank on downtown side of left pier of bridge on State Highway 215, 0.5 mile northeast of Clifton, Bosque County, and 2.9 miles downstream from Meridian Creek.
Drainage area. 971 sq mi; 957 sq mi at site 1.1 miles upstream.
Gage. Nonrecording prior to Oct. 1, 1955, Apr. 23, 1957, to Mar. 26, 1958, Oct. 1, 1959, to Sept. 30, 1960. Recording Oct. 1, 1955, to Apr. 22, 1957, and Mar. 27, 1958, to Sept. 30, 1959. At site 1.1 miles upstream at datum 17.02 ft higher October 1923 to Sept. 30, 1955, Apr. 23, 1957, to Mar. 26, 1958. Datum of gage is 605.43 ft above mean sea level, datum of 1929, supplementary adjustment of 1942.
Stage-discharge relation. Defined by current-meter measurements below 40,000 cfs and by contacted-opening measurement at 92,900 cfs.
Bankfull stage. 32 ft.
Historical data. Flood of Oct. 4, 1959, is the greatest since at least 1854.
Remarks. Flow from 46.2 sq mi above station partly controlled by 13 flood-detention reservoirs, built 1951-57. Base for partial-duration series, 8,300 cfs. Only annual peaks are shown prior to 1948.

Peak stages and discharges

Water year	Date	Gage height (feet)	Discharge (cfs)	Water year	Date	Gage height (feet)	Discharge (cfs)
1887	August 1887	a27	—	1949	Apr. 20, 1949	6.89	9,550
1922	May 9, 1922	b25	—		May 17, 1949	10.20	15,200
1924	Apr. 26, 1924	9.65	14,300	1950	Sept. 5, 1950	7.04	9,750
1925	May 10, 1925	5.98	7,760	1951	June 3, 1951	4.26	4,100
1926	Apr. 10, 1926	7.08	10,400	1952	Apr. 21, 1952	8.10	11,900
1927	May 13, 1927	10.15	15,200		May 24, 1952	21.60	35,400
1928	Apr. 4, 1928	8.56	12,700	1953	Nov. 25, 1952	4.25	3,990
1929	Sept. 8, 1929	16.8	26,800	1954	June 16, 1954	4.48	4,570
1930	May 18, 1930	12.00	18,300	1955	May 19, 1955	14.0	21,300
1931	Oct. 6, 1930	16.30	25,900		Sept. 23, 1955	7.66	11,100
1932	Feb. 18, 1932	15.4	24,300	1956	May 2, 1956	27.82	29,900
1933	May 25, 1933	13.80	21,400	1957	Apr. 21, 1957	—	c17,000
1934	Apr. 6, 1934	8.20	12,000		Apr. 23, 1957	—	c36,000
1935	May 18, 1935	21.3	38,300		Apr. 27, 1957	22.48	37,400
1936	Sept. 27, 1936	19.8	32,400		May 3, 1957	18.80	29,800
1937	Oct. 25, 1936	11.20	16,900		May 13, 1957	18.4	29,100
1938	Jan. 23, 1938	21.82	38,500		May 18, 1957	11.15	16,700
1939	June 19, 1939	15.46	24,500	1958	Apr. 30, 1958	17.55	14,800
1940	Apr. 7, 1940	4.68	4,970		May 2, 1958	28.60	32,200
1941	May 5, 1941	22.10	36,400	1959	June 5, 1959	11.45	6,280
1942	Sept. 7, 1942	17.70	27,900	1960	Oct. 4, 1959	34.88	92,800
1943	Oct. 17, 1942	13.30	20,100		Jan. 5, 1960	13.70	9,210
1944	May 2, 1944	21.9	36,000	1961	Jan. 7, 1961	18.76	14,900
1945	Apr. 22, 1945	23.2	39,000		Jan. 12, 1961	17.96	13,800
1946	Mar. 13, 1946	8.65	12,800		Feb. 5, 1961	18.66	16,000
1947	Nov. 4, 1946	5.75	7,270		Feb. 20, 1961	13.40	8,820
1948	Feb. 25, 1948	19.9	31,900		June 18, 1961	13.0	8,300
	May 11, 1948	8.05	11,700				
	June 24, 1948	8.48	12,600				

a About 34 ft, present site and datum.
b About 32 ft, present site and datum.
c Computed on basis of comparison with Nolands River at Blum, Tex.
From Patterson, James L. (1963) Floods in Texas: Texas Water Commission, Bull. 6311, p. B-70.

Patterson, James L. (1963) Floods in Texas: Texas Water Commission, Bull. 6311, p. B-70

GLOSSARY*

ACRE-FOOT. The quantity of water required to cover one acre to a depth of one foot; equivalent to 43,560 cubic feet.

AQUIFER. A geologic formation, a group of formations, or a part of a formation that is water-bearing; use of the term is usually restricted to those water-bearing units capable of yielding water in sufficient quantity as to constitute a usable supply.

CUBIC FEET PER SECOND. cfs. A unit rate of discharge of a flowing liquid, in a stream channel or through a conduit or other structure, which is equivalent to flow at a velocity of one foot per second through a section having a cross-sectional area of one square foot.

DISCHARGE. The rate of flow at a particular instant in terms of volume per unit of time.

DRAINAGE BASIN. A part of the surface of the lithosphere that is occupied by a drainage system or contributes surface water to that system.

GROUND WATER. That part of the subsurface water which is in the zone of saturation.

HYDROGRAPH. A graph showing some property of water with respect to time (i.e. flow, velocity, stage).

METEORIC WATER. That water which occurs in or falls from the atmosphere.

PARTS PER MILLION. ppm. One part by weight of an ion to a million parts by weight of water; 1 ppm=1 mg/liter.

PRECIPITATION. The discharge of water in liquid or solid state (dew, rain, snow, hail, sleet) from the atmosphere to a land or water surface.

RUNOFF. The discharge of water through natural surface channels. In the general sense, it is defined as that portion of precipitation which is not absorbed by the deep strata but finds its way into the streams after meeting the persistent demands of evapotranspiration including interception and other losses.

SEDIMENT. Solid material carried in suspension in a river or stream or that which has been carried in suspension from its site of origin and deposited elsewhere.

SEDIMENTATION. The deposition of sediments.

SURFACE WATER. Water that flows or rests upon the surface of the earth. (In this study meteoric water is included as surface water).

WATER YEAR. The year extending from October 1 to September 30. October 1, 1959 to September 30, 1960 is water year 1960.

*Definitions derived primarily from Texas Water Development Board publications.

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