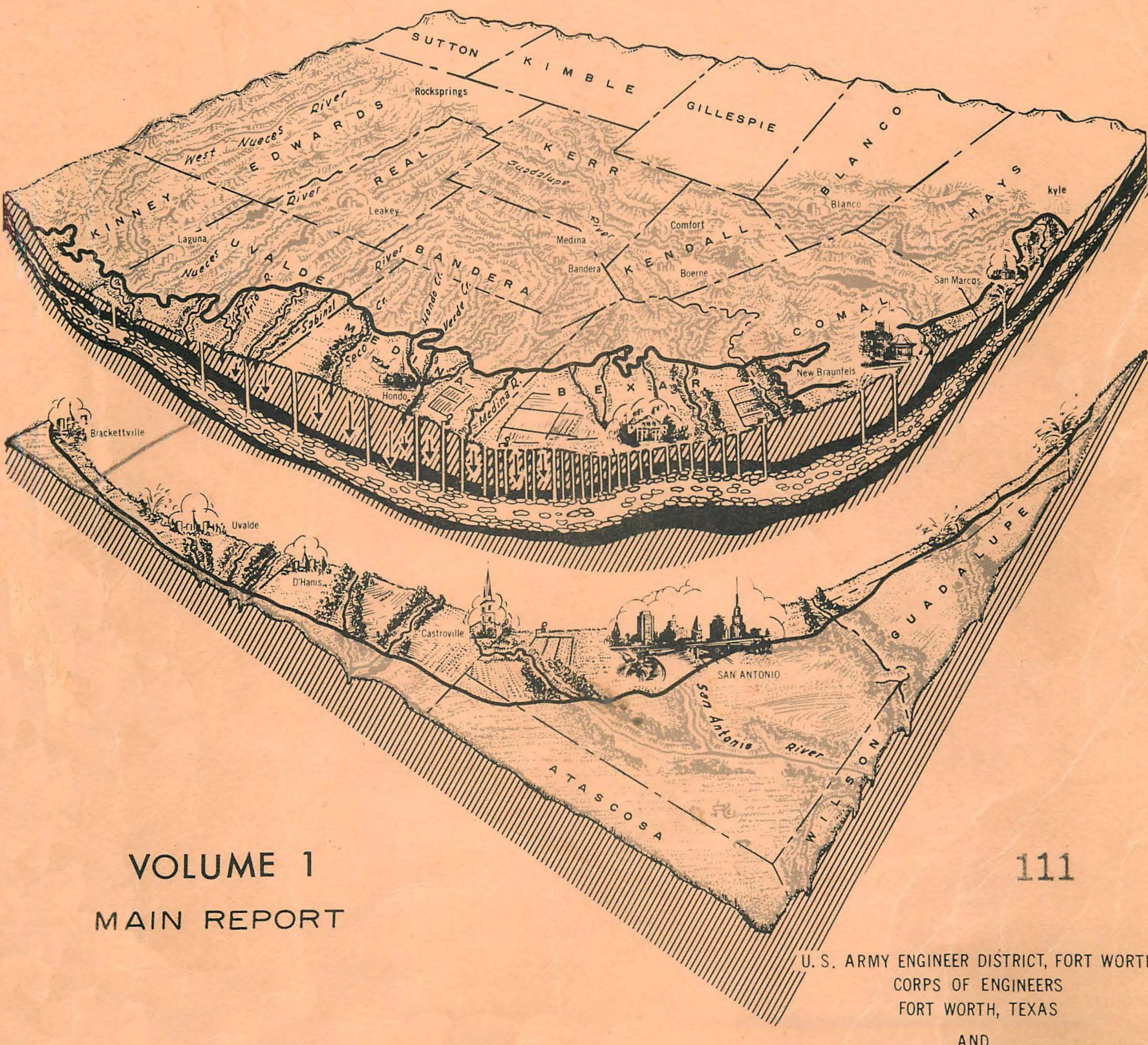
SURVEY REPORT
ON
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO AND NUECES RIVERS AND TRIBUTARIES, TEXAS.



VOLUME 1

MAIN REPORT

111

U. S. ARMY ENGINEER DISTRICT, FORT WORTH
CORPS OF ENGINEERS
FORT WORTH, TEXAS

AND

EDWARDS UNDERGROUND WATER DISTRICT
SAN ANTONIO, TEXAS

SURVEY REPORT
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SYLLABUS

The Edwards Underground Reservoir, a limestone aquifer that stretches about 175 miles across south-central Texas at the foot of the Edwards Plateau, provides the water supply in this portion of three river basins which includes many farms and ranches, five large military installations, and seventeen cities and communities, the largest of which is the city of San Antonio. Because of the rapid economic growth in this area, the water demands on the underground reservoir are exceeding the dependable yield of the resource.

Streams that flow through the hill and canyon country of the Edwards Plateau in the Guadalupe, San Antonio, and Nueces River Basins recharge the underground reservoir as they flow across the outcrop of the Edwards limestone in the Balcones fault zone. Floods on these streams cause extensive damage to cities, farms, and ranches south of the Balcones escarpment and are the source for increased recharge through upstream reservoir control.

The major portion of the recharge to the underground reservoir comes from streams in the Nueces and San Antonio River Basins, but the major portion of the discharges from the aquifer occurs through many large wells in the San Antonio area and several large springs in the San Antonio and Guadalupe River Basins. For this reason, the 14 counties in the watershed of the artesian reservoir were considered as a unit in formulating a water supply plan for the area.

The plan of improvement would provide for construction of Montell Reservoir on the Nueces River, Concan Reservoir on the Frio River, and Sabinal Reservoir on the Sabinal River with joint-storage for flood control and recharge purposes. A small conservation pool would be provided in the Montell Reservoir for a downstream water supply. Two reservoir projects are also proposed in the Guadalupe River Basin to provide a supplemental surface water supply for the Edwards Reservoir area. Cloptin Crossing Reservoir, a multiple-purpose project on the Blanco River, is proposed for Federal construction. Dam No. 7 Reservoir on the Guadalupe River is proposed for construction by local interests for water conservation purposes.

The proposed plan of improvement would meet the municipal, rural, industrial, military, thermal power, and irrigation demands of the Edwards Reservoir area to approximately the year 2000. To meet the anticipated future water demands beyond this date will require more adequate use of return flows and development of additional water supply outside the Edwards Reservoir area. The estimated total first cost of the four reservoir projects proposed for authorization and construction by the Federal Government is $84,048,000, of which $51,620,000 would be reimbursable to the United States. The annual operation, maintenance, and major replacement costs are estimated at $379,400, of which $147,300 would be the responsibility of local interests.

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GUADALUPE, SAN ANTONIO AND NUECES RIVERS
AND TRIBUTARIES, TEXAS

MAIN REPORT

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CORPS OF ENGINEERS
FORT WORTH, TEXAS

AND

THE EDWARDS UNDERGROUND WATER DISTRICT
SAN ANTONIO, TEXAS

December 22, 1964

SUBJECT: Survey Report on the Edwards Underground Reservoir, Guadalupe, San Antonio, and Nueces Rivers and Tributaries, Texas

THROUGH: Division Engineer
U. S. Army Engineer Division, Southwestern
Dallas, Texas

TO: Chief of Engineers
Department of the Army
Washington, D. C. 20315

INTRODUCTION

1. AUTHORITY.-- This report has been prepared in response to the Congressional authorization contained in section 209 of Public Law 86-645, 86th Congress, which was approved on July 14, 1960. Section 209 is quoted as follows:

> "The Chief of Engineers, under the direction of the Secretary of the Army, is authorized and directed to cause an investigation and study to be made, in cooperation with appropriate agencies of the State of Texas, with a view to devising effective means of accomplishing the recharge and replenishment of the Edwards Underground Reservoir as a part of plans for flood control and water conservation in the Nueces, San Antonio, and Guadalupe River Basins of Texas: _Provided,_ That the State of Texas or its agencies contribute towards the cost of such study, such funds or services as the Secretary of the Army may deem appropriate; _Provided further_, that the findings of such study shall

be presented in a joint report signed by the appropriate representatives of the Governor of Texas and the Chief of Engineers."

2. The Edwards Underground Water District is the state agency designated by Governor Price Daniel on November 1, 1960, to cooperate with the Corps of Engineers in this study. On August 16, 1961, a "Memorandum of Understanding" between the Corps and the Water District was approved by the two agencies. This memorandum set forth the obligations each was to share during preparation of the report, including local interest participation of 40 percent of the cost of the study. The memorandum was approved by the Secretary of the Army on June 8, 1961.

3. SCOPE.- This report presents the results of an investigation of the problems associated with the water resources of the Edwards Underground aquifer and the portions of the three river basins which contribute to the recharge of the Edwards aquifer. The projects investigated were studied with a view toward devising an effective means of accomplishing the recharge and replenishment of the Edwards Underground Reservoir as a part of plans for flood control and water conservation in the Guadalupe, San Antonio, and Nueces River Basins of Texas. The plan of improvement presented herein can serve as a guide to the development and control of the water and related land resources of the study area within the framework of a state water plan and is based upon analysis of detailed technical data and investigations presented in the various appendixes to this report. The elements of the plan recommended for authorization were developed in consonance with the overall plan taking into consideration current and projected conditions and economic justification.

4. PURPOSE OF THE INVESTIGATION.- The Edwards Reservoir area comprises the northern 6,400 square miles of three major river basins in the western portion of south-central Texas, which cover some 27,300 square miles. The area's most valued natural water resource, the Edwards Underground Reservoir, lies along the southern boundary of this area and provides the only existing water supply to many ranches, farms, industries, military installations, and a number of communities, the largest of which is the city of San Antonio with an estimated 1962 population in excess of 700,000 people. In addition, discharges from this reservoir through springs provide a substantial amount of the base flow of the Guadalupe and San Marcos Rivers, which extends its area of influence southward to the Gulf of Mexico. The accelerated growth of cities, industries, military installations, and irrigation in the region in recent years, coupled with extremes of floods and droughts, has multiplied water problems which affect the economic well-being of all citizens throughout this vast area. Responsible local, State, and Federal agencies are keenly aware of the needs for preserving the Edwards Reservoir, protecting the area from

damaging floods and providing the region with a dependable future water supply. For these reasons they have requested that this investigation be made.

5. ARRANGEMENT OF REPORT.- The sections of the report which follow present the results and conclusions of the investigations and present the recommendations of the District Engineer, based on analysis of technical data and studies reported upon in the following appendixes of this report:

Appendix I	-	Project Formulation
Appendix II	-	Hydrology and Hydraulic Design
Appendix III	-	Geology
Appendix IV	-	Flood Control Economics
Appendix V	-	Economic Base Study
Appendix VI	-	Recreation and Fish and Wildlife
Appendix VII	-	Comments of Other Agencies

6. HISTORY OF INVESTIGATIONS.- Because of its importance, the Edwards limestone reservoir has been the most intensively studied aquifer in Texas. From 1900 to the present, many investigations have been made of the geologic and hydrologic character of this underground reservoir. In recent years intensive studies have been conducted by private consultants and by the U. S. Geological Survey in cooperation with the Texas Water Commission, the San Antonio City Water Board, the San Antonio City Public Service Board, the Bexar County Metropolitan Water District, and the Edwards Underground Water District.

7. In 1949 the San Antonio City Water Board requested the cooperative assistance of the Texas Water Commission and the U. S. Geological Survey in making a comprehensive study of the ground water resources of the San Antonio area (covering all or parts of several counties), paying particular attention to the Edwards limestone aquifer. The studies thus initiated have been more or less continuous since that time and reports have been published periodically by the Water Commission concerning the results of studies made and data obtained.

8. Although the Corps of Engineers has not previously prepared a report dealing in particular with the Edwards Reservoir area, and more specifically with the aquifer itself, two major river basin reports and one interim report have been prepared on the region in recent years. One of the reports is entitled "Report on Survey of Guadalupe and San Antonio Rivers and Tributaries, Texas, for Flood Control and Allied Purposes" submitted by the District Engineer in 1950. The report was printed as House Document 344, 83d Congress. Based on recommendations of this report, Congress, by the Flood Control Act of 1954, authorized the construction of Gonzales Reservoir on the San Marcos River, the San Antonio Channel Improvement project on the San Antonio River and its tributaries within the city of San Antonio, the Kenedy Channel

Improvement project on Escondido Creek in the city of Kenedy, and modifications to the Canyon Reservoir on the Guadalupe River, previously authorized by the River and Harbor Act of 1945. The Canyon Reservoir has been completed and the San Antonio Channel Improvement project is under construction. Gonzales Reservoir is in an inactive status and the Kenedy Channel Improvement project has been deauthorized because of the lack of assurance of local cooperation.

9. A second report entitled "Blieders Creek Watershed Flood Protection - New Braunfels, Texas" was submitted by the District Engineer on June 10, 1958. Based on the recommendations included in this report, the Blieders Creek Flood Protection project was authorized by Congress through Public Law 86-645 on July 14, 1960. This project is currently in the advance planning stage.

10. A resolution of the Committee on Public Works of the House of Representatives dated August 15, 1961 authorized a restudy of the Guadalupe River Basin in the interest of flood control in the vicinity of San Marcos. Funds for this investigation have been budgeted for fiscal year 1965. In addition, funds have been allotted and investigations by the Galveston District are proceeding on a channelization feasibility study of the San Antonio River.

11. In addition to the above studies concerning the Guadalupe and San Antonio River Basins the District Engineer, under authority contained in the Flood Control Act of 1936, investigated the water problems on the Nueces River and Tributaries, Texas, in the interest of flood control and allied purposes, and in July 1944 submitted to higher authority a report of survey in which were included the results of the study. The report was returned to the District Engineer on May 29, 1946 for review and revisions to reflect any changed economic conditions in the Nueces Basin. The restudy of the area has not been initiated to date due to lack of funds. The investigation made in connection with the report of survey dated July 1944 indicated that a local flood protection project at Three Rivers was justified. However, based on developments in the watershed, further investigation will be required to determine the current feasibility of the desired improvements. Authority to restudy the water problems in the area of Three Rivers is contained in Public Law 88-367, approved by Congress on July 9, 1964.

12. In conjunction with its "Texas Basins Project" investigation, the Bureau of Reclamation is currently making a study of a number of reservoir sites in the Guadalupe, San Antonio, and Nueces River Basins. Among the reservoir sites being investigated are those proposed in the master plans of the Guadalupe-Blanco River Authority and the Nueces River Conservation and Reclamation District.

13. The Soil Conservation Service has published work plans on Martinez, Salado, and York Creek watersheds within the Edwards Reservoir area. The reports propose 38 floodwater retarding structures in the vicinity of San Antonio. On July 1, 1964 the Service had completed 18 projects on two watersheds in the study area.

14. The "Report of the U. S. Study Commission - Texas," published in March 1962 presents a plan which provides for development of the land and water resources to meet the projected needs of the eight river basins studied. In the development of plans for the Nueces, San Antonio, and Guadalupe River Basins, the Study Commission recognized the importance of the Edwards aquifer and recommended the construction of the Concan Reservoir on the Frio River and the Sabinal Reservoir on the Sabinal River for recharge purposes. The Study Commission also recommended the construction of a number of other reservoirs in the three basins, including Ingram, Cloptin Crossing, Lockhart, Blieders Creek, Cuero (stages I and II) and Confluence Reservoirs in the Guadalupe River Basin; Cibolo, Ecleto, and Goliad Reservoirs in the San Antonio River Basin; and Crystal City, Caimanche, Cotulla, Fowlerton, Choke Canyon, and enlargement of Wesley Seale Reservoir (Corpus Christi) in the Nueces River Basin.

15. The Texas Water Commission in 1961 published a report entitled "A Plan for Meeting the 1980 Water Requirements of Texas." The report recommends the construction of Cuero I Reservoir and Salt Water Barrier Reservoir on the Guadalupe River; East Lake, Cibolo, Ecleto, and Goliad Reservoirs in the San Antonio River Basin; and enlargement of Wesley Seale Reservoir (Corpus Christi) on the Nueces River.

16. The "Supplement to the Initial Plan of Development of the Guadalupe-Blanco River Authority," published in May 1961 by the Guadalupe-Blanco River Authority was prepared by Forrest and Cotton, Inc., Consulting Engineers. The supplement presents a plan of development of the water resources of the Guadalupe River Basin. The report also recognizes the importance of the Edwards Underground Reservoir and its contribution to the water resources of the Guadalupe River Basin. To supplement the authorized Canyon and Blieders Creek Reservoirs, the Authority proposes the construction of Dam No. 7, Cloptin Crossing, Lockhart, Cuero (stages I and II), and Salt Water Barrier Reservoirs.

17. In March 1958 the Nueces River Conservation and Reclamation District published the "Nueces River Master Plan Study," prepared by Freese and Nichols, Consulting Engineers. This master plan study presents a plan of development for the Nueces River Basin. It proposes the construction of Concan and Sabinal Reservoirs for recharge of the Edwards Underground Reservoir. It also proposes the construction of the Tom Nunn Hill, Cotulla, Fowlerton, and Whitsett Reservoirs and the enlargement of Wesley Seale Reservoir.

18. The plans and reports mentioned above are the most important of the many investigations which have been made concerning the Edwards limestone aquifer and other water resources of the Guadalupe, San Antonio, and Nueces River Basins. Several state and local agencies have initiated and completed studies of a specific nature concerning the ground water resources of the area.

19. PUBLIC HEARING AND IMPROVEMENTS DESIRED.- During the initial stages of this study a public hearing was held at San Antonio, Texas, on December 7, 1961 to afford all interested parties an opportunity to state and describe their water problems, and to express their views concerning the character and extent of improvements desired.

20. The local interests through the public hearing, correspondence, and various conference discussions have expressed the desire for a Federal improvement project in the Edwards Reservoir area to include the following features: (a) recharge reservoirs at the Concan site on the Frio River and at the Sabinal site on the Sabinal River; (b) construction of reservoirs for flood control and water conservation at the Comfort site on the Guadalupe River and at the Cloptin Crossing site on the Blanco River; (c) recharge structures on Cibolo and Comal Creeks; (d) preservation of Comal Springs; (e) diversion of water from the upper Guadalupe River into the Medina watershed; (f) recognition of prior water rights of downstream areas of the Guadalupe and Nueces Rivers; and (g) preservation of the Edwards Reservoir and water supply for the city of San Antonio.

21. The Texas Water Commission has publicly expressed its policy that all future reservoir projects planned in the state for flood control should also contain the maximum practical conservation storage for water supply to meet the anticipated future demands for municipal, industrial, and irrigation purposes; for fish and wildlife and general recreation, and for water quality control purposes.

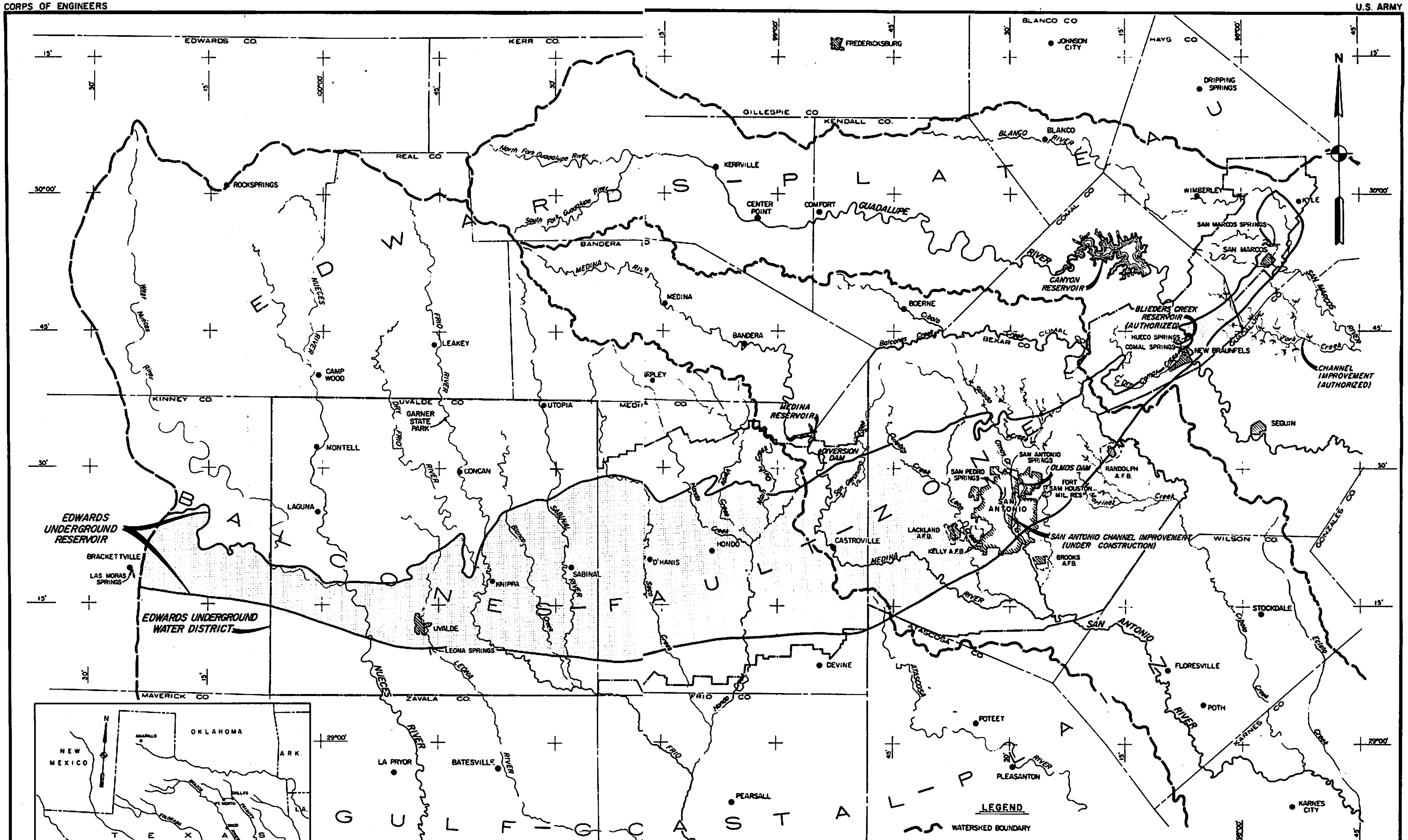
DESCRIPTION OF THE EDWARDS RESERVOIR AREA

22. LOCATION.- The Edwards Underground Reservoir is a segment of an aquifer that stretches some 250 miles from Austin westward to Comstock. That segment known as the Edwards Reservoir lies between the cities of Kyle and Brackettville, where hydraulic divides or barriers control the waterflow in the "San Antonio Area." The Texas Water Commission has designated the boundary of the reservoir in Kinney, Uvalde, Medina, Bexar, Comal and Hays Counties. The center-line of the aquifer connects roughly the cities of Kyle, San Marcos, New Braunfels, San Antonio, Hondo, Uvalde, and Brackettville. Its overall length is about 175 miles and it varies in width from 5 to 40 miles. This aquifer provides the water supply for some 850,000 people in three major river basins, including the city of San Antonio, the third largest city in the state. It supplies water to several thousand wells and several large springs, including Comal Springs at New Braunfels, the largest in the southwest. The general location of the reservoir is shown on plate 1.

23. THE EDWARDS FORMATION.- The Edwards Underground Reservoir lies in the Balcones Fault Zone, a zone of major faulting which separates two distinct physiographic provinces known as the Edwards Plateau on the north and west and the Gulf Coastal Plain on the south and east. The principal water-bearing formations that make up the main aquifer are rocks of an ancient geologic age known as the Cretaceous period. They are known as the Edwards and associated limestones, a part of the Comanche series which has a maximum thickness of some 2,300 feet.1/* The Edwards and associated limestones consist of three principal formations, from oldest to youngest, the Comanche Peak, Edwards and Georgetown limestones. These limestones are usually considered as a geologic unit since they are comparatively thin and are not generally separated by any confining beds. The combined thicknesses average between 350 and 500 feet in the artesian portion of the aquifer.

24. EDWARDS PLATEAU.- The vast Edwards Plateau north of the Balcones escarpment is the recharge area of the Edwards limestone aquifer. It covers some 6,400 square miles. Throughout most of the plateau, the rough to rolling "hill country" rises from about elevation 1000 to about 2700 feet above sea level along its northern edge. The Edwards limestone, named for the Plateau, covers most of the surface throughout the Edwards Plateau except in portions of the Guadalupe and San Antonio River Basins where the plateau has been dissected by the streams and only remnants of the Edwards limestone remain to cap the hills. In contrast to most of the Edwards Plateau country of rolling

*The numbers 1/, etc., pertain to specific references in the bibliography attached to the back of this volume.



GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR

EXISTING AND AUTHORIZED IMPROVEMENTS

SCALE IN MILES

U.S. ARMY ENGINEER DISTRICT, FORT WORTH — DEC 1964

SUBMITTED / APPROVAL RECOMMENDED / APPROVED

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD. 707-2

hills and wide, flat mesas, portions of the Guadalupe Basin are characterized by sharp divides. The hills have "stairstep" terraces formed by alternating beds of hard, massive Glen Rose limestone and more easily eroded clays, shales, and marls. Results of intensive erosion effects are apparent on the land surfaces throughout the plateau area. The soils are thin and have a limestone base but are sufficient to provide for the growth of cedar, small oak, mesquite, and extensive ranges of grass and weeds.

25. BALCONES FAULT ZONE.- The Balcones Fault zone, which extends some 250 miles across the western portion of central Texas at the foot of the Edwards Plateau, is an intricate system of major and minor faults or shearing of underground strata, and minor folding or rock warping. These faults are roughly parallel, have a downthrow to the south and southeast and a total displacement as great as 1500 feet in Comal County.[2/] The zone varies in width from 5 to 40 miles but averages approximately 20 miles. The direction of movement of ground water is largely controlled by these faults. Historically, the Balcones escarpment is believed to have been formed in ancient times by the tensional stresses accompanying the gradual sinking of the Gulf Coastal Plain toward the sea. The "upthrown," or upper portion of the faulted area, has further been described as being a line of southward or eastward facing hills, which in some locations have the appearance of balconies when viewed from the plain below. It is believed that this accounts for its Spanish name, "balcones."[3/] Typical sections across this zone are shown in figure 4.

26. GULF COASTAL PLAIN.- South of the Balcones escarpment, the Gulf Coastal Plain stretches as a gently rolling prairie southward to the Rio Grande and the Gulf of Mexico. This area is also known as the Rio Grande Plain and is frequently referred to as the "brush country," since the vegetal cover on a significant portion of the plains consists of low brush and mesquite trees. This description, however, does not hold true for the lush "winter garden" area along the Nueces River near the cities of Crystal City and Carrizo Springs nor for areas along the Leona River where extensive irrigation has been developed. The elevation of the plains ranges from about 700 feet along the foot of the Balcones escarpment to sea level at the Gulf. The streams in this area are characterized by wide valleys and gentle sloping banks. Soils in this area are characteristically sedimentary, or soils washed down from the "hill country" and deposited as new earth.

27. THE UNDERGROUND RESERVOIRS.- Two distinct ground water reservoirs have been formed in the Edwards limestone formation, one an unconfined reservoir in the Edwards Plateau area and the other an artesian reservoir in the Balcones fault zone. In the Edwards Plateau area, the rock formations slope gently to the south and southeast. The slope is equal to or slightly more than the natural slope of the

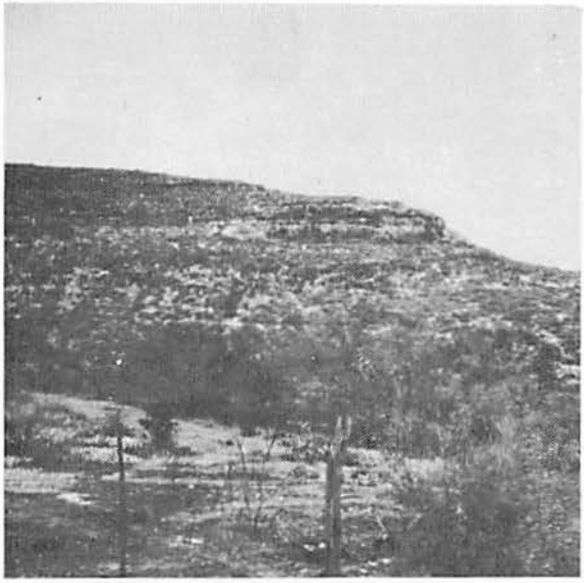


FIGURE I

EDWARDS PLATEAU

NUECES RIVER BASIN

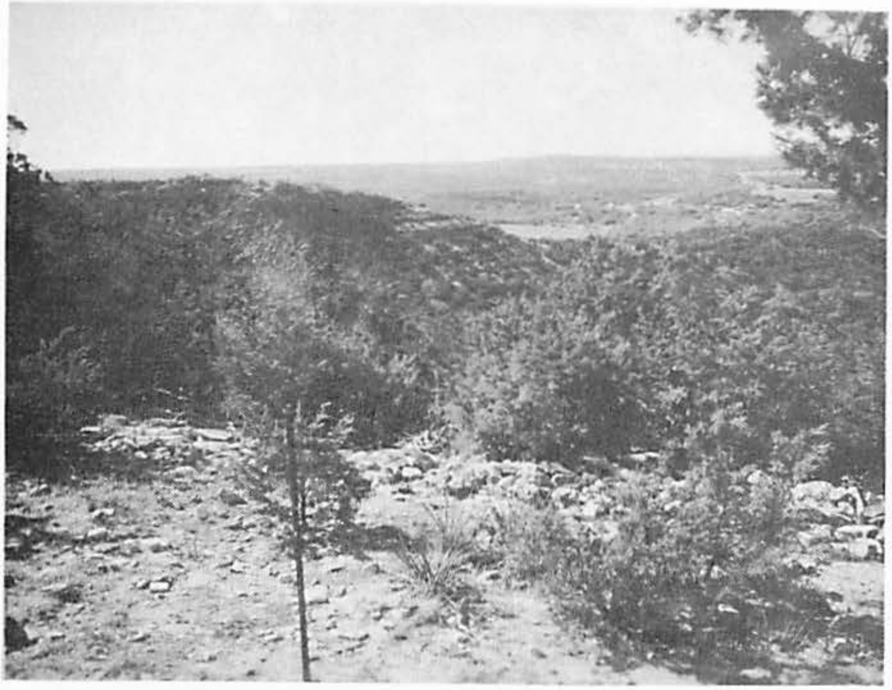
EDWARDS UNDERGROUND RESERVOIR

GARNER STATE PARK
(NOTE EDWARDS LIMESTONE ABOVE DARK AREA)

(NOTE EDWARDS LIMESTONE ABOVE DARK AREA)

FIGURE 2
EDWARDS PLATEAU
FRIO RIVER WATERSHED
NUECES RIVER BASIN

EDWARDS UNDERGROUND RESERVOIR



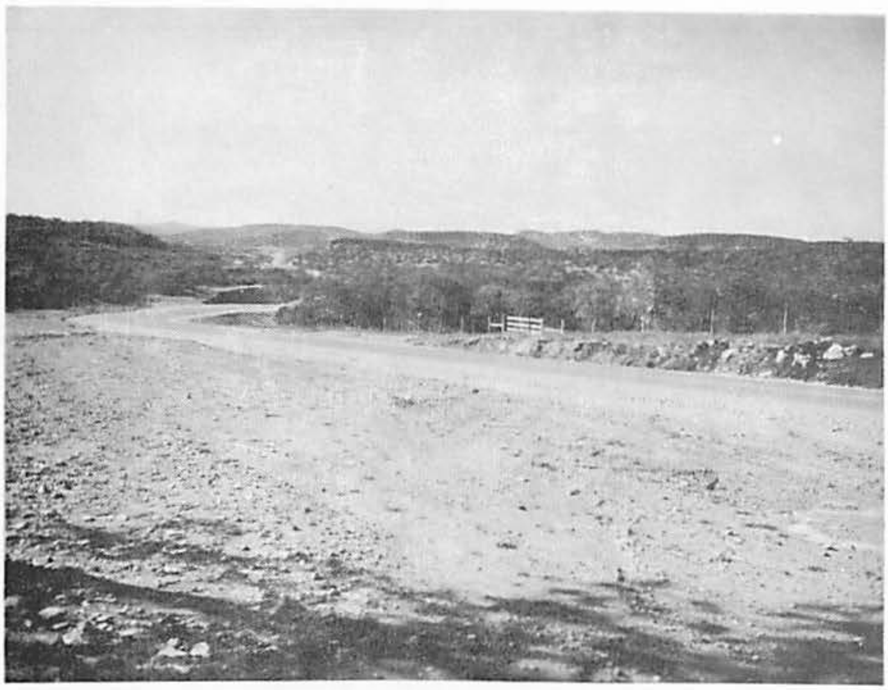


FIGURE 3

EDWARDS PLATEAU

GUADALUPE RIVER BASIN

(Vicinity of Canyon Reservoir)

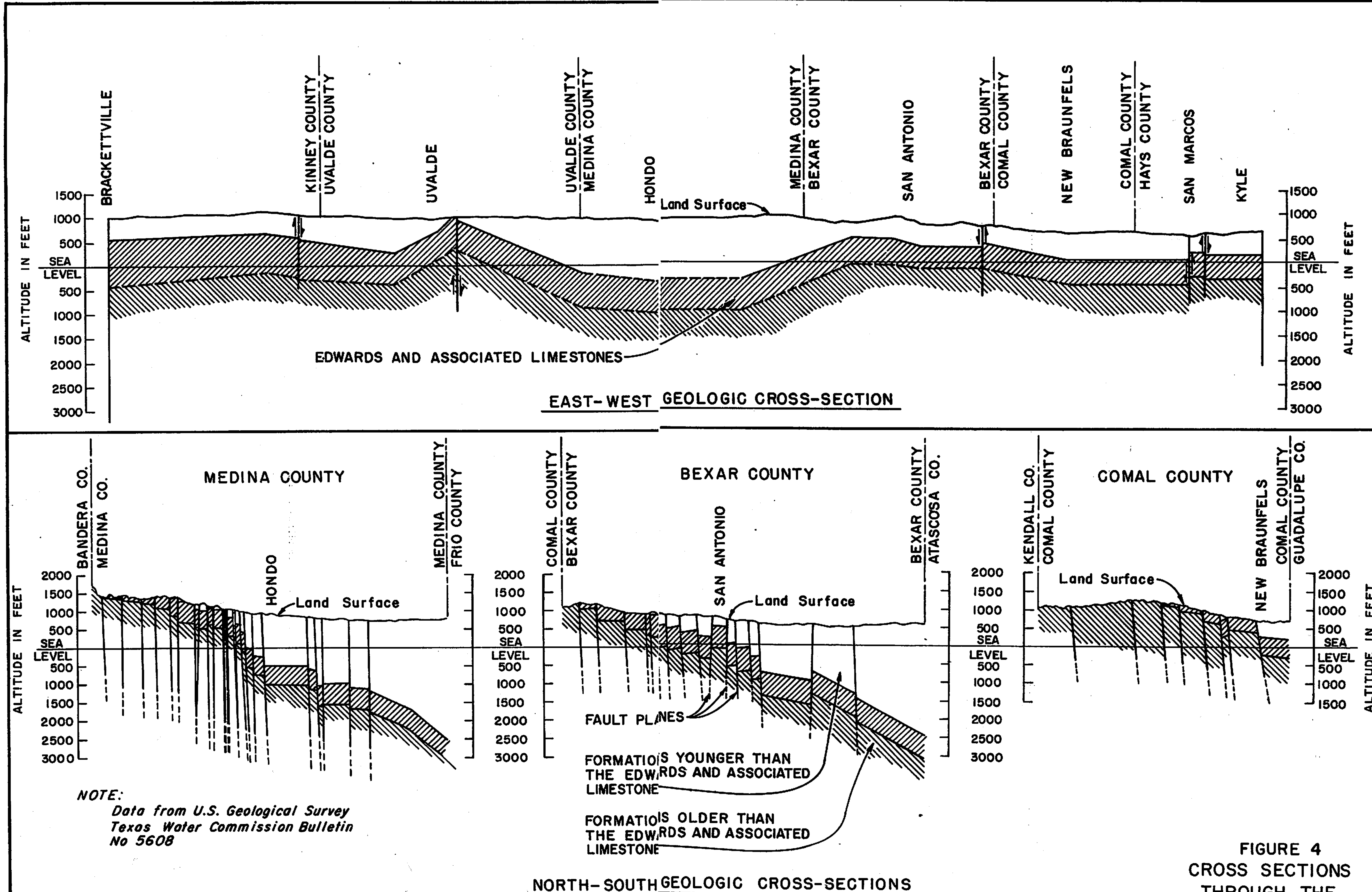


FIGURE 4
CROSS SECTIONS THROUGH THE EDWARDS AQUIFER

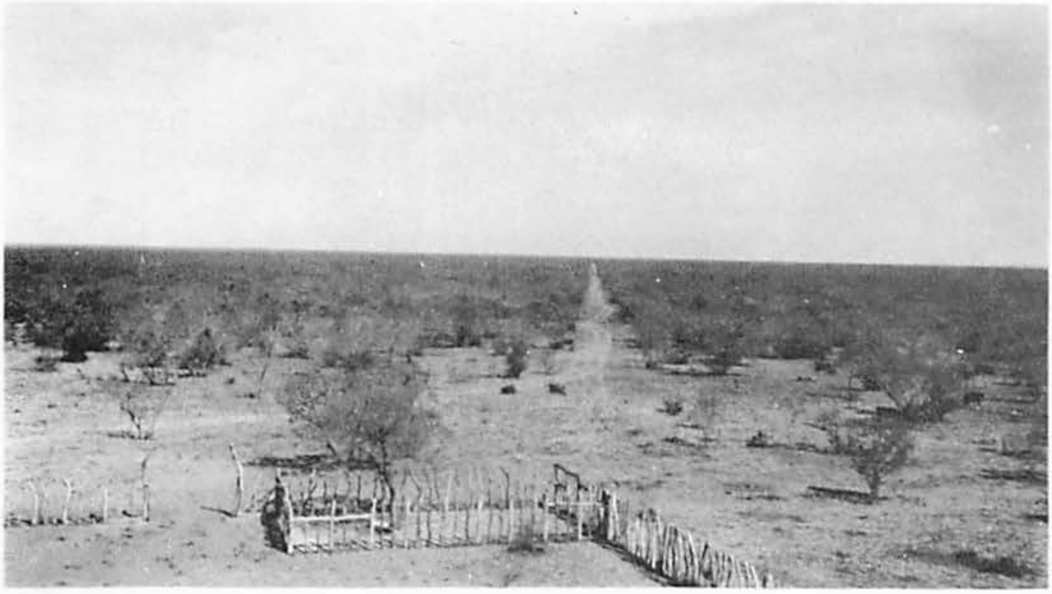


FIGURE 5
"BRUSH COUNTRY"
of the GULF COASTAL PLAIN
ZAVALA COUNTY

EDWARDS UNDERGROUND RESERVOIR

land surface which is about 20 feet to the mile. The Edwards limestone, which covers most of this area, absorbs a substantial amount of rainfall. This percolates downward through cracks and fissures to the lower parts of the Edwards formation where it comes in contact with relatively impermeable formations, thus forming an unconfined water body. The water then moves by gravity flow laterally through the limestone with much of it reappearing as springflow at or near the base of the Edwards and associated limestones in the valleys that have been cut by the streams. These springs are the source of perennial streams that drain the Edwards Plateau country. Except for the Guadalupe River, these streams then lose virtually all of their perennial flow and much of their floodflow as they cross long stretches of honeycombed and cavernous limestone in the Balcones fault zone.

28. In the Balcones fault zone, where the Edwards limestone has been extensively faulted downward under younger and relatively impervious formations, the artesian water circulates freely along fractures and faults and through honeycombed limestone solution channels and caverns. Once the water enters the underground artesian aquifer the normal southerly flow is blocked by the major faults and decreased permeability of the rock formation. The water then begins to flow through the honeycombed limestone in an easterly and northeasterly direction generally along the lines of major faulting toward San Antonio, New Braunfels, and San Marcos. The passages through which the water travels vary in size from small joints and fissures to solution channels of greater sizes. Some of the solution channels have resulted in the formation of rather large caverns, the largest of which are found near major faults.

29. The northern limit of the artesian reservoir generally lies along the base of the Balcones escarpment. The southern boundary is relatively well defined in a line known as the "bad-water line." South of this line the water is charged with noticeable amounts of hydrogen sulfide, and there is an appreciable increase in the hardness of the water. Generally from this line, the Edwards limestone has a progressively greater dip toward the southeast of approximately 100 feet per mile, reaching depths of more than 5000 feet below sea level. Also, in the downdip of the Edwards limestone south of the "bad-water line" the water becomes highly mineralized.

30. SPRINGS.- The Edwards Plateau, together with the Balcones fault zone area, is one of the greatest spring regions in the United States. In the plateau country hundreds of springs issue from the base of the Edwards limestone to feed the perennial streams that flow through the area. However, the largest springs in this region lie in the Balcones fault zone where artesian pressure forces water to the surface through fissures leading from the subsurface aquifer. Two of

SPRINGS ISSUING FROM THE FISSURES
IN THE LIMESTONE FORMATIONS

FIGURE 6

SPRINGS IN THE EDWARDS PLATEAU

EDWARDS UNDERGROUND RESERVOIR

these springs, Comal Springs at New Braunfels and San Marcos Springs at San Marcos, are listed among the sixty-five springs of first magnitude in the United States.[3] Other springs are located at Uvalde, San Antonio, and north of New Braunfels.

31. The springs at San Antonio were used for water supply and for irrigation by the Spanish missions as early as 1718, and were also used by the Indians for the same purposes even prior to that date. The springs at San Marcos and New Braunfels, which discharge into the San Marcos and Comal Rivers, respectively, provide a substantial amount of water for the municipal, industrial, and irrigation needs of the Guadalupe River Basin. These, and the other springs shown in the following tabulation, contribute a significant amount of the water supply to the areas in which they are located.

PRINCIPAL SPRINGS OF THE EDWARDS RESERVOIR AREA

Name	Location	Springflow - 1000 acre-feet per year[4]			
		Maximum	Minimum	1935-56 Average	Sept. 1964[5]
Leona	Uvalde	29.3	0	9.0	0
San Antonio & San Pedro	San Antonio	81.9	0	30.9	0
Comal	New Braunfels	304.3	0	199.9	102.1
Hueco	New Braunfels	69.5	0	19.6	-
San Marcos	San Marcos	211.5	33.3	93.0	65.3
Total				352.4	

32. DISCHARGE FROM WELLS.- The first well was drilled into the artesian reservoir by George W. Brackenridge in about 1884 for use as a public water supply for the city of San Antonio. Prior to this date all discharge from the Edwards Reservoir had been from springs. By 1907 there were more than 100 artesian wells in Bexar County alone, some with a reported natural flow of about 30 million gallons per day.[1] By the year 1953 there were more than 2000 wells in Bexar County tapping the Edwards aquifer. There are today about 4000 wells drawing water from the reservoir in the five-county area which includes Uvalde, Medina, Bexar, Comal, and Hays Counties.

33. The 1962 use from wells in the artesian reservoir was 268,200 acre-feet (239.3 million gallons per day), of which 212,000 acre-feet (189 mgd) was in Bexar County[2] (see figure 8). Prior to

AQUARENA AT SAN MARCOS SPRINGS

ONE OF MANY SPRINGS THAT MAKE UP COMAL SPRINGS.

FIGURE 7

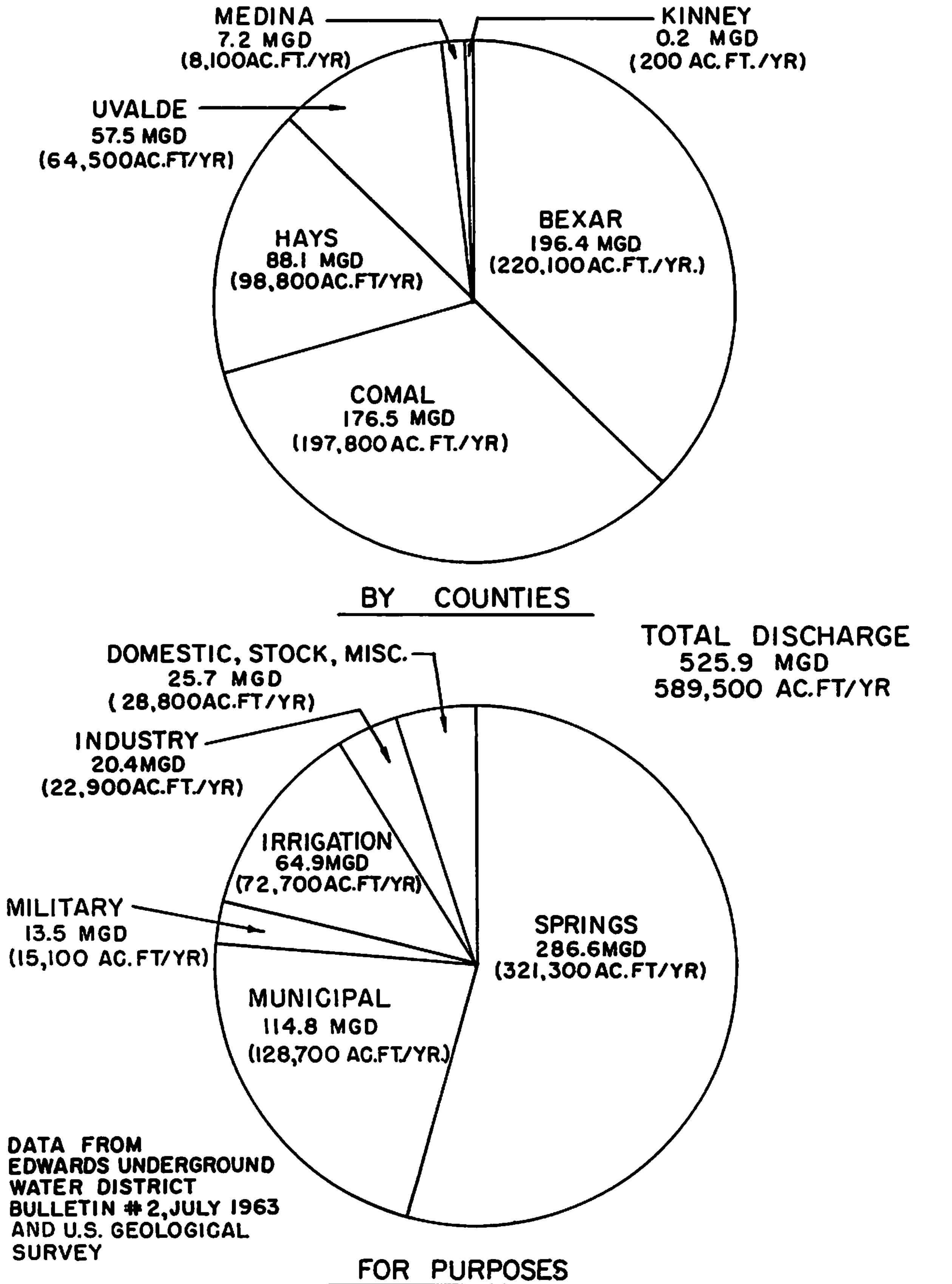
MAJOR SPRINGS

GUADALUPE RIVER BASIN

EDWARDS UNDERGROUND RESERVOIR

1954 most of the discharge from the aquifer had been from springs. However, during the 1947-1957 drought period, the discharge from wells exceeded that from springs in 1954, and by 1956, 80 percent of the discharge from the aquifer was from wells.4/ For the period 1935-1956 the average annual discharge from wells was 171,300 acre-feet.

34. Among the many wells which draw from the Edwards aquifer, two wells in Bexar County have perhaps produced the highest water flows. One of the wells, number 164, is reported to have had a natural flow of 16,800 gallons per minute in 1942. The other well is located in the San Antonio City Water Board's Market Street Plant, and its yield was about 15,000 gallons per minute when completed in 1954. Four other wells in the area are reported to yield in excess of 6,000 gallons per minute.7/



DISCHARGE FROM THE
EDWARDS UNDERGROUND RESERVOIR (1962)

FIGURE 8

35. STORAGE IN THE RESERVOIR.- Studies pertaining to storage in the Edwards Underground Reservoir are referenced to a well in San Antonio, Beverly Lodges H-26. Fluctuation in levels in this well are considered to be representative of those in the aquifer in this area. The lowest water level of 612 feet msl was recorded in August 1956, and the highest level of 685 was recorded in October 1942. Studies have indicated that above elevation 612 a change of water level in this well of one foot reflects an average change of storage in the aquifer of about 38,400 acre-feet. In the recorded range of elevations it is estimated that approximately 2,800,000 acre-feet of water is in storage in the underground reservoir. Because of the irregular pattern of openings in the honeycombed structure, no adequate means have been devised to determine the amount of storage below elevation 612.

36. STREAMS OF THE EDWARDS RESERVOIR AREA.- The streams that flow through the Edwards Reservoir area are in the drainage systems of three major river basins:the Guadalupe, San Antonio, and Nueces. The principal ones are shown on plate 1 and certain of their characteristics are listed in table 1.

a. Guadalupe River Basin.- In the Guadalupe River Basin, the principal streams crossing the Edwards limestone aquifer are the Guadalupe River and two of its major tributaries, Blanco River, and Dry Comal Creek. These streams meander through the rolling hill country of the Edwards Plateau in a pattern characteristic of old streams. In places they have cut deep canyons through the Glen Rose and into the Travis Peak limestones, some as great as 200 to 300 feet. The prolonged weathering has greatly reduced the area of Edwards limestone and it is now found only on the caps of the hills. The flood plains are generally narrow and contain isolated thin strips of flat bottom land. The streambeds lie principally in hard limestone and are void of sediments except for large boulders. Rapids are found where major faults cross the streams. The Guadalupe River is a perennial stream and has a substantial flow maintained by springs issuing from the Edwards limestone, except during periods of well below normal rainfall.

(1) Where the streams cross the Balcones fault zone, losses to the Edwards aquifer are generally from the Blanco River and Dry Comal Creek. In contrast to other streams in the area, the Guadalupe River contributes very little recharge to the underground reservoir. Stream records indicate that its base flow along the river between the cities of Comfort and New Braunfels is almost constant. The U. S. Geological Survey has indicated that there are two principal reasons for this condition: one, the stream channel of the Guadalupe River has been cut deeper in the Edwards and underlying limestones than the channels of other streams in the area;

and two, the water levels in wells in the Edwards limestone in the adjacent area stand at approximately the same elevation as the streambed.7/ This indicates that the water table and the streambed are approximately on the same plane.

(2) A major tributary of the Guadalupe River is the San Marcos River. Although this stream is not located in the recharge area of the Edwards aquifer, it is considered a part of the river system because of its proximity to the area and relationship to the underground reservoir. This stream has its origin within the city limits of San Marcos at the San Marcos Springs, from which it derives its base flow. Its principal tributary, the Blanco River, flows some 70 miles through the Edwards Plateau, around the eastern edge of the city of San Marcos, and continues in a southerly direction to join the San Marcos River about five miles below the city. The U. S. Geological Survey has determined that the Blanco River and streams in the adjacent area contributed an average of approximately 25,400[4/] acre-feet per year of recharge water to the underground aquifer between the years 1935 and 1956. The infiltration of water into the reservoir from the Blanco River has been estimated to occur at a rate of about 15 second-feet.7/

(3) The Comal River, only three miles in length, has its origin in the Comal Springs area and flows through the city of New Braunfels to the Guadalupe River. One of its tributaries, Blieders Creek, about seven miles in length, joins and becomes the Comal River at Comal Springs. A short distance downstream from the Comal Springs area, another tributary, Dry Comal Creek, enters the Comal River from the southwest. Dry Comal Creek contributed an average of about 20,500[7/] acre-feet per year to the underground reservoir from 1935 to 1956. The Dry Comal Creek watershed is also the principal recharge area for Hueco Springs located north of New Braunfels.

b. San Antonio River Basin.- The San Antonio River originates at the San Antonio Springs within the city limits of San Antonio. It flows for a distance of about 238 miles in a southeasterly direction to join the Guadalupe River about 10.6 miles upstream from the mouth of the Guadalupe. The San Antonio River and its tributaries, Olmos, San Pedro, Alazan, Apache, and Martinez Creeks flow through the city of San Antonio. These streams have rather steep banks and narrow channels. In the past they have created severe flood problems within the city; however, they are not considered as contributors to the Edwards Reservoir.

(1) Other streams flowing through the Edwards Reservoir area in the San Antonio River Basin are Cibolo, Salado, and Leon Creeks and the Medina River. These streams and their tributaries are considered as major contributors to the artesian aquifer. Table 1 lists the estimated annual recharge from these streams.

TABLE 1
STREAMS OF THE EDWARDS RESERVOIR AREA
GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS

Stream	Above lower edge of Edwards outcrop: Approx. length (miles)	Above lower edge of Edwards outcrop: Drainage area (sq. mi.)	Estimated average annual resources above lower edge of Edwards outcrop (ac-ft) (1935-1956)	Estimated average annual recharge to the aquifer (ac-ft)[4] (1935-1956)
GUADALUPE RIVER BASIN				
Blanco River and adjacent area	70	514	99,500	25,400
Guadalupe River	155	1,510	246,000	0
Dry Comal Creek	8	90	28,900	20,500
Subtotal		2,114	374,400	45,900
SAN ANTONIO RIVER BASIN				
Cibolo Creek	61	258	58,900	54,100
Salado Creek	18)	270	53,700	49,000
Leon Creek	19)			
Medina River	83	630	94,300	42,700
Subtotal		1,158	206,900	145,800
NUECES RIVER BASIN				
Verde Creek	27)			
Hondo Creek	32)	412	71,300	55,600
Seco Creek	21)			
Sabinal River	38	256	40,500	21,000
Frio River	58	450)		41,700
Dry Frio River	45	193)	105,000	23,600
Nueces River	64	896)		73,600
West Nueces River	76	905)	142,600	16,000
Subtotal		3,112	359,400	231,500
TOTAL		6,384	940,700	423,200

FIGURE 9

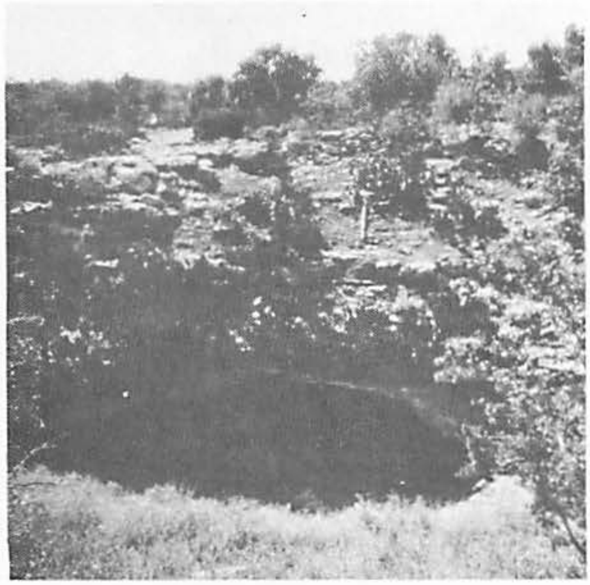
BLANCO RIVER
GUADALUPE RIVER BASIN

These streams have deeply entrenched channels with large carrying capacities, and overbank flooding is infrequent. The flood damages in these areas are small because of the stream characteristics, the small flood plain development, and the improvements for flood control in the areas by local interests. These improvements will be discussed in later sections of this report.

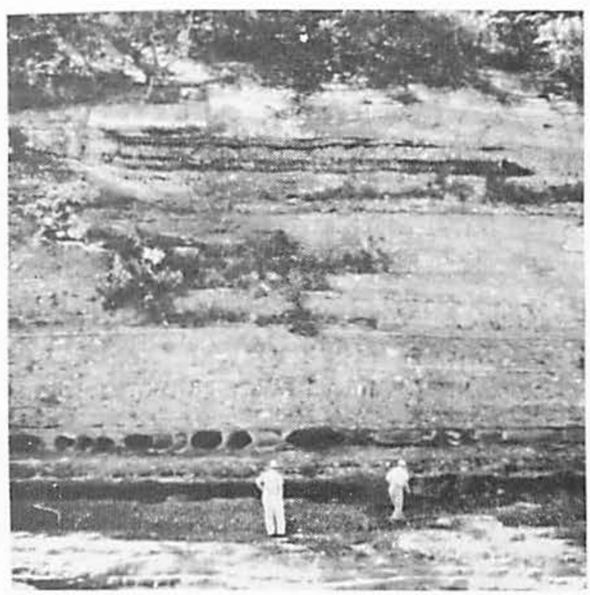
(2) Losses to the Edwards Reservoir from streams in the San Antonio River Basin total approximately 145,800 acre-feet per year (1935-1956). The Geological Survey has estimated that one stream in this basin, Cibolo Creek, together with Dry Comal Creek in the Guadalupe River Basin, contributes from one-fourth to one-third the long-term average discharge of Comal Springs.[2/] Along the wide meanders of Cibolo Creek there are many caverns, sink holes, crevices, and areas of honeycombed limestone which provide escape routes for the flows of this stream into the underground solution channels leading to the Edwards aquifer. One of the largest caverns in the state, the Natural Bridge Caverns, lies in this area about 18 miles north-northeast of San Antonio. Most of this vast cavern lies within the Upper Glen Rose limestone, having a depth of about 250 feet and extending some 5,300 feet in a northerly direction to within about 750 feet of Cibolo Creek. However, the entrance is located in the Edwards limestone formation. Another large cave in the area is Bat Cave which is also located in the same general area near Cibolo Creek. A view of the entrance to this cave is shown in figure 10.

(3) Recharge conditions on the Medina River are somewhat different from those on other streams of the area because of the presence of the Medina Lake and the associated Diversion Reservoir, which are discussed in a later section of this report. Mr. R. L. Lowry, Consulting Engineer, made an extensive study of the leakage from these projects and determined in 1955 that the average annual recharge to the underground reservoir resulting from this leakage totals 46,900 acre-feet per year.[8/] Extension of data through 1956, or through the critical drought period, reduced this average to approximately 42,700 acre-feet per year.[4/] Figure 11 shows views of the Medina Lake and the spillway discharge channel from the reservoir.

c. Nueces River Basin.- The principal streams in the Nueces River Basin which flow across the Edwards Reservoir area and make a significant contribution to recharge of the Edwards limestone aquifer are the Nueces and West Nueces, Frio and Dry Frio, and Sabinal Rivers; and three creeks, Verde, Hondo, and Seco, which are tributaries of the Frio River. As shown in table 1, these streams drain 3,112 square miles of the Edwards Plateau country and contributed an average of 231,500 acre-feet per year[4/] of recharge water to the Edwards Reservoir from 1935 through 1956.



BAT CAVE



OTHER CAVES ALONG CIBOLO CREEK
(IN GLEN ROSE LIMESTONE FORMATION)

FIGURE 10
CAVES NEAR SAN ANTONIO

(Flow from leakage at the Reservoir)

FIGURE 11

MEDINA LAKE

AND

SPILLWAY DISCHARGE CHANNEL

EDWARDS UNDERGROUND RESERVOIR

(1) These streams have cut deep gorges through the Edwards limestones and, for the most part, are bedded in the underlying more impervious Glen Rose limestone. In the escarpment area, the gorges occasionally widen into narrow valleys, particularly where tributaries enter the main streams. Downstream from the Balcones escarpment, the gorge section changes into a wide valley section and the stream channels decrease in depth, size, and capacity. Two of the larger streams, the Frio and Nueces Rivers, have bankfull capacities in the plateau country ranging from 5,000 to more than 30,000 second-feet.

(2) Most of these streams which flow through the plateau are perennial streams fed by springs. However, as these streams flow over the outcrop of the Edwards limestone in the Balcones fault zone, most of their flow is lost to the underground aquifer. Downstream from the fault zone the streams become dry or flow only intermittently.

(3) An example of the potential recharge from the streams that cross the outcrop of the Edwards limestone is shown in gage records and recharge investigations by the Geological Survey covering the March 1958 flood on the Frio and Dry Frio Rivers. Investigations of these two streams indicate that the streambed exposures in the outcrop area of the Edwards limestone extend 11 miles along the Frio River and 14 miles along the Dry Frio River. 9/ Gage records for the 1958 flood indicate that water was absorbed into the aquifer at a rate as great as 939 second-feet where the combined streams cross the outcrop. 4/ Similar recharge conditions occur along a 13-mile stretch of the Nueces River west of Uvalde and along a 3-mile stretch of the Sabinal River. 9/

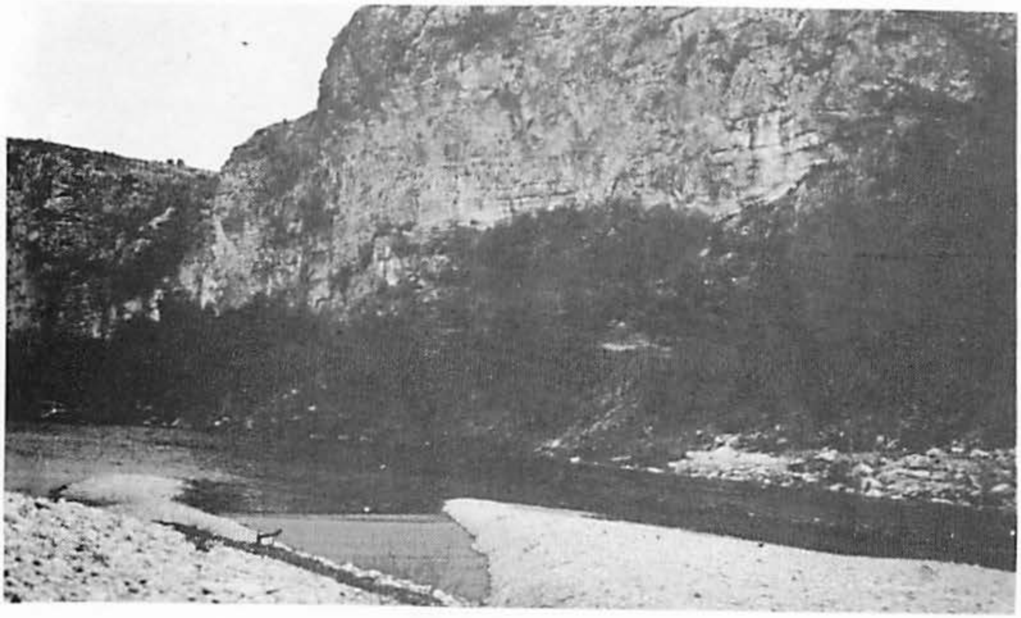
(4) The West Nueces River is the only stream in the area which does not follow the general characteristics described above. Although it is the largest tributary of the Nueces River in the plateau area, the stream is dry most of the time and seldom has any flow at its mouth, except in periods of heavy rainfall. For the most part, the bed of the stream is underlain by gravel and most of the recharge moves eastward as underflow.

FRIO RIVER

SECO CREEK

FIGURE 12

STREAMS OF THE EDWARDS AREA
NUECES RIVER BASIN



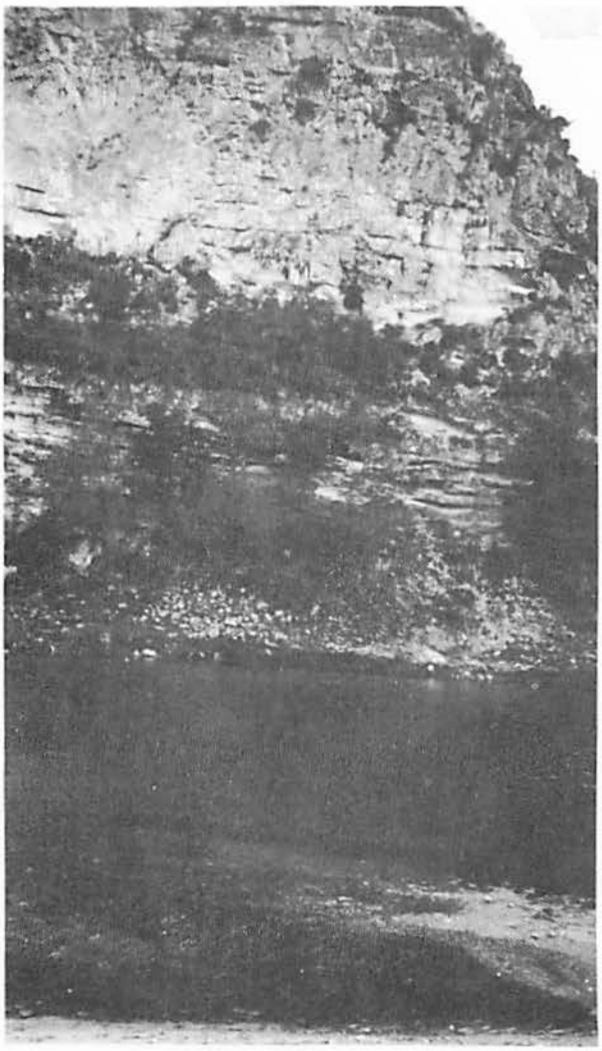
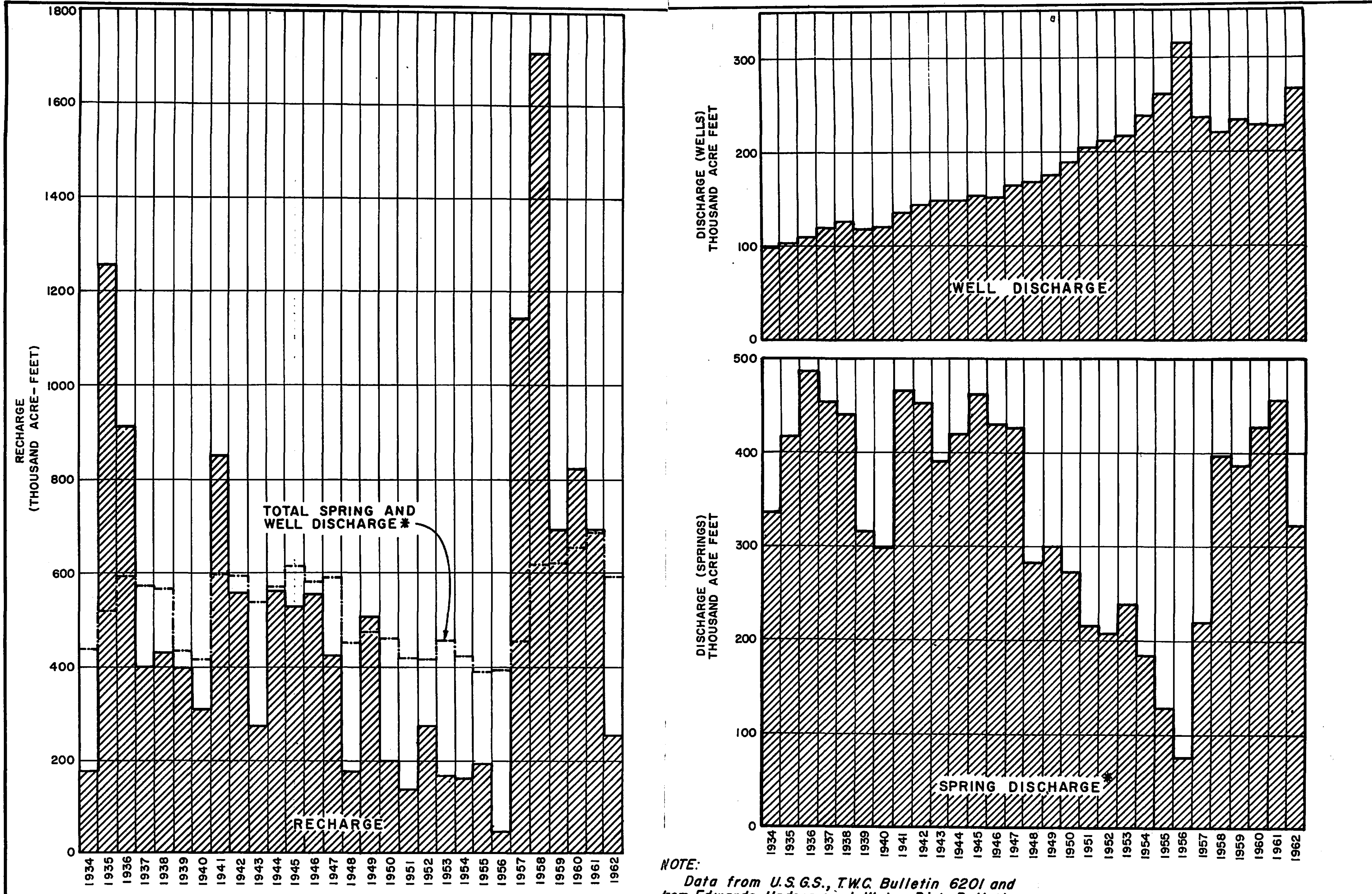


FIGURE 13
NUECES RIVER IN THE
VICINITY OF CHALK BLUFF

EDWARDS UNDERGROUND RESERVOIR



NOTE:
Data from U.S.G.S., T.W.C. Bulletin 6201 and from Edwards Underground Water Dist. Bulletin Number 2 and Number 3.

FIGURE 14
RECHARGE AND DISCHARGE

37. QUALITY AND CHEMICAL CHARACTER OF THE GROUND WATER.-- The water in the Edwards limestone is of good quality, although moderately hard. Its principal mineral constituent is calcium bicarbonate, generally in concentration in excess of 200 parts per million. 4/ All ground water contains dissolved mineral solids, the amount depending largely on the type of formation through which the water passes, the length of time the water is in contact with the rock, the temperature and pressure. The principal constituent of the Edwards limestone is calcium carbonate, a mineral that is highly soluble by the action of carbon dioxide (carbonic acid) in water. Rainwater absorbs the carbon dioxide from the air and from decaying vegetable matter in the soil. The presence of carbon dioxide gas in water increases the capacity of the water to dissolve the limestone and hold the calcium carbonate in solution. Temperature and pressure play an important part in regulating the volume of carbon dioxide gas that the water will hold in solution. As the ground water travels through the formation in the underground limestone reservoir it may pass through zones of different temperatures and at different levels. Slight changes in temperature and pressure cause a change in the carbon dioxide content of the water and are believed to cause the water to dissolve or deposit limestone. 10/ The dissolving of the limestone results in the honeycombed channels and caverns. The deposition of limestone in these caverns forms stalactites, stalagmites, or secondary calcite in veins.

38. Through chemical analyses of water from the artesian reservoir, the Geological Survey has estimated that all wells and springs along this aquifer remove approximately 450 tons or 200 cubic yards of solid rock per day, 1/ of which about 200 tons per day are removed through Comal Springs alone. 2/ This indicates that the underground reservoir is slowly increasing in capacity as the rock is dissolved by the circulating ground water.

39. The average concentration of dissolved solids in the underground reservoir varies from 250 to 450 parts per million. 7/ An increase occurs generally in the deeper portions of the reservoir toward the south and southeast. In the zone of poor quality along the southern extremity of the artesian aquifer called the "bad water line," the water is charged with hydrogen sulfide, a chemical that has an offensive odor and is highly corrosive to metal. In this zone the dissolved solid concentration increases to over 1000 parts per million. This condition is believed to have resulted from restrictions in the formation which have prevented the free circulation of the underground water. However, this water is not entirely wasted since it is generally acceptable for irrigation purposes. The hydrogen sulfide may also be removed from the water by prolonged aeration or filtration through charcoal. Further south along the downdip of the Edwards limestone the water becomes highly mineralized with the dissolved solid concentration as great as 5000 ppm. Chloride concentration as great as 2000 ppm 1/ has also been found in the downdip area.

40. Results of studies made by the Geological Survey2/ of the artesian water flowing from Comal Springs at New Braunfels indicate the high quality of the water from the underground reservoir. The long time average discharge from these springs is in excess of 280 second-feet. The water issues from fissures along the escarpment formed by the Comal Springs fault and is crystal clear without a trace of turbidity. The springflows have almost a constant temperature of 74 degrees Fahrenheit throughout the year. The maximum observed variation from this temperature has been less than one degree. Since the springflow temperature is some 6 degrees higher than the mean annual temperature at New Braunfels, it is assumed that this water circulates through portions of the reservoir as deep as 300 to 500 feet below the ground surface.

41. OTHER WATER-BEARING FORMATIONS.- In addition to the Edwards and associated limestones, there are other water-bearing formations in the Edwards area which make a significant contribution to the water resources of the region. Among these formations are the Carrizo sands, the Glen Rose limestone, the Leona gravels and the Austin chalk, three of which are shown on plate 2. The Carrizo sand formation stores large volumes of good quality water, though moderately hard. The formation is relatively uniform in permeability and wells in this formation frequently yield from 1 to 2 million gallons per day.1/ The Trinity sands of the Travis Peak, or Pearsall, formation yield water in fairly small quantities on the Edwards Plateau for domestic and stock uses. The Glen Rose limestone, which overlies the Trinity sands, is a major source of water in the Edwards Plateau area where water is not available from the Edwards and associated limestones. A few wells are known to yield from 200 to 300 gallons per minute.1/ Supplies from this formation, however, are only sufficient in most areas for domestic and stock supplies.9/ This water is generally very hard and, in most places, the concentration of sulfates and dissolved solids is high.11/ The gravels of the Leona formation are found in the valley of the Leona River, and are variable in both thickness of the formation and yield to the wells. However, many shallow wells drawing from the Leona gravels yield 300 to 500 gallons per minute under sustained irrigation pumping. This water is generally hard with a high nitrate content but of good quality otherwise.11/ The Austin chalk formation yields moderate quantities of potable water in a few localities. This water generally has a moderately high concentration of sulfate.11/

42. FLOODS AND DROUGHTS.- In the Edwards Reservoir area, weather patterns are generally typical of the southwest. Years of normal rainfall and plentiful water supply for growing cities, industries, military reservations, and agricultural irrigation projects are most often followed by years of decreasing annual rainfall. As this latter condition is extended over a period of years, drought conditions are experienced. By past records, these droughts have only been broken by devastating

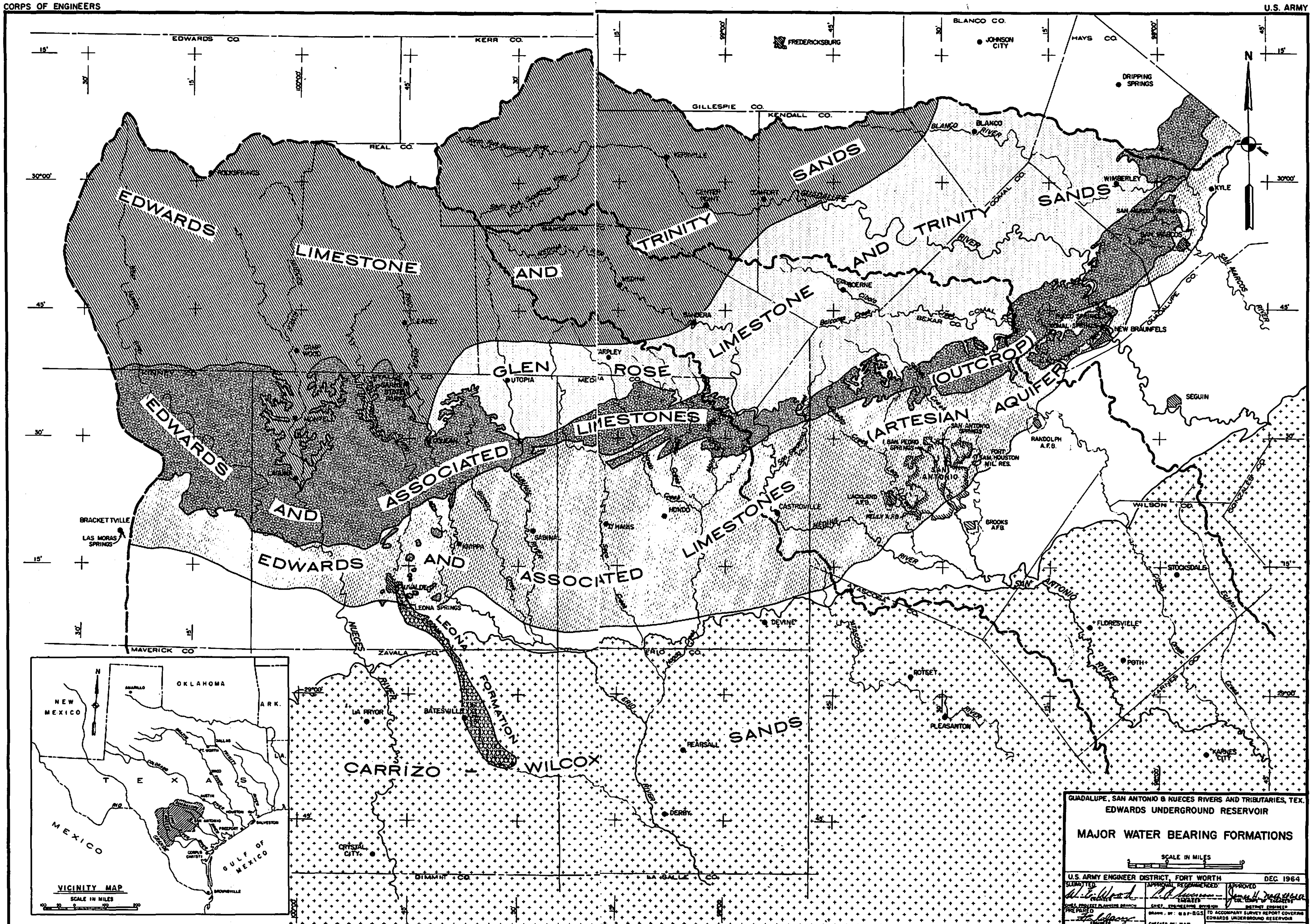

EDWARDS LIMESTONE AND TRINITY SANDS
GLEN ROSE LIMESTONES
EDWARDS AND ASSOCIATED LIMESTONES
EDWARDS AND ASSOCIATED LIMESTONES (OUTCROP)
EDWARDS AND ASSOCIATED LIMESTONES (ARTESIAN AQUIFER)
LEONA FORMATION
CARRIZO - WILCOX SANDS
EDWARDS CO.
KERR CO.
REAL CO.
BLANCO CO.
HAYS CO.
GILLESPIE CO.
KENDALL CO.
COMAL CO.
BEXAR CO.
GUADALUPE CO.
WILSON CO.
GONZALES CO.
KARNES CO.
ATASCOSA CO.
FRIO CO.
ZAVALA CO.
MAVERICK CO.
DIMMIT CO.
LA SALLE CO.
MEDINA
KINNEY
UVALDE CO.
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
WIMBERLEY
KYLE
SAN MARCOS
NEW BRAUNFELS
SEGUIN
BOERNE
BANDERA
KERRVILLE
CENTER POINT
COMFORT
LEAKEY
CAMP WOOD
ROCKSPRINGS
TARPLEY
UTOPIA
HONDO
CASTROVILLE
SAN ANTONIO
RANDOLPH A.F.B.
FORT SAM HOUSTON MIL. RES.
BROOKS A.F.B.
KELLY A.F.B.
LACKLAND A.F.B.
SAN PEDRO SPRINGS
SAN ANTONIO SPRINGS
SABINAL
KNIPPA
UVALDE
LEONA SPRINGS
BRACKETTVILLE
LAS MORAS SPRINGS
DEVINE
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
PEARSALL
DERBY
CRYSTAL CITY
NUECES RIVER
LEONA RIVER
FRIO RIVER
SAN ANTONIO RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
MEDINA RIVER
CIBOLO CREEK
ATASCOSA RIVER
VICINITY MAP
SCALE IN MILES
NEW MEXICO
OKLAHOMA
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
N
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
MAJOR WATER BEARING FORMATIONS
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 707-2

PLATE 2

floods, or at a minimum, several years of excessive rainfall. The drought years of 1947 through 1956 caused critical water shortages to occur over most of the southwest region. Cities and industries had to drastically curtail water use and in some cases make extensive provisions to supplement their dwindling water supplies. Surface water irrigation, for the most part, came to a standstill and irrigation from ground water diminished considerably due to the lowering of water tables. Such was the case with irrigation projects in the Edwards Reservoir area. In addition, the city of San Antonio, including its military installations, and others found the elevations of the water levels in their wells reaching an all time low, some 70 feet below normal, as pumping reached an all time high in order to meet large demands of water, demands which had formerly been partially satisfied by normal yearly rainfall. Many of the perennial streams of the Edwards Plateau ceased to flow and others flowed only for a short time following periods of rainfall. By the summer of 1956, all major springs in the Balcones fault zone had ceased to flow with the exception of San Marcos Springs, which had decreased from a yearly average of about 165 second-feet to a minimum flow of 46 second-feet. Comal Springs at New Braunfels, the largest of the group, whose yearly discharge had averaged over 280 second-feet, ceased to flow on June 13, 1956. It remained dry until November 3, 1956, when it started flowing at a slow rate. The decreased water level in the artesian reservoir caused pumping costs throughout the area to accelerate and caused many wells to become dry.

43. By the spring of 1957, heavy rains began to fall over most of the state and the southwest region. From April to June of that year, some areas of the state suffered hundreds of millions of dollars in flood damages. Some of these floods were estimated as 100-year frequency floods, or floods that would not be expected to occur more than once in 100 years. In the Edwards Plateau country, heavy rains of 1957 and even greater ones of 1958 caused flooding of urban areas within the Balcones fault zone and further downstream. The heavy rains also caused flooding of agricultural lands lying in the valleys of the Edwards Plateau, those within the Balcones fault zone, and downstream of the fault zone in the Gulf Coastal Plain where the streambeds and valleys are considerably wider.

44. In general, the flooding experienced along the Edwards Plateau is produced by intense storms with relatively limited areal coverage. The storm of June 30-July 2, 1932 was more general in character than any other major storm of record in the vicinity of the Edwards Plateau. This storm had centers of rainfall of 35.6 inches at the State Fish Hatchery near Ingram in the upper Guadalupe River watershed; 33.5 inches at Humble Pump Station in the upper Sabinal River watershed; and 24 inches at Rio Frio in the upper Frio River watershed. Runoff from this storm produced the maximum known peak discharges in the upper part of these three watersheds. Several additional intense storms which covered

small areas follow: the storm of May 25-30, 1929 which produced flooding in the Blanco River watershed; the storm of May 31, 1935 which produced the maximum known peak discharge of 230,000 second-feet on the Seco Creek about 11 miles north of D'Hanis; the storm of June 10-15, 1935 which produced the maximum known peaks of 550,000 second-feet on the West Nueces River at Brackettville and 616,000 second-feet on the Nueces River near Uvalde; the storm of September 26-27, 1946 which produced the maximum known peak discharge on Calaveras Creek; the storm of September 9-11, 1952 which produced serious flooding on the Blanco River; and the storm of September 23-25, 1955 which produced the maximum known peak discharge of 307,000 second-feet on the Nueces River at Laguna. Each of these periods is discussed more fully in Appendix II, Hydrology and Hydraulic Design.

45. Floods and droughts, in general, cause extensive economic losses directly to the areas in which they occur and indirectly affect the economy of the state and the nation. These disasters also strongly point out needs for increased vigorous pursuit of conservation, development, and protection of our water resources to meet increasing future demands. Although extensive investigations and water resource planning and development have been made for many years in the Edwards Reservoir area by a number of Federal, State, and local agencies, this most recent drought has made all concerned even more keenly aware of the urgent need to protect and preserve the most valued natural water resource of this vast area - the Edwards Underground Reservoir.

46. CLIMATOLOGICAL DATA.- The climate over the Edwards Underground area is generally mild with hot summers and cool winters. Freezing temperatures and snowfalls are experienced occasionally, caused by the rapid movement of cold, high-pressure air masses from the northwestern polar regions and the continental western highlands. The mean annual temperature is about 68 degrees Fahrenheit over the Edwards Reservoir area. Temperature extremes range from a maximum of 114 degrees to a minimum of minus 7 degrees. January, the coldest month has an average daily minimum temperature of 37.6 degrees; August, the warmest month, has an average daily maximum temperature of 96.3 degrees. The average length of the growing season between killing frosts is about 254 days.

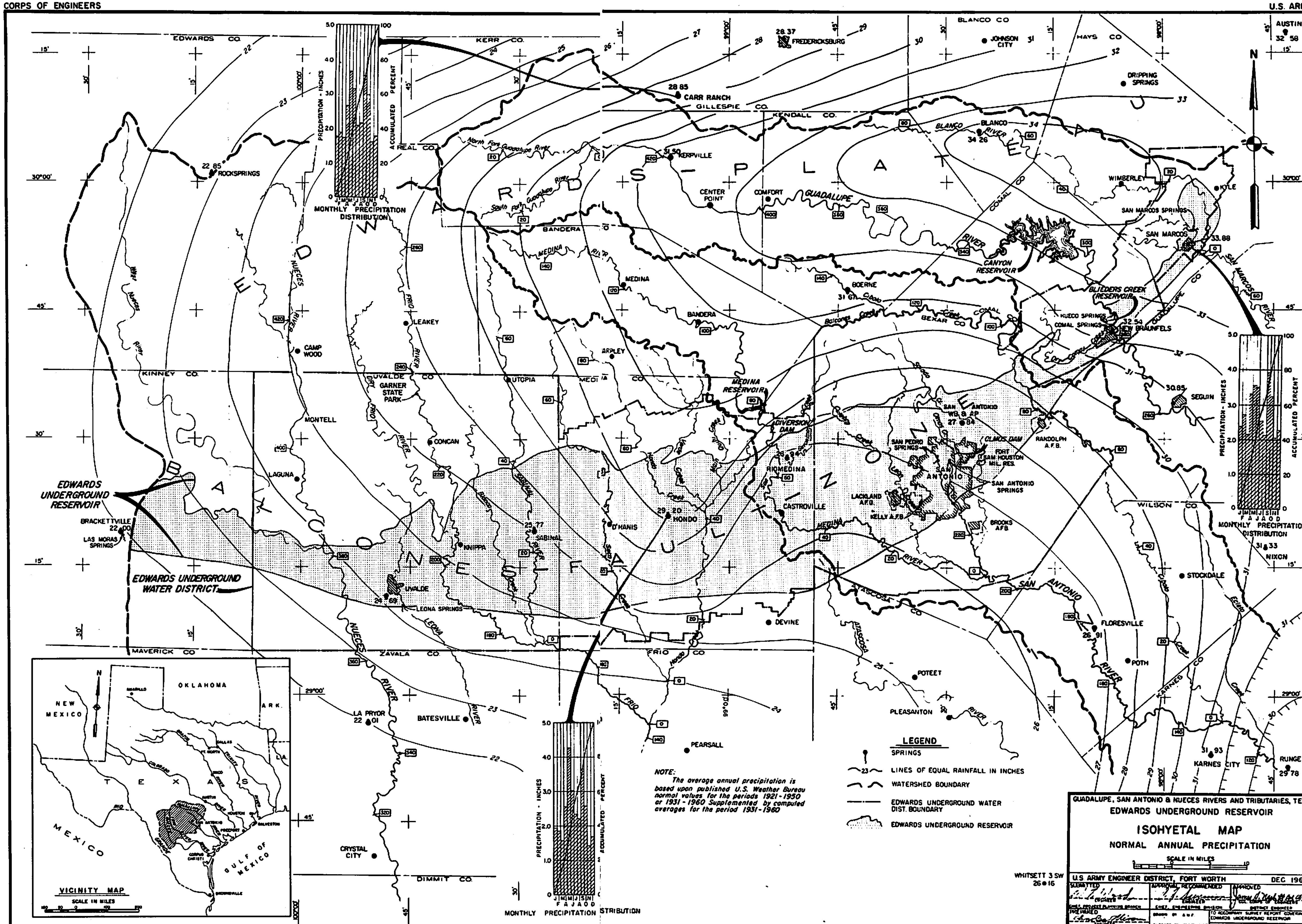
a. Precipitation.- The mean annual precipitation over the Edwards Underground area is approximately 27.8 inches, and varies from about 34 inches in the eastern part to about 22 inches in the western part. Extremes in annual precipitation range from a maximum of 62.47 inches reported in Boerne in 1919 to a minimum of 6.45 inches reported in Brackettville in 1893. The normal seasonal distribution of rainfall over the area is generally favorable for agricultural purposes, with the two heaviest rainfall periods occurring during the periods April through June and September through October. Plate 3 shows the isohyetal map for the average annual precipitation on the Edwards Plateau area, based on published U. S. Weather Bureau normal values; and also contains graphs of the normal monthly distribution of the average annual precipitation at Hondo, San Marcos, and Carr Ranch.

b. Evaporation.- The mean evaporation rate from a free water surface in the general vicinity of the Edwards Plateau varies from 50.1 inches at Austin to 59.2 inches at Winter Haven. The rainfall of the two stations varies from 32.6 inches to 21.6 inches, respectively; and the net evaporation from a free water surface varies from 17.5 inches at Austin to 37.6 inches at Winter Haven.

c. Runoff.- There are two or more stream-gaging stations on most of the streams that were investigated in this report. Plates 2 and 3, appendix II, show the location and drainage area for these stream-gaging stations. The following tabulation includes only the gages that were used in determining resources for the surface reservoirs investigated for this report.

Stream-gaging station	Drainage area (sq.mi.)	Period of record: From	Thru	Length: Year	Month	Annual runoff (in.): Maximum (1)	Minimum (1)	Mean
Nueces at Laguna	764	10/23	9/62	39	0	10.85	0.41	2.45
Frio at Concan (2)	405	11/23	9/62	38	11	14.21	0.29	3.35
Sabinal nr Sabinal	206	10/42	9/62	20	0	11.39	0.05	2.47
Hondo nr Tarpley	101	9/52	9/62	10	1	16.66	0.06	4.24
Seco nr Utopia	53	9/52	9/61	9	1	15.19	0.09	4.02
Guadalupe nr Comfort	762	10/22	9/32	10	0	6.72	0.99	2.48
Guadalupe at Comfort	836	6/39	9/62	23	4	5.81	0.24	2.36
Guadalupe nr Spring Branch	1,282	7/22	9/62	40	3	8.37	0.14	2.81
Blanco at Wimberley (3)	353	7/28	9/62	33	6	13.69	0.25	4.67

(1) Water year.
(2) Runoff for 1930 water year was estimated (USCE).
(3) Runoff records were missing for 8 months in 1929 water year.



GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
NORMAL ANNUAL PRECIPITATION
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2
LEGEND
SPRINGS
LINES OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
NOTE:
The average annual precipitation is based upon published U.S. Weather Bureau normal values for the periods 1921-1950 or 1931-1960 Supplemented by computed averages for the period 1931-1960
MONTHLY PRECIPITATION DISTRIBUTION
PRECIPITATION - INCHES
ACCUMULATED PERCENT
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
EDWARDS PLATEAU
BALCONES FAULT ZONE
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK.
TEXAS
MEXICO
GULF OF MEXICO
EDWARDS CO.
KERR CO.
BLANCO CO
HAYS CO
GILLESPIE CO.
KENDALL CO.
REAL CO.
BANDERA
KINNEY CO.
UVALDE CO
MEDINA CO
BEXAR CO
COMAL CO
GUADALUPE CO
WILSON CO
MAVERICK CO
ZAVALA CO
FRIO CO
ATASCOSA CO
KARNES CO
DIMMIT CO
AUSTIN 32.58
FREDERICKSBURG 28.37
JOHNSON CITY
DRIPPING SPRINGS
CARR RANCH 28.85
KERRVILLE 31.50
CENTER POINT
COMFORT
BLANCO 34.26
WIMBERLEY
KYLE
SAN MARCOS SPRINGS
SAN MARCOS 33.88
CANYON RESERVOIR
BLIEDERS CREEK RESERVOIR
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS 32.54
SEGUIN 30.85
ROCKSPRINGS 22.85
CAMP WOOD
LEAKEY
MEDINA
BOERNE 31.61
BANDERA
PIPE CREEK
UTOPIA
GARNER STATE PARK
MONTELL
CONCAN
LAGUNA
BRACKETTVILLE 22.00
LAS MORAS SPRINGS
KNIPPA
SABINAL 25.77
UVALDE 24.69
LEONA SPRINGS
D'HANIS
HONDO 29.20
CASTROVILLE
RIOMEDINA
MEDINA RESERVOIR
DIVERSION DAM
SAN ANTONIO WB & AP 27.84
SAN PEDRO SPRINGS
OLMOS DAM
FORT SAM HOUSTON MIL. RES.
SAN ANTONIO
SAN ANTONIO SPRINGS
RANDOLPH A.F.B.
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
DEVINE
POTEET
PLEASANTON
FLORESVILLE 26.91
POTH
STOCKDALE
NIXON 31.33
KARNES CITY 31.93
RUNGE 29.78
PEARSALL
LA PRYOR 22.01
BATESVILLE
CRYSTAL CITY
WHITSETT 3 SW 26.16
NUECES RIVER
FRIO RIVER
SABINAL RIVER
MEDINA RIVER
SAN ANTONIO RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
LEONA RIVER

REGIONAL ECONOMIC DEVELOPMENT

47. INTRODUCTION.- This study is concerned primarily with water problems and demands associated with the water resources of the Edwards Underground Reservoir that can be solved by the construction of water resource improvements having as a primary purpose the recharge or preservation of the ground water resources of the reservoir. The areas affected by these problems and requirements range from relatively narrow flood plains to widespread areas from which will be drawn the recipients of the recreational benefits of proposed reservoirs. The extent of the area affected by each project purpose varies and is limited by the practical and economic aspects of the purpose served. Figure 15 shows the composite of all areas considered and the three subareas into which it was divided for greater ease of analysis. The economy of the area in and immediately adjacent to the flood plain was used in planning for flood plain improvements. The economy of a 14-county area, including Bandera, Bexar, Blanco, Caldwell, Comal, Edwards, Guadalupe, Hays, Kendall, Kerr, Kinney, Medina, Real, and Uvalde Counties, was taken into account in planning for water supply. The economy of the entire base study area was considered in connection with planning projects which might affect recreation, fish and wildlife problems. The area selected for the economic base study comprises 60 counties and contains about 63,959 square miles, 24 percent of the total land area of the state of Texas. Appendix V, Economic Base Study, contains a detailed analysis of current and historical economic conditions and projections of industrial development, population, employment, and income for the base study area.

48. The Edwards Underground Reservoir has been a primary factor in the development of the water supply area. Many of the Spanish missions were established in the 16th century at or near flowing springs fed from the underground reservoir. A mission established at San Pedro Springs in 1718 was the beginning of the city of San Antonio, now the third largest city in the state. The spring-fed Comal, San Marcos, and Guadalupe Rivers attracted early colonists. Low head channel dams were constructed for power purposes over a century ago. The first Texas cotton mill was founded at New Braunfels in Comal County in 1850.

49. Violent, abrupt storms in the Edwards Reservoir area, due at least in part to the upsweep of warm, moist air over the Balcones Escarpment, result in high velocity, sharp crested floods on the streams and rivers of the study area. Control of these floods is of major importance to the complete development of the study area.

50. POPULATION.- The population of the base study area in 1960 was 2,035,000, of which 845,968 resided within the 14-county area which is almost totally dependent upon the Edwards Underground Reservoir for its municipal and industrial water supply. The comparative rates of

growth between 1890 and 1960 of these two areas and those of the state and the nation are as follows:

	Average annual percent of change in population 1890-1960
United States	1.50
Texas	2.10
Base study area	1.73
14-county water supply area	2.71

Eighty-one percent of the 1960 population of the water supply area resided in the San Antonio standard metropolitan statistical area (Bexar County).

51. Three other of the state's 21 standard metropolitan statistical areas are within the study area. Austin, the capital of the state and the sixth largest in the state, is about 60 miles northeast of San Antonio, beyond the limits of the water supply area. Corpus Christi, seventh largest in the state, is located on the Gulf of Mexico at the mouth of the Nueces River, which originates on the surface above the Edwards Underground Reservoir. Corpus Christi is the only deep water port within the limits of the base study area. Laredo, a port of entry at the Mexican border, is separated from its Mexican counterpart, Nuevo Laredo, by the Rio Grande.

52. The population of the base study area is projected to rise at the average annual rate of 1.90 percent to the total of 6.9 million in the year 2025. Most of this growth will occur in subarea I and principally in the urban areas.

53. Projection of the population of the 14-county water supply area shows a rise of 1.94 percent to a total of 2.9 million at year 2025.

54. REAL PERSONAL INCOME.- Real personal income is the most comprehensive available measure of economic activity and bears a close and generally constant relationship with the gross national product over the long run. At the national level, it has been found that personal income exhibits the same rate of increase that characterizes the gross national product. Personal income, when reduced by taxes, becomes disposable personal income, that portion of the income most representative of the economic condition of an area. In 1960, the disposable personal income of the 2,035,000 persons in the study area and the 846,000 persons in the water supply area was $3.0 billion and $1.3 billion, respectively. On the basis of a per capita total, this amounted to $1,473 for the study area and $1,573 for the water supply area. The per capita disposable income for the nation was $1,937.

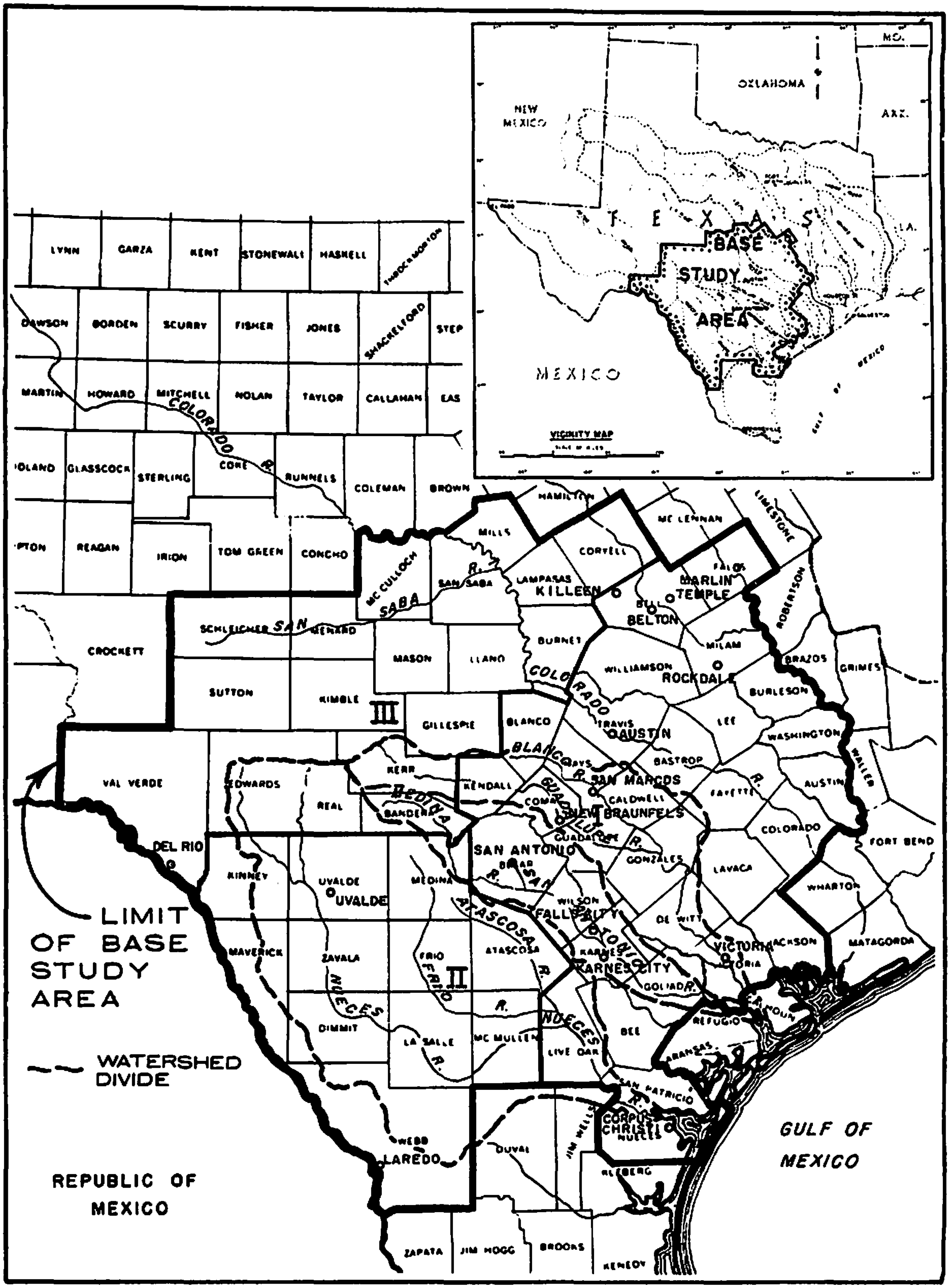


FIGURE 15. EDWARDS UNDERGROUND BASE STUDY AREA

55. MANUFACTURING.- Prior to 1940, manufacturing in Texas was dependent largely on agriculture and forestry for raw materials and furnished the farmer with the tools of his livelihood. There was the beginning of a mineral-oriented industrial expansion but nothing like the upsurge that followed the advent of World War II.

56. During the war years, the national policy of industrial dispersion and development and the availability of large quantities of mineral resources combined to give impetus to the growth of the refining industry, established the aircraft industry, and gave the state a tremendous boost in the chemical field. The state's income originating in this industry is about 16 percent of the total, nearly double the 9 percent which was derived from manufacturing in 1940.

57. For the study area, manufacturing is not of such relative importance. In 1960, about 9.5 percent of the total income was derived from manufacturing. However, the rate of expansion has been nearly the same as for the state. Measured in terms of the value added by manufacture, the study area has maintained about 10 percent of the state's total for the past 30 years.

58. Nearly two-thirds of the manufacturing in the area is due to three major cities, San Antonio, Austin, and Corpus Christi. Since its founding, San Antonio has been one of the major food processing cities of the state, with flour mills, meat processing plants, and canneries. About one-sixth of the value added for the study area originates in these San Antonio food processing plants. Two large breweries are located in San Antonio. Other important non-durable manufacturing includes printing and publishing and fabrication of apparel. Two large cement plants at San Antonio utilize the high calcium limestone of the Edwards formation.

59. Austin, the capital of the state, manufactures principally food and kindred products, printing and publishing, and allied products.

60. Nueces County, of which Corpus Christi is the principal city, contains six of the 72 refineries of the state of Texas, with about 7 percent of the total refining capacity of the state. Ten percent of the value added by manufacture for the study area is contributed by these refineries. The growth and industrialization of Corpus Christi has been accelerated by the completion of the Gulf Intracoastal Waterway and the deep water channel to the Gulf of Mexico. Most of the refineries in the area are located on deep water channels and process both domestic and foreign oil. Cement and lime are manufactured from shell dredged from the coastal waters. Forty percent of the primary metals industry of the study area is located in Nueces County processing waterborne aluminum, zinc, iron, copper, and cadmium.

61. The Aluminum Corporation of America operates an aluminum reduction plant in Milam County. Bauxite imported through Corpus Christi is processed in the Port Comfort plant and forwarded to Milam County for reduction. The Reynolds Metals Company operates alumina and reduction plants in San Patricio County processing imported bauxite.

62. Within the study area, 96 percent of the manufacturing is found in subarea I. The value added by manufacture in 1958 for the three subareas is as follows:

Area	Value added in 1958 (millions of 1960 dollars)
I	475.7
II	11.8
III	9.5
Total	497.0

63. For the water supply area, income from manufacturing represents about 7.7 percent of the total. About 88 percent of the manufacturing is concentrated in the San Antonio metropolitan area. By far the most important products of San Antonio manufacturers are food and kindred products. In 1958, the value added in this segment of manufacuring in San Antonio was $74 million, 47 percent of the total for the county. Included in the plants in this category are two large breweries, two large flour mills, several meat processing plants, and canneries specializing in Mexican foods. Cement plants; stone, clay, and glass products; apparel and related products; fabricated metal products; machinery except electrical; furniture and fixtures; and printing and publishing comprise the other large contributors to the total of value added by manufacture within Bexar County.

64. Manufacturing in the other counties of the water supply area is principally food and kindred products, such as flour and feed mills; printing and publishing; apparel and related products; and textile mill products. The relative importance of manufacturing categories is illustrated by table 2 which shows the employment in these categories as a percent of the total manufacturing employment for the United States, Texas, the base study area, and the water supply area. The table was prepared from information extracted from the U. S. Bureau of the Census, U. S. Census of Population: 1960. General Social and Economic Characteristics.

65. AGRICULTURE.- Although agriculture has been displaced as the largest industry, farming and ranching is still of major importance in the study area. Crop and livestock production provides livelihood for

TABLE 2

EMPLOYMENT IN MANUFACTURE
1960

	United States	Texas	Study area	Water supply area
	Percent of manufacturing employment			
Furniture, lumber, and wood products	6.09	6.11	6.97	5.20
Primary metal industries	6.99	4.99	7.26	1.44
Fabricated metal industries	7.38	5.79	4.56	6.39
Machinery except electrical	8.95	8.68	4.82	5.68
Electrical machinery	8.49	4.08	1.40	1.75
Motor vehicles and motor vehicle equipment	4.81	1.25	0.61	0.89
Transportation equipment except motor vehicle equipment	5.58	9.09	2.33	2.85
Other durable goods	7.83	6.34	8.83	9.65
Total durable goods	56.12	46.33	36.78	33.85
Food and kindred products	10.41	14.77	24.74	29.38
Textile mill products	5.48	1.44	4.80	6.87
Apparel and other fabricated textiles	6.62	6.16	7.24	10.89
Printing, publishing, and allied products	6.52	7.46	11.98	11.30
Chemical and allied products	4.92	8.70	6.28	2.13
Other nondurable products	9.93	15.14	8.15	5.58
Total nondurable products	43.88	53.67	63.22	66.15
TOTAL	100.00	100.00	100.00	100.00

about 58,000 operators of farms and ranches in the study area, including about 10,300 in the water supply area. Income from agriculture is about 3 percent of the total for the water supply area and about 8.2 percent of the total for the study area. However, this is not the measure of its total importance. In 1958 about $110 million, or 60 percent of the value added by manufacture for the water supply area, came from industries which process agricultural products. Additional effort was expended in the manufacture, distribution, and sale of supplies needed by agriculture and the marketing, processing, and distribution of agricultural products.

66. In 1959 the total value of all farm products sold was $392 million for the study area and $72 million for the water supply area. Sale of livestock and livestock products represented 63 percent and 77 percent of the respective amounts.

67. TRANSPORTATION.- The history of the growth of the water supply area has been the history of the growth of modern transportation. In the 19th century San Antonio, already an important distribution point, was served by ox and mule train from the coast. By 1850, the year of the first United States census in Texas, the two urban centers in Texas were San Antonio, the commercial center for most of south Texas and northern Mexico; and Galveston, the major seaport west of New Orleans. The problem of transportation of cattle from the ranches of Texas to the packing house centers of the north was first solved by enormous cattle drives. It has been estimated that 10 million head of cattle were driven from Texas between 1866 and 1895 in 4,000 drives averaging 2,500 head.

68. The advent of the interstate railroad in the 1870's was the beginning of the end of the big trail drives and the start of the industrialization of Texas.

69. In 1877 San Antonio was reached by its first railroad, an intrastate line connecting to the ports of Houston and Galveston. Shortly thereafter the city was reached by the first of the three major lines that now serve the city.

70. Texas' excellent system of highways and farm and ranch roads link all parts of the state to allow rapid transportation by motor vehicle from virtually every farm and ranch gate to the urban centers.

71. Water transportation is furnished the base study area by the Gulf Intracoastal Waterway and by the deep water channel at Corpus Christi. Completion of the deep water channel to the port of Corpus Christi in 1926 provided the initial stimulus for the industrialization of the coastal portion of the study area. The port has now become the 12th largest in the nation in terms of total tonnage, and the city of Corpus Christi has increased in population about 1,500 percent from 10,500 in 1920 to 167,700 in 1960.

72. In 1962, exports and imports were about 65 percent crude petroleum and petroleum products; 24 percent metallic ores and metals; 7 percent agricultural commodities; 3 percent chemicals and derivatives of the petro-chemical industry; and 1 percent other. About 4.5 million tons of bauxite, 17 percent of the total commerce, were imported for processing within the base study area. Foreign, as well as domestic, oil is processed at the six refineries near Corpus Christi.

73. MINERAL PRODUCTION.- Over 85 percent of the value of mineral production for the base study area came from subarea I in 1960. Slightly over 10 percent of the 1960 study area value of mineral production came from subarea II. The total value of crude oil, natural gas and hydrocarbon liquids was $313,844 in 1960, which represents over 77 percent of the total value of mineral production in the study area. The value of asphalt, sand and gravel, stone, uranium, high calcium limestone, shell, clays and lignite production in the study area make up the remaining 23 percent of the value of mineral production. The hydrocarbon products play a very important role in the study area. The production of crude oil represents about 61 percent of the value of hydrocarbon production in the study area, followed by natural gas production, representing 36 percent of hydrocarbon production value. The remaining portion consists of hydrocarbon liquid production. Uranium "yellow cake" is being recovered at the $2 million, 300 ton-a-day uranium mill of Susquehanna-Western, Inc., at Falls City. The mill treats ore from open pits in Karnes County; uranium ore is also being recovered in Live Oak County. Lignite is being mined from open pits in Milam County for use at the 240,000 KW steam-electric plant which furnishes power for aluminum reduction near Rockdale. Uvalde County supplied all the native asphalt produced in Texas in 1960. Nueces County was the Texas leader in 1960 lime output. About equal quantities of limestone and shell are used as basic raw material for lime production. Most of the lime output, 94 percent, was consumed within the state; the major part was captive. Out of state shipments were sent mostly to adjoining states. Principal chemical and industrial uses are in manufacture of alkalies, paper, and petrochemicals and as metallurgical lime in open hearth and electric furnaces. A large quantity is used for purifying and softening water. Bexar County led the state in the value of stone (shell excluded) production in 1960. High calcium limestone for cement is important in the mineral economy of the study area. Three of the seventeen cement plants in the state are located in the study area. Two of these plants are located in San Antonio and the other is located in Corpus Christi.

74. Several minerals are imported in significant quantity for processing in the study area, such as bauxite, which is extracted at the Aluminum Company of America plant in Calhoun County at Point Comfort, and at the Reynolds Metal Company plant in San Patricio County near Corpus Christi. Copper and zinc are imported at Corpus Christi and processed at the American Smelting and Refining Company smelter.

75. For the water supply area, petroleum production is not of such high relative importance as for the whole of the study area. In 1960, the value of crude oil, natural gas, and hydrocarbon liquids was $22.1 million, about 48 percent of the total value of minerals produced. All of the native asphalt produced in Texas is derived from pits in the water supply area. Two cement plants utilizing limestone in manufacture are located at San Antonio. Crushed rock, building stone, limestone for lime, sand and gravel are other minerals produced in the water supply area.

76. THE ROLE OF GOVERNMENT IN THE ECONOMY.- For the water supply area, as well as the study area, the role of Government is the most important single segment of the economic structure. In 1960, employment in Government, including the military, was 27 percent of the total for the water supply area and 20 percent of the total for the study area. Large permanent military installations are maintained at various points within the study area. These include:

a. San Antonio.-

(1) Fort Sam Houston, Headquarters of the Fourth U. S. Army; location of Brooke Army Medical Center; a field office of the U. S. Army Map Service; Central Service Center; Army and Air Force Exchange Service and Fort Sam Houston National Cemetery.

(2) Brooks Air Force Base.

(3) Lackland Air Force Base.

(4) Randolph Air Force Base.

(5) Kelly Air Force Base.

b. Austin.-

(1) Bergstrom Air Force Base.

(2) Headquarters of the XIII U. S. Army Corps.

c. Killeen.-

(1) Fort Hood, Headquarters of III U. S. Army Corps, Second Army Division, First Armored Division, First Logistic Command, and Fourth U. S. Army Language Training Facility. Fort Hood contains 207,000 acres.

d. Laredo.-

(1) Laredo Air Force Base.

e. Del Rio.

(1) Laughlin Air Force Base.

f. Corpus Christi.

(1) Corpus Christi Naval Air Station. Partially deactivated. Numerous small military installations and reserve components are located throughout the study area.

77. In Bexar County alone about 81,000 persons are engaged in Government, 66,000 of whom are military or civilian employees attached to the military. This includes an undetermined number engaged in the space programs.

WATER RESOURCE DEVELOPMENT

78. CORPS OF ENGINEERS PROJECTS.- At present, Canyon Reservoir is the only Corps of Engineers Reservoir in operation in the study area and is located at river mile 303.0 on the Guadalupe River about 12 miles northwest of New Braunfels. It was constructed for flood control, water supply, and recreational purposes. Construction of the project began in April 1958 and deliberate impoundment began on June 16, 1964. Blieders Creek Reservoir, a flood control only project to be located at river mile 5.8 on Blieders Creek, 1.5 miles north of New Braunfels, is in the advance planning stage. Blieders Creek Reservoir, when constructed, will control the runoff from a 14.8 square mile area and provide flood protection to the city of New Braunfels. The Corps of Engineers also has under construction a channel improvement project in the city of San Antonio which includes the clearing, widening, deepening, and straightening of approximately 31 miles of river and creek channels and construction of certain related structures. This project was begun in November 1957 and, when completed, will control the runoff from approximately 114 square miles of drainage area in and adjacent to the city of San Antonio. Pertinent data for the Canyon and Blieders Creek Reservoir projects and the San Antonio Channel Improvement project are given in tables 3 and 4. Construction pictures of the Canyon and San Antonio projects are shown in figure 16.

79. SOIL CONSERVATION SERVICE PROGRAM.- The Soil Conservation Service of the U. S. Department of Agriculture has formulated "Work Plans" for the Martinez, York, and Salado Creeks watersheds within the Edwards Reservoir area. The plans provide for construction of 38 watershed protection and floodwater retarding structures to provide control over a drainage area of about 218 square miles. The structures will contain a total of about 63,767 acre-feet of detention storage.

80. On July 1, 1964, the Soil Conservation Service had in operation 18 structures in two of the watersheds in the study area. Of these structures, five are located in the watershed on Martinez Creek, a tributary of Cibolo Creek in Bexar County, and 13 are in the watershed of York Creek, a tributary of the San Marcos River. Pertinent data on the projects which have been constructed and on those additional projects which are planned for the area are presented in table 5.

81. PROJECTS CONSTRUCTED BY LOCAL INTERESTS.- Development of surface water resources by local interests in the Edwards Reservoir area has been minimal due largely to the availability of ground-water resources. The principal reservoir projects within the three basins are described below.

82. In the Guadalupe River Basin, Comal County has constructed one flood-water retarding structure, with a detention capacity of 350 acre-feet, in the Comal Creek watershed to increase ground-water recharge and to provide flood protection.

83. Local interests developments on the San Antonio River and tributaries consist of Lake Medina and Medina Diversion Reservoir on the Medina River, and Olmos Reservoir on Olmos Creek in San Antonio. Lake Medina with a capacity of 254,000 acre-feet, and Medina Diversion Reservoir with a capacity of 5,750 acre-feet, were completed in 1913. These projects are owned and operated by the Bexar-Medina-Atascosa Counties Water Improvement District No. 1 to provide a water supply and gravity diversion for irrigation of lands in the District. In 1926 the City of San Antonio constructed Olmos Reservoir on Olmos Creek to provide flood protection for certain areas of the city. Olmos Reservoir has a storage capacity of about 15,500 acre-feet and controls the runoff from about 32 square miles of drainage area. Upon completion of the San Antonio Channel Improvement project, discussed previously, Olmos Reservoir will become an integral part of the plan for flood protection of the San Antonio area. Pertinent data for the existing reservoir projects in the San Antonio River Basin are presented in table 6. Photographs of the Medina projects are shown in figure 17.

84. Except for stock ponds and several small recreation lakes, there has been no development by local interests in the Nueces River Basin upstream of the Balcones fault zone of reservoirs for surface water supply or flood control; however 13 structures have been built in Uvalde County near Uvalde to improve the natural facilities for ground-water recharge. The recharging of an aquifer artificially may be accomplished by water spreading or injection of water through wells, pits, shafts, or other natural surface openings. The 13 structures in Uvalde County are of the latter type, consisting generally of small impounding structures and preservation of existing surface openings into the water-bearing formations of the area. The impounding structures allow an increased amount of water, collected during periods of high discharge, to enter the water-bearing formations through the existing openings by reducing the velocity of the water across the land surface. The addition of the impounding structures and installation of devices to protect existing openings have resulted in the introduction of surface waters to the underground strata at higher rates. Views of some of the recharge structures are shown in figure 18.

CANYON DAM
GUADALUPE RIVER

SAN ANTONIO CHANNEL IMPROVEMENT

FIGURE 16
CORPS OF ENGINEERS PROJECTS

EDWARDS UNDERGROUND RESERVOIR

TABLE 3

PERTINENT DATA - EXISTING AND AUTHORIZED
CORPS OF ENGINEERS RESERVOIRS

	RESERVOIR	
	Canyon	Blieders Creek
Stream	Guadalupe	Blieders Creek
River mile	303.0	5.8
Contributing Drainage Area (square miles)	1,425	14.8
Net Storage - acre feet		
Sediment Reserve		
Conservation Pool	19,800	-
Flood Control Pool	8,300	400
Conservation	366,400	-
Flood Control	346,400	7,312
Total Controlled Storage (acre-feet)	740,900	7,712
Yield (acre-feet per year)	96,400	-
Pertinent Elevations - ft. msl		
Top Conservation Pool	909.0	-
Top Flood Control Pool	943.0	750.5
Design Water Surface	969.1	763.1
Top of Dam	974.0	768.0
Dam		
Type	Earth Fill	Earth Fill
Length	4,410 ft. (Main Emb.)	3,730 ft.
Maximum height	224 ft.	84 ft.
Top width	20 ft.	20 ft.

TABLE 4
PERTINENT DATA - EXISTING LOCAL IMPROVEMENT (FLOODWAY)
PROJECTS BY CORPS OF ENGINEERS

Project	Local Agency	Stream	Drainage area at head of project - sq. mi.: Controlled	Drainage area at head of project - sq. mi.: Uncontrolled	Drainage area at head of project - sq. mi.: Total	Drainage area at lower limit of project (sq.mi.)	River mile limits of project	Improved channel length (ft)
San Antonio Channel Improvement	San Antonio River Authority	San Antonio River	32.0	1.6	33.6	113.7	221.8 to 237.3	60,600
		San Pedro Creek	0.0	1.0	1.0	44.5	0.0 to 4.9	26,100
		Apache Creek	0.0	17.6	17.6	22.6	0.0 to 3.4	18,115
		Martinez Creek	0.0	2.6	2.6	7.1	0.0 to 4.5	23,830
		Alazan Creek	0.0	3.9	3.9	17.7	0.0 to 4.3	22,770
		East Fork Martinez Creek	0.0	0.5	0.5	1.7	0.0 to 1.6	8,300
		North Fork Martinez Creek	0.0	0.9	0.9	1.2	0.0 to 0.7	3,910

TABLE 5

SUMMARY OF PERTINENT DATA FOR EXISTING AND PROPOSED SOIL CONSERVATION SERVICE RESERVOIRS

Watershed	Number of structures completed (1)	Total Proposed Structures (2)			
		Number	Drainage area controlled (sq.mi.)	Sediment storage (ac.ft.)	Detention storage (ac.ft.)
Martinez Creek	5	6	29	2,478	6,511
Salado Creek	0	16	118	5,263	42,005
York Creek	13	16	71	4,950	15,251

(1) Completed as of July 1, 1964.

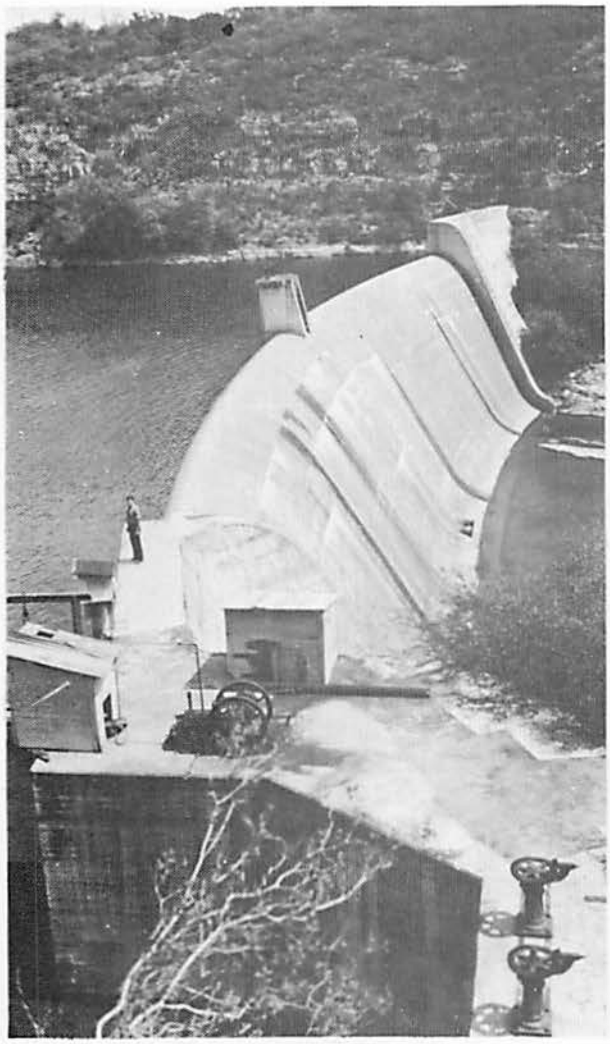
(2) Includes completed structures.

TABLE 6

PERTINENT DATA - EXISTING NON-FEDERAL RESERVOIRS WITH CAPACITIES GREATER THAN 5,000 ACRE-FEET

Project	Ownership	Location		Contributing drainage area	Total storage	Elevation at maximum controlled storage	Year con-	Dependable yield
		Stream	River mile	(sq.mi.)	(ac.ft.)	(ft. msl)	structed	(cfs)
Medina Lake	Bexar-Medina-Atascosa Counties W.I.D. No. 1	Medina River	70.4	633	254,000	1064.5	1913	0
Medina Lake Diversion Reservoir	Bexar-Medina-Atascosa Counties W.I.D. No. 1	Medina River	66.4	-	5,750	919.0	1913	0
Olmos Dam	City of San Antonio	Olmos Creek	0.8	32	15,500	728.0	1926	(1)

(1) Olmos Dam constructed for flood control only.



DIVERSION DAM

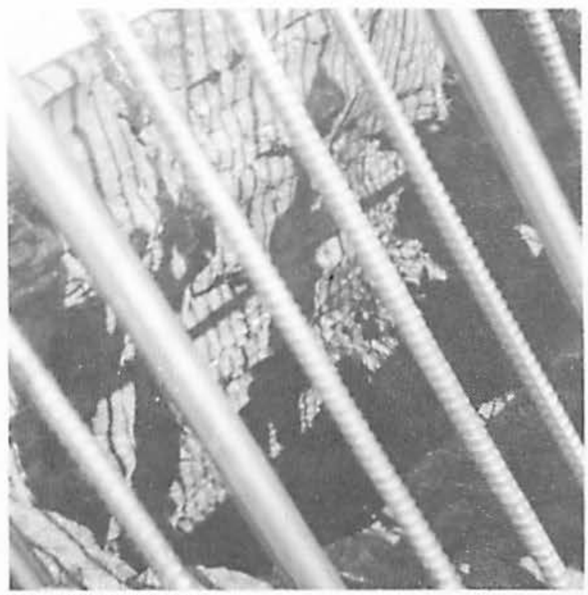
IRRIGATION CANAL FROM DIVERSION DAM TO BELOW CASTROVILLE

FIGURE 17

MEDINA RESERVOIR PROJECT

EDWARDS UNDERGROUND RESERVOIR

RECREATION LAKE
SABINAL RIVER



SMALL RECHARGE PROJECTS

TRASH RACKS OVER DRILLED WELLS
DRY FRIO RIVER

TRASH RACK OVER 20-FOOT NATURAL
RECHARGE OPENING
INDIAN CREEK

FIGURE 18

PROJECTS CONSTRUCTED BY LOCAL INTEREST

EDWARDS UNDERGROUND RESERVOIR

85. INTRODUCTION.- Water problems are known to exist in many parts of the Guadalupe, San Antonio and Nueces River Basins. However, only those portions of the three river basins that would be affected by projects constructed upstream from the Edwards Underground Reservoir for recharge, water conservation and flood control purposes are considered to be within the scope of this report. Subsequent paragraphs of this section will describe problems associated with the Edwards Reservoir, other water supply problems and requirements within the study area, flood problems along the principal streams that flow through the Edwards Reservoir area, and the needs in this area for the surface water storage and facilities for fish and wildlife and general recreation purposes.

86. PROBLEMS ASSOCIATED WITH THE EDWARDS UNDERGROUND RESERVOIR.- In efforts to devise a sound feasible means of accomplishing the effective recharge of the Edwards Reservoir, consideration must be given to certain important features and problems peculiar to the aquifer and its recharge area. These problems are discussed briefly in the following paragraphs.

a. Problems in availability of ground water.- In estimating the availability of ground water in certain parts of the region to meet the anticipated future water requirements, certain peculiarities of the water-bearing formations should be borne in mind. In most every area, some formations yield large quantities of good water, some yield little or no water or small amounts of poor quality, and still others are water-bearing in some localities but not in others. In the artesian reservoir area ground water is found in the cracks and solution channels along the belt of faulting. The size of these channels is extremely variable, even in the same general location. Wells drilled only a few feet apart can have wide variations in yield; however, those drilled near the faults in the main zone of faulting generally yield large amounts of water. Yield from other wells can frequently be improved by treatment with acid, which enlarges minute openings connected to large solution channels in the vicinity of the well. Along the southern limits of the Balcones fault zone wells yield variable quantities of hydrogen sulfide water with a high dissolved solid content. Also, many of the wells in this zone of poor quality water are practically dry.

b. Structural problems.- Structural features of the geology of the region present the greatest problem to construction of reservoirs containing a permanent pool for water conservation on streams of the Edwards Plateau. Limestones are dissolved by the solution action of meteoric waters, or waters derived from the atmosphere. Particularly soluble are those limestones, like the Edwards and associated limestones, whose principal constituent is calcium carbonate. The solution action of ground water filtering through this formation forms channels and caverns for escape of any water that may be impounded in a surface reservoir or flowing through a stream channel in this limestone. This limestone is also very hard and brittle making it particularly susceptible to fracturing, shattering, and jointing, which is associated with the faulting in the area. These fractures or faulted areas also provide escape routes for surface water.

(1) This is not necessarily the case involving the underlying Glen Rose limestone. This formation contains significant quantities of dolomite, which is more resistant to the solution action of water. In addition, this limestone formation is more "earthy," softer and more flexible, and is more susceptible to folding than to fracturing in the presence of minor earth movement. Providing the water table in the area of a proposed surface reservoir slopes toward the stream from the surrounding hills, the chances are rather favorable that a reservoir constructed in this limestone would be relatively tight and would not have appreciable leakage.

(2) For construction of flood control or recharge structures designed primarily to stop high floodflows and release them at a slower rate, which are structures that are not intended to impound permanent storage, the Edwards and associated limestones are considered to be a good foundation rock. During periods when water is impounded in the reservoir leakage would occur along joint systems or fractures that may be present in or around the structure or in the reservoir area. This leakage condition, however, should present no problem in construction or stability of the dam.

c. Conditions affecting recharge.-

(1) Evaporation.- In the semi-arid Edwards Plateau country of the Nueces River Basin evaporation is a major problem in impounding water in surface reservoirs. The net annual loss from a reservoir surface in this region ranges from 35.7 inches at San Antonio to 55.3 inches at Del Rio. Approximately two-thirds of this annual evaporation normally occurs during the spring and summer months from April through September, when high temperatures and hot dry winds prevail. A surface reservoir in this region covering an area of 5,000 acres would lose from 15,000 to 23,000 acre-feet per year by evaporation.

(2) Siltation.- The perennial streams of the Edwards Plateau which recharge the Edwards Underground Reservoir are crystal clear with very little sediment, except when they are at or above flood stage. During periods of high water flows, however, the streams carry leaves, trash, and brush and also some top soil in suspension. The streams also roll and slide a substantial amount of gravel, sand, and

boulders along the streams. These materials would tend to obstruct the openings in the Edwards outcrop, at least temporarily, and reduce the infiltration rate of the surface water into the underground aquifer. It is significant, however, to note that over a long period of years siltation under existing recharge conditions has seemingly presented no serious problems. The openings in the limestone outcrop are larger than those in a sand or gravel aquifer and the rock material that is deposited in the openings is largely calcium carbonate, which in itself is soluble. The organic material, including the brush, leaves, and other debris aids in the solution of the limestone by releasing carbon dioxide upon decay. The Geological Survey concludes that in spite of the large volume of material washed into the openings of the Edwards outcrop there is no evidence that recharge from the streams has been reduced during the thirty years of observation prior to 1958.10/ The many openings and solution channels in the Edwards limestone which carry recharge water from the streams to the underground reservoir are adequate to absorb all flow from the streams under moderate discharge conditions. A good example of continued leakage from a reservoir project over a long period of time may be seen at Medina Dam and Diversion Dam on the Medina River constructed in the Balcones fault zone. This project has been in operation for 50 years and the leakage at present is as great as at any time in the past.

d. Problems related to excess withdrawals from the aquifer.- Withdrawals of water by pumping from an underground reservoir of this type upsets the natural balance of inflow and outflow, with a resultant decrease in the water level in the wells and to a lesser degree in the entire aquifer. Since underground aquifers like the Edwards Underground Reservoir are replenished by rainfall on the outcrop of the formation, moderate pumping presents no appreciable problem or damage to the resource, except to decrease the springflow. Serious problems arise from depletion of the reservoir by pumping in excess of the rate of recharge. As the reservoir is depleted and the water levels fall, the cost of pumping increases. This causes economic loss and hardship to all users, especially to small users and farmers in irrigated areas, including those who depend on the springflow for water supply.

(1) The maximum recorded recharge to the Edwards Reservoir occurred in 1958, the second successive year of abundant rainfall following the end of the drought which extended from 1947 through 1956. The annual recharge for this year was in excess of 1,700,000 acre-feet, in contrast to the minimum recorded recharge of 44,000 acre-feet in 1956. However, the average annual recharge between the years 1935 and 1956 has been estimated to be 423,200 acre-feet per year. Competent ground-water hydrologists and engineers have concluded that the quantity of withdrawal, including springflow, from the Edwards aquifer should not exceed between 385,000 and 400,000 acre-feet per year in order that the reservoir, which is

partially depleted in drought years, could be fully replenished by subsequent rainfall and recharge. Figure 19 shows the effects of constant pumpage on water levels in the Edwards Underground Reservoir under existing conditions of recharge..

(2) W. F. Guyton, Consulting Ground-Water Hydrologist, in a report to the San Antonio City Water Board in 1959 12/ listed the results which it is generally believed can be expected if the reservoir is subjected to the sustained increase in pumpage. The expected results are the following:

"a. Water levels in wells will drop steadily and rapidly.

b. The water in some of the large wells along the southern and southeastern sides of the reservoir may become salty.

c. Comal Springs will soon dry up again.

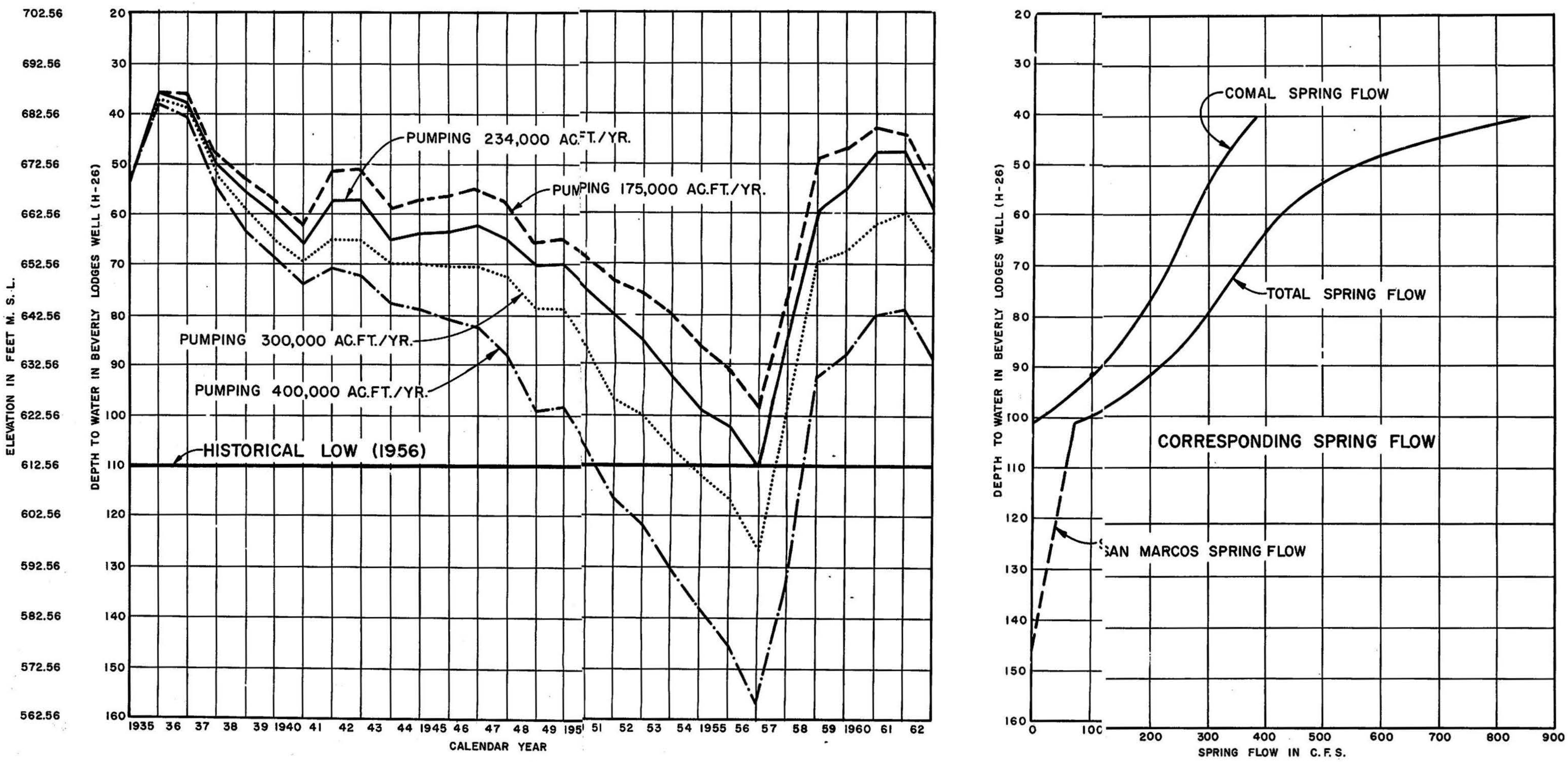
d. San Marcos Springs will dry up a few years after Comal Springs.

e. Except for relatively minor variations due to wet cycles, the reservoir will be on a depletion schedule after about 1964, when it is estimated that the needs will start exceeding the available supply and the reservoir will be headed toward drying up.

f. Sooner or later, depending on storage in the reservoir, the water levels will become so low that many wells will fail and the area will have a serious shortage of water."

e. Problems in quality of water.- In 1954 1/ the Geological Survey reported that sewage and other wastes have been allowed to enter the Austin chalk and alluvial deposits which form the land surface in the San Antonio metropolitan area. Since these formations have hydrologic connections with the Edwards limestone aquifer, this type situation presents danger of contamination. The reservoir is also extremely vulnerable to pollution from such activities involving discharge of oil field brine, sewage or industrial wastes into abandoned wells, streams, or in coarse sands, gravels or limestone outcrop in the recharge or artesian areas of the reservoir.

(1) In the San Antonio area it has been found that there exist wells which produce significant quantities of water charged with



NOTE:
For hydrologic routings above El. 682.0 spring flow curves were extended.

FIGURE 19
EFFECTS OF CONSTANT PUMPAGE ON WATER LEVELS IN THE EDWARDS UNDERGROUND RESERVOIR - EXISTING CONDITIONS

hydrogen sulfide that have not been cased or capped and have been allowed to flow freely into streams below the Balcones escarpment.

(2) One of the greatest problems concerning pollution of the aquifer involves the ever-present danger of encroachment of the highly charged hydrogen sulfide water from the "bad-water zone" into the important well fields in the San Antonio area. This problem is believed to be closely related to large pressure differentials that may be produced by prolonged heavy withdrawals from the reservoir. In 1956, when water in the aquifer was at its lowest recorded level, it was observed that some wells along the line of poor quality water became more saline. After the drought, the quality of the water in these wells returned to normal. 13/ No changes in quality, however, were noted in the water from wells in the "good-water" area during this period. 14/

87. FUTURE WATER REQUIREMENTS.- There are now 17 cities and communities which are dependent upon the Edwards Underground Reservoir as the source of their municipal water supplies. Among them are Uvalde, Sabinal, Hondo, San Antonio, New Braunfels, San Marcos, and Kyle. San Antonio, the state's third largest city, overlies a portion of the Edwards Underground Reservoir, and is the largest city in the United States which obtains its entire water supply from underground sources. The Geological Survey determined that in 1962 the six counties which overlie the artesian reservoir, Kinney, Uvalde, Medina, Bexar, Comal, and Hays pumped approximately 268,200 acre-feet (239.3 million gallons per day) from the underground reservoir. The spring discharge from the aquifer for that one year totaled 321,300 acre-feet (286.6 mgd), making a total discharge of 589,500 acre-feet (see figure 8). This quantity exceeded the average annual recharge for the entire period of record by about 90,000 acre-feet. More recent information relative to withdrawals also indicates that the reservoir has continued on a depletion schedule since 1962 with the additional yield being taken from storage in the aquifer.

88. Demands on the Edwards Reservoir for water supply have shown a rapid increase in recent years. Projections of future water demands for the area, developed by the Public Health Service and graphically illustrated in figures 20 and 21, indicate that the 2025 needs for the 14 counties comprising the Edwards Reservoir area will be four times as great as the 1962 use and will be five times as great by the year 2075, with 84 percent of the increase expected to occur in the San Antonio area. The report of the Public Health Service is presented as an attachment to appendix I.

89. There are at present only two major surface reservoirs in the Edwards area. However, Medina Reservoir, constructed and operated for irrigation purposes, becomes virtually ineffective during periods of moderate to severe drought because of leakage from the main

reservoir and the downstream diversion reservoir. Canyon Reservoir, recently completed by the Corps of Engineers on the Guadalupe River, is the only reservoir in the Edwards area that contains conservation storage for municipal and industrial water supply purposes. This project will provide the area with a dependable yield of 86 mgd (96,400 acre-feet per year).

90. Based on future projections for increased municipal and industrial water use in the area, it is apparent that the future water requirements of the area cannot be provided by the Edwards Underground Reservoir as now constituted. It is also apparent that the additional yield provided by Canyon Reservoir will not be sufficient to meet the anticipated future demands of the area. It, therefore, appears that in the absence of other sources of water supply increased pumping rates from the Edwards Underground Reservoir are clearly indicated, with the result that the level of water in the wells will be lowered and springflows will be severely reduced. Because of this anticipated depletion, the area is confronted with dwindling water supplies and the problem of providing for the further expected increase in water demand occasioned by improved living standards, increased population, irrigation of additional lands, and industrial growth.

91. MUNICIPAL, RURAL, INDUSTRIAL, AND POWER DEMANDS.- Although an extensive increase in water demands for communities and industry throughout the Edwards area is expected to occur, the greatest increase is expected to be in the San Antonio metropolitan area. This city, in addition to being the principal trade and industrial center of south-central Texas, is the center of a large complex of permanent military installations, as previously described. For basic flying, the climate of the area is particularly ideal. The municipal and industrial water use in the San Antonio area in 1962 was in excess of 159 million gallons per day. It is anticipated that future demands when compared to the use experienced in 1962 will about double by the year 1990, be four times as much by the year 2025, and be seven times as much by the year 2075. It is not expected that municipal and industrial requirements will accelerate at such a rapid rate in other portions of the Edwards area as those in the San Antonio metropolitan area. The principal increases in water demands in the other areas are expected to result from an increase in irrigation.

92. IRRIGATION DEMANDS.- Irrigation in the Edwards area dates back to around the beginning of the eighteenth century when Indians dug irrigation ditches to water crops from springs in the region. As early as 1718 the Spanish missions at San Antonio irrigated some 3,000 acres from the San Antonio and San Pedro springs in that vicinity.12/ However, the history of irrigation from wells drilled into the Edwards aquifer did not begin until almost two centuries later.

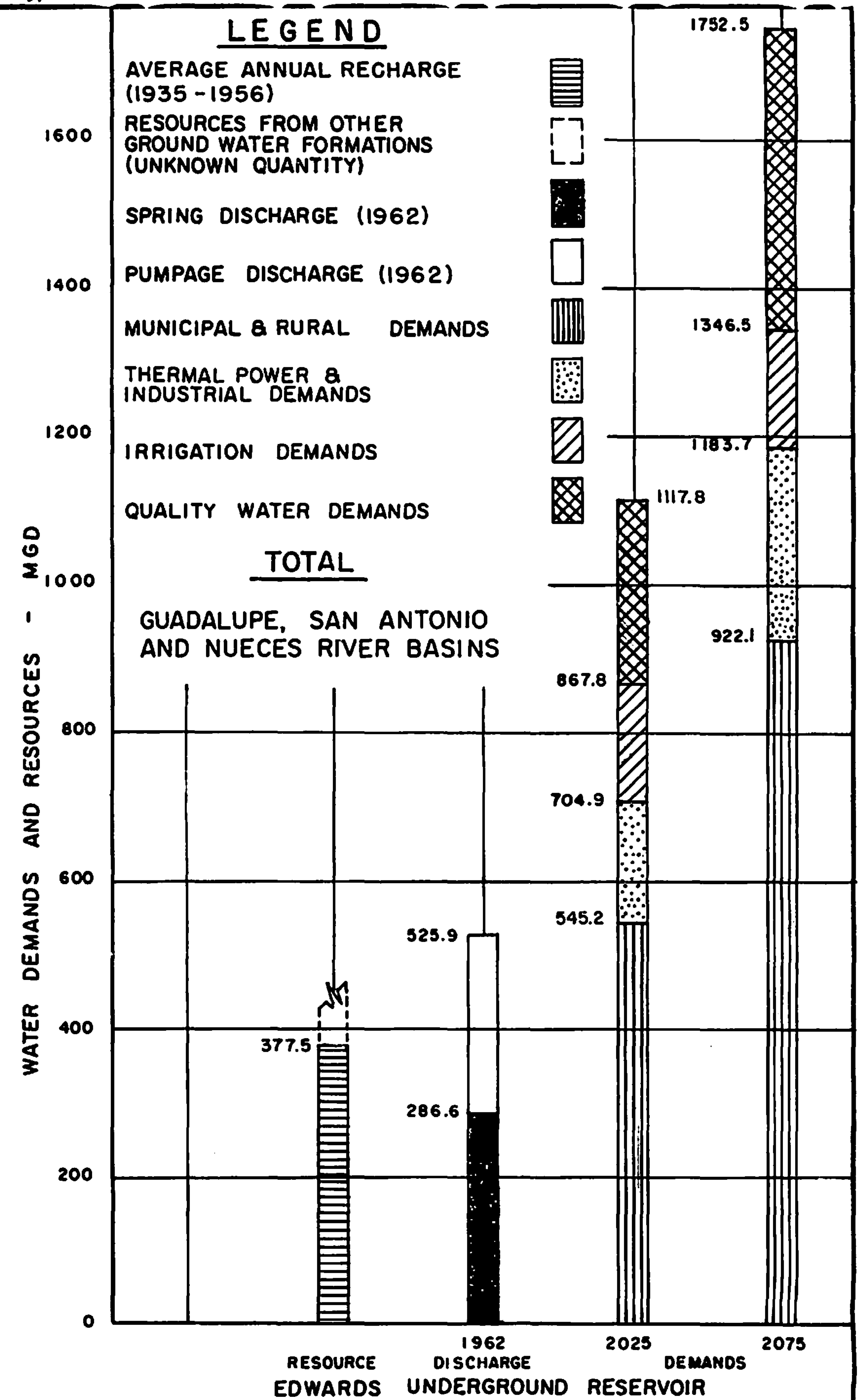


FIGURE 20
WATER DEMANDS AND RESOURCES

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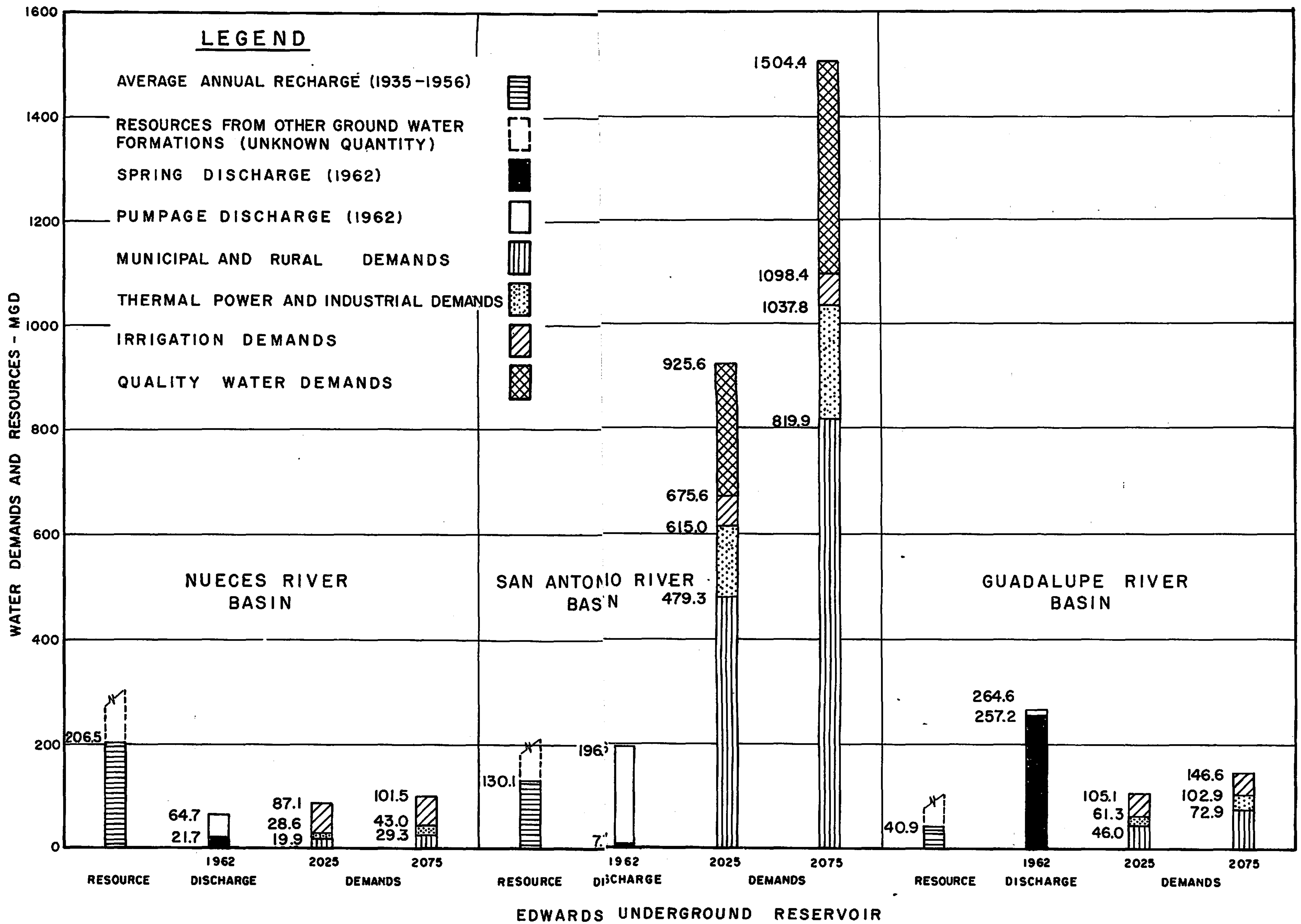


FIGURE 21
WATER DEMANDS AND RESOURCES

The first irrigation wells producing water from this aquifer appeared in about 1884 in Bexar County, 1924 in Uvalde County, and 1947 in Medina County.12/

93. In the western portions of the Edwards area, Leona Springs at Uvalde was the first source of water for irrigation in that area. The Leona formation supplied the first irrigation wells in the Edwards area outside Bexar County. Wells were drilled into the Leona formation in 1908 in Uvalde County9/ and 1934 in Medina County.11/

94. Today there are approximately 300 wells throughout the area which furnish water from the Edwards formation for irrigation. Most of the irrigation water has been used for production of vegetables and feed crops. In 1959 there were about 15,000 acres in Bexar County; 14,000 acres in Uvalde County; and 3,600 acres in Medina County irrigated by ground water.4/ The irrigation by ground water in Medina County is a rather recent development, the major portion of which has occurred since 1947.11/

95. Although ground-water irrigation began as late as 1934 in Medina County, surface-water irrigation began as early as 1918 following the completion of Medina Reservoir project in 1913.

96. The land area within the boundaries of the Bexar-Medina-Atascosa Counties Water Improvement District Number 1, owner of the Medina project, covers approximately 35,500 acres. The original plans concerning the project involved the proposed irrigation of some 150,000 acres12/ from the storage capacity of 254,000 acre-feet in Medina Reservoir. However, because of the large seepage losses from the reservoir and conveyance channel, the district has been able to furnish enough water to irrigate only a small portion of the original area, about 25,000 acres in 1962. During the 1947-1956 drought period, little or no water was available for irrigation from this project.

97. The water used for irrigation in the Edwards area totaled about 105 million gallons per day during 1962. This amount includes water withdrawn from all the underground formations plus surface water obtained from the Medina Reservoir. As shown in figures 20 and 21, it is anticipated that water demands for irrigation in the area will increase to slightly above 160 million gallons per day by the year 2025, then remain relatively constant.

98. It has been estimated that within the Edwards area there are about 255,000 acres of land suitable for irrigation from ground water12/ in addition to the 35,000 acres within the district supplied from the Medina Reservoir project. Because of the diversified crop activity in this region and the long growing season, a water-use factor of about three acre-feet per acre irrigated could be considered applicable. very high

1-2 is more

If it were possible to irrigate the 290,000 acres, the water demands would approach 870,000 acre-feet per year or some 776 million gallons per day. The estimated average annual resources available above the lower edge of the Edwards outcrop are about 940,700 acre-feet per year, which would be wholly inadequate to meet this demand in addition to municipal, industrial and other uses in the area. It is also anticipated that increased heavy pumpage from the artesian aquifer will sufficiently lower the water level to the extent that the cost of pumping for irrigation purposes in some areas will be prohibitive.

99. WATER QUALITY REQUIREMENTS.- In any large or growing metropolitan area disposal of municipal and industrial waste is a prime problem. Even with the best available means of treatment and disposal of wastes, pollution of streams below the outfall of the sewage disposal plants will result. The Public Health Service has determined that water needs for quality control along the San Antonio River downstream from the city to eliminate this health hazard will approach 250 million gallons per day by the year 2025 and 406 million gallons per day by the year 2075. This problem is discussed more fully in the report of the Public Health Service, which is attached to appendix I of this report.

100. FLOOD PROBLEMS.- The streams in the Edwards Plateau area flow through rugged hill country in narrow valleys and canyons with steep gradients which concentrates storm waters rapidly to create floods characterized by sharp peaks of short duration. These floods diminish quickly as they pass the Balcones escarpment into the wider valleys of the coastal plains. Floods originating downstream from the escarpment normally have lower peak discharges but a longer duration.

a. Guadalupe River Basin.- Canyon Reservoir is the only existing major flood control improvement in the Guadalupe River Basin. This project will substantially decrease flood damages along the main stem of the Guadalupe River. Sufficient flood control storage has been provided in this project to control the floods of record originating in the upstream area. Also, construction of the authorized Blieders Creek Reservoir will partially alleviate a serious flood problem in the city of New Braunfels.

(1) For the purpose of analysis of the remaining flood problems which exist in the Guadalupe River Basin, the Canyon, Blieders Creek, and Cuero flood-control projects were considered as existing and in operation. The Cuero Reservoir (stage II) on the Guadalupe River and Sandies Creek is a flood control and water conservation project recommended for construction in reports prepared by the Texas Water Commission, the Guadalupe-Blanco River Authority, the U. S. Study Commission - Texas, and the Bureau of Reclamation. The most severe residual, or remaining flood damages are expected to occur along the lower reaches of the Guadalupe River downstream from the mouth of the

San Marcos River, and along the Blanco and San Marcos Rivers. These damages will be predominantly agricultural with some damages to urban areas, oilfields, transportation and utility facilities. The residual damages are estimated to total approximately $1,080,000 annually. However, with the projected increase in population and industrial expansion, particularly in the downstream reaches of the basin, the average annual damages are expected to double within the next 50 years without additional flood control improvements.13/

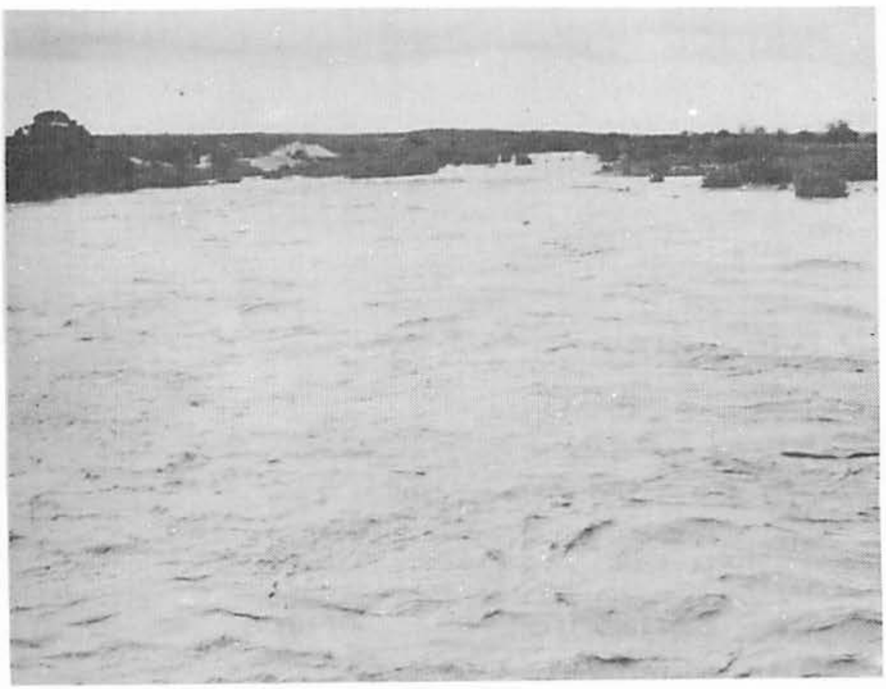
(2) Estimates were made of the annual flood damages along a reach of the Guadalupe River within the Edwards Reservoir area extending from the community of Comfort to the headwaters of Canyon Reservoir. The annual damages in this reach were computed to be approximately $16,500.

(3) A local flood problem exists at the city of San Marcos, which suffers damages from floodwaters originating on the tributary areas of the San Marcos River upstream from and within the city, and from backwater produced by floods on the Blanco River. The average annual damages to the city are estimated at $104,300. Downstream from San Marcos the cities of Gonzales, Cuero, and Victoria are damaged by floods originating on the Blanco, San Marcos, and Guadalupe Rivers.

b. San Antonio River Basin.- In the past the more severe flood problems in the San Antonio River Basin have been largely concentrated in the Metropolitan area of the city of San Antonio. On numerous occasions the San Antonio River and several of its tributaries in and upstream from the city have spilled floodwaters over their banks into the low-lying areas of the city. This problem will be virtually solved, however, upon completion of the San Antonio Channel Improvement project. The new stream channels through the city will have capacities to carry floodflows greater than any of record. It is anticipated that future flood damages within this basin will occur to agricultural lands, transportation facilities, and to utilities along the downstream reaches of the main stem and principal tributaries.

c. Nueces River Basin.- Heavy rainfalls experienced over the portion of the Edwards Plateau area in the Nueces River Basin have produced floods with extremely high peak discharges. Records indicate that the storms of June 1935 and September 1955 produced floods in this area having some of the highest peak discharges ever recorded in Texas from drainage areas of comparable size. On May 31, 1935, a storm occurred over the 153 square-mile drainage area of Seco Creek upstream from the town of D'Hanis, with one unofficial rainfall report of about 22 inches in a 3-1/2-hour period. Although the resulting flood had a rather short duration and relatively small volume, the high water experienced during the passage of the peak discharge of 230,000 second-feet caused extensive damage to the agricultural lands in the valley

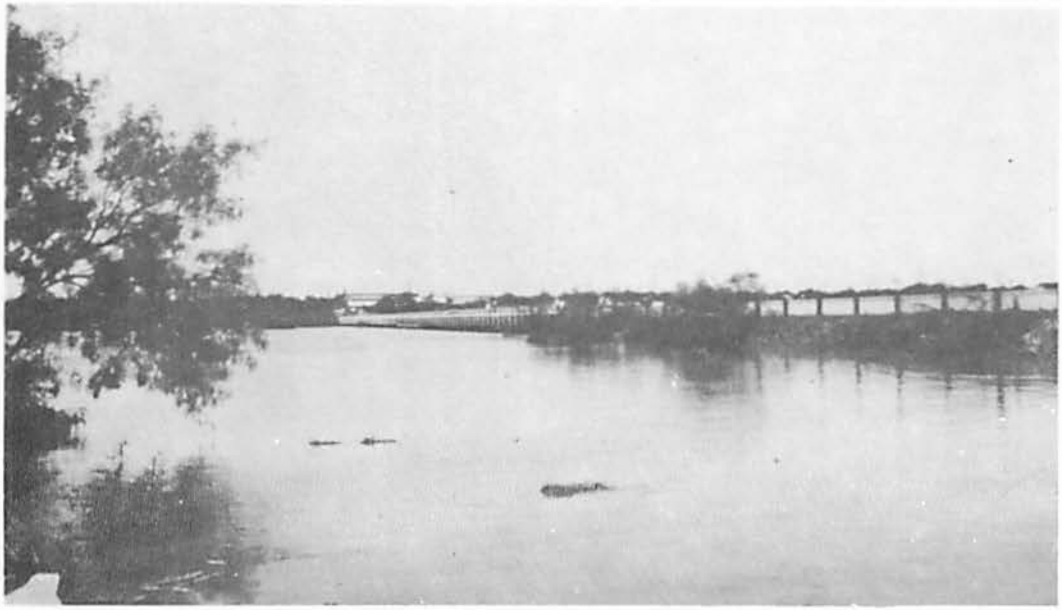
FLOOD OF SEPTEMBER 1952. DAMAGE IN THE CITY OF SAN MARCOS FROM BACKWATER OF THE BLANCO RIVER.



FLOOD OF OCTOBER 1953. DAMAGE TO AGRICULTURAL LANDS ALONG BLANCO RIVER.

PHOTOS COURTESY OF SAN MARCOS RECORD.

FIGURE 22
FLOODS ON THE BLANCO RIVER



JUNE 1935 AT COTULLA

JUNE 1935 AT COTULLA

FIGURE 23
FLOODS ON THE NUECES RIVER

EDWARDS UNDERGROUND RESERVOIR

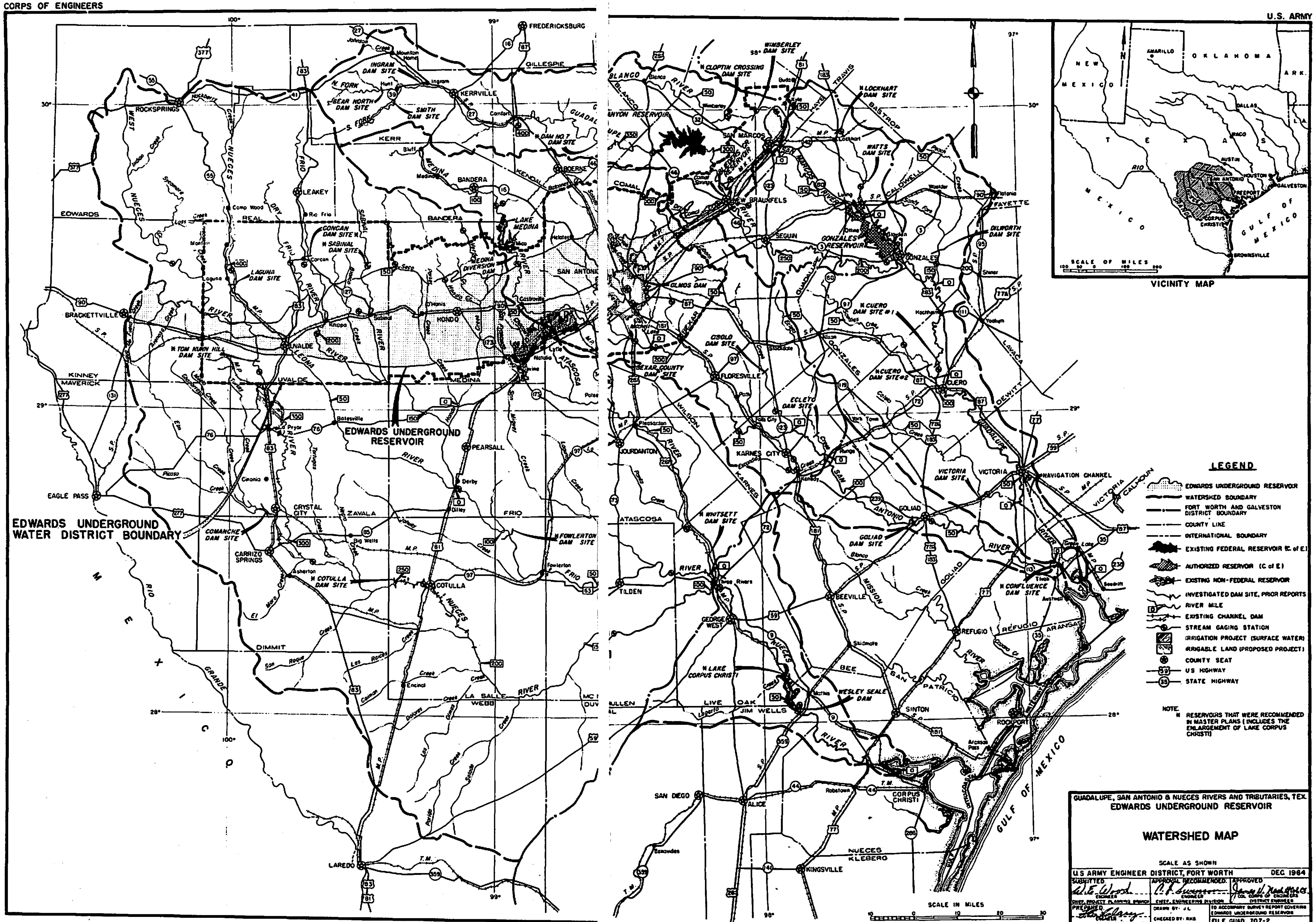
between Parker and Seco Creeks and extensive urban damage in the town of D'Hanis. The flood damages based on July 1964 price levels and conditions of development would have been approximately $2,375,900. The flood of record on the Nueces River at Uvalde in June 1935 had a peak discharge of 616,000 second-feet and caused damages along the river estimated to be in excess of $10 million.

(1) Most of the streams in the Nueces River Basin that flow through the canyon country of the Edwards Plateau have very little flood plain development. The valleys are narrow and are generally suitable only for ranching. Because of the rough terrain, the area has been primarily devoted to the raising of sheep and goats. The principal flood damages are sustained from loss of livestock and extensive ranch fencing.

(2) The highest flood damages in the basin have been experienced on the Nueces River downstream from the Balcones fault zone in the "winter garden" area near the communities of Crystal City, Carrizo Springs, and Cotulla. In this area ground-water irrigation, fertile lands, mild climate, and infrequent killing frosts combine to make winter gardening a successful and profitable industry. Spinach, Bermuda onions, tomatoes, beans, lettuce, and strawberries are the chief crops; citrus fruits are also produced in some areas. During severe floods heavy losses are experienced in this area from destruction of crops and irrigation facilities, and from land erosion and weed infestation. Some urban damages are experienced during floods in the communities of Crystal City on the Nueces River, Three Rivers on the Nueces and Frio Rivers, and Tilden on the Frio River. The average annual flood damages to property and crops along the Nueces River are estimated at $716,100.

101. RECREATION.- The demands for outdoor recreation have greatly accelerated in recent years and should continue to increase in the future. Much of this recreation activity is concerned with the use and enjoyment of our water resources. Regardless of the measure used (the number of visitors to Federal and State recreation areas, number of fishing license holders, or number of outboard motors in use), it is clear that Americans are seeking the outdoors as never before. The general public has found that outdoor recreation produces many benefits--it provides healthful exercise necessary for individual physical fitness, it promotes health, it is valuable for education in the world of nature, and it satisfies simple recreational needs. Water is a key factor of outdoor recreational development and serves as a magnet. Americans from both urban and rural areas show a strong urge for water-oriented recreation. The Edwards Plateau has long been noted for its scenic beauty and, if properly developed, could become one of the outstanding recreational areas in the state. With the addition of a considerable water surface in this area, the recreational potential will be greatly increased. The warm climate is ideal for all types of water-oriented recreation.

102. FISH AND WILDLIFE.- The hill country of the Edwards Plateau abounds in spring-fed perennial streams and timbered lands. The streams usually are clear and provide productive fish habitat. The principal fish species are largemouth bass, catfish, and sunfish. Wildlife resources are diverse and large populations of white-tailed deer, wild turkeys, mourning doves, and fox squirrels exist in the area. Private groups and conservation agencies have succeeded in establishing exotic animal species such as European boar, black buck antelope, axis deer, and aoudad and mouflon sheep. Fish and wildlife are living natural resources and, like other living things, they are initially associated with the land and the water. A great deal is at stake in the preservation and development of our fish and wildlife resources since they are vitally important to our economy and way of living. The recreational value of fish and wildlife is of profound significance to the well-being of people, possibly even more so than the food value of this resource. In our way of life, we no longer have to hunt and fish for food, but the pleasure and sport of hunting and fishing are widely enjoyed. The opportunity to hunt and fish will not automatically remain, and fish and wildlife resources must be considered in the overall plan of improvement for the Edwards Underground Reservoir area. The recommendations of the Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, will be given every consideration in the development of projects in this area.


EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT BOUNDARY
VICINITY MAP
SCALE OF MILES
LEGEND
EDWARDS UNDERGROUND RESERVOIR
WATERSHED BOUNDARY
FORT WORTH AND GALVESTON DISTRICT BOUNDARY
COUNTY LINE
INTERNATIONAL BOUNDARY
EXISTING FEDERAL RESERVOIR (C. of E.)
AUTHORIZED RESERVOIR (C of E)
EXISTING NON-FEDERAL RESERVOIR
INVESTIGATED DAM SITE, PRIOR REPORTS
RIVER MILE
EXISTING CHANNEL DAM
STREAM GAGING STATION
IRRIGATION PROJECT (SURFACE WATER)
IRRIGABLE LAND (PROPOSED PROJECT)
COUNTY SEAT
US HIGHWAY
STATE HIGHWAY
NOTE
* RESERVOIRS THAT WERE RECOMMENDED IN MASTER PLANS (INCLUDES THE ENLARGEMENT OF LAKE CORPUS CHRISTI)
SCALE IN MILES
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
WATERSHED MAP
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2
GULF OF MEXICO

103. INTRODUCTION.- During the course of the study of the Edwards Underground Reservoir special geologic and hydrologic investigations were conducted to study the geology of the Edwards limestone aquifer and the water movement in the underground reservoir. The geology of the Edwards aquifer and of the area in general has been studied by drilling, geologic mapping, and electric logging.

104. A deep core boring was drilled in northeastern Bexar County to study the underground aquifer. In addition to this boring and those at the investigated dam sites, core borings were made at the existing Medina Dam to investigate the possibility of reducing or eliminating leakage from the reservoir. General geologic reconnaissance and mapping were performed on almost all of the streams and rivers flowing from the Edwards Plateau. A program of electric logging of various wells in the area was designed to help delineate the vertical and horizontal extent of the Edwards and associated limestones.

105. To study the hydrological aspects of the Edwards Underground Reservoir, radioactive tracer studies were made in cooperation with the Geological Survey and Isotopes, Inc., of Westwood, New Jersey. The purpose of this investigation was to determine the feasibility of using the tritium measuring method as a means to further define flow paths and rates of flow within the reservoir. The various geologic and hydrologic studies are described in the following paragraphs.

106. EDWARDS EXPLORATION BORING.- A geologic investigation of the underground aquifer by means of a core boring was made in cooperation with the Geological Survey. The location of the exploration boring was in an area northeast of San Antonio where the artesian aquifer narrows to approximately five miles in width. In this area the wells are known to have very high water yields. Large quantities of water pass through this five-mile strip to emit from Comal and San Marcos Springs, making this particular zone one of high permeability. The plans for the investigation included: (1) to penetrate the entire section of the Edwards and associated limestones; (2) to extract a continuous core through the entire formation; (3) to photograph the entire section of the Edwards formation by use of the "Bore Hole Camera;" (4) to electric-log the entire boring; (5) to case the drilled hole from the ground surface down to the top of the Georgetown limestone, the upper member of the Edwards formation; and (6) to allow for the installation of a recorder in the well for future use by the Geological Survey and the Edwards Underground Water District for their continuing study of the aquifer.

107. A summary of the core boring and depth of the formations penetrated are shown in the following tabulation:

Core boring diameter	Depth from ground surface	Material or formation
10" (1)	0.0 to 29.0	Sand and gravel
	29.0 to 92.0	Austin chalk
	92.0 to 127.0	Eagle Ford shale
	127.0 to 175.0	Buda limestone
	175.0 to 229.0	Grayson shale
6" (2)	229.0 to 243.8	Georgetown limestone
3" (3)	243.8 to 711.5 ±*	Edwards limestone
	711.5 ± to 777.5	Glen Rose limestone

*Defined with the assistance of representatives of Shell Oil Company.
(1) With 8-inch casing.
(2) 6-inch boring began at depth 238.8.
(3) 3-inch boring began at depth 321.5.

108. Drilling difficulties occasioned by the presence of hard chert lenses in the limestone, hole caving, and large cavities in the formation limited the core recovery to approximately 65 percent and prevented photography below a depth of 480 feet. However, from the data obtained the following conclusions were reached concerning the Edwards formation in this area:

a. The Walnut Clay and Comanche Peak limestone, the oldest member of the Edwards and associated limestones, were not found in this area. However, the bottom 60 feet of the Edwards limestone is believed to be the time equivalent of the two formations.

b. The Edwards formation has an approximate thickness of 482.5 feet at this point.

c. The Edwards limestone, as revealed by the core samples, is hard, dense, subcrystalline, highly broken, and solutioned. The most highly solutioned and broken zone occurs between the depths of 486 feet and 598 feet. Several cavities were found in this zone measuring up to about two feet in diameter.

d. The Edwards limestone is not uniformly permeable as evidenced by the discovery of favored flow paths throughout the section.

e. The rock samples obtained from the boring were too highly borken and fractured to define a definite joint pattern.

Figure 24 shows photographs taken at four different elevations by the Bore Hole Camera.

109. MEDINA DAM.- Geologic investigations were made at the Medina Dam in an effort to determine the feasibility of reducing leakage from the reservoir project. The dam at the Medina Reservoir is founded on the Glen Rose limestone, Walnut clay, Comanche Peak limestone and Edwards limestone. The Glen Rose limestone is present in the river valley and in the canyon walls to about elevation 1000, some 70 feet below the top of the Medina Dam. All of the rock in the vicinity of the dam has been rather extensively jointed and fractured due to its proximity to the Balcones fault zone. Solutioning is well developed along these fractures as revealed by rather spectacular springflows in the spillway discharge channel and along the river bluff in the left abutment downstream from the dam. From observations during the past year, it has been noted that the volume of springflow in the spillway channel appears to be directly proportional to the storage in the reservoir. Some of the springs which flow when the reservoir is high cease to flow as the lake level drops and the discharge from those that continue to flow is considerably reduced.

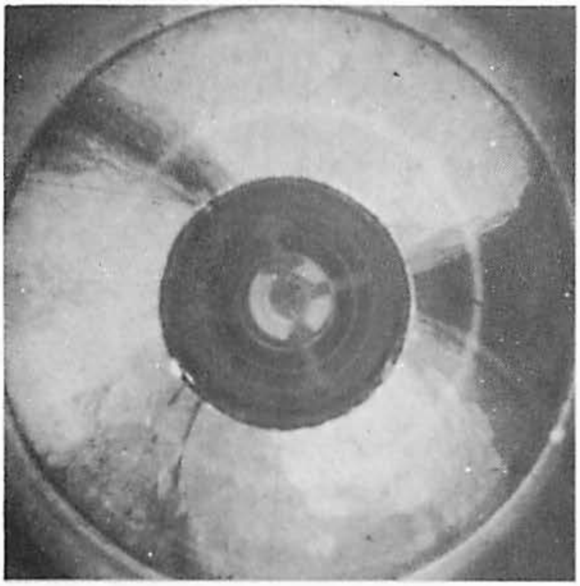
110. Explorations in the dam and spillway areas consisted of geologic mapping and drilling. Eight borings were made in this area. Electric logs were obtained and water pressure tests were made at each boring. Dye injection tests were made at three of the borings.

111. The explorations to date point to the conclusion that leakage from the lake occurs principally through a well-developed joint system. Two sets of joints were identified in the dam and spillway area. The joints, fractures, and bedding planes act as conduits carrying water from the reservoir to springs in the river and spillway discharge channels. Water pressure tests conducted in all of the borings showed the rock to be generally tight except when joints and fractures were encountered.

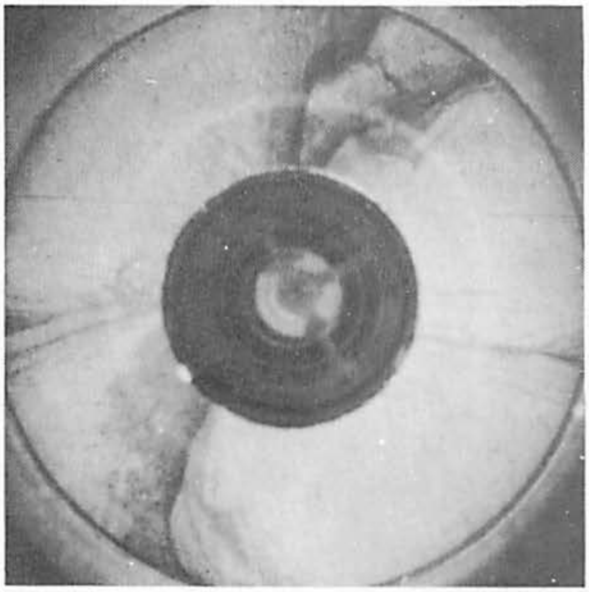
112. Further evidence of the interconnection of the joint system can be seen from the results of the dye tests. After introducing dye and pumping about 1700 cubic feet of water over a three-hour period in a boring located in the spillway saddle, dye appeared in a spring in the spillway channel some 1350 feet south of the hole. In the boring the water was pumped in the zone between 108.8 feet and 120.0 feet. Similar results were obtained with dye tests in two borings on the left abutment of the dam. Dye was introduced in one boring below a depth of 80 feet and, after pumping about 51 cubic feet of water over a 30-minute period dye emitted from a spring in the river channel located approximately 435 feet southwest of the boring. At the time of this study, this spring had a discharge of from 50 to 75 gallons per minute. Dye introduced in another boring in the left abutment appeared in a spring about 700 feet south of the boring after pumping about 733 cubic feet of water in the boring below a depth of 55 feet over a 2-1/2-hour period. This spring had a discharge of from 300 to 400 gallons per minute. These tests prove rather conclusively that large volumes of water can be lost from a full reservoir through this joint system.

THE BORE HOLE CAMERA

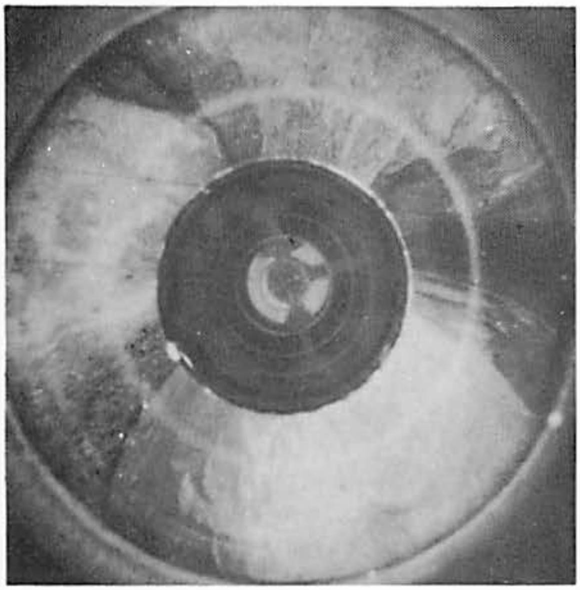
The Bore Hole Camera is a smooth, stainless steel cylinder, 2-3/4 inches in diameter and 34 inches long, with a cable attached to one end by which it is lowered into the boring with a special lowering device. Near its lower end is a transparent quartz window encircling the cylinder and inside the window is a conical mirror which directs an image of the bore hole as viewed through the window upward into the camera lens. A 360°, one-inch section of the bore hole is photographed at 3/4-inch intervals as the camera is raised in the hole. In the center of each picture is an image of a compass and a drift indicator. The camera uses 8-mm color movie film which is exposed one frame at a time by flashing a strobe light as each frame moves into position behind the lens. Photos obtained are viewed on a special projector and appear in a plane as a "doughnut." The photographs should be viewed as if one were in the bottom of the hole looking out. The outside of the "doughnut" is the bottom or lowermost portion of the one-inch segment. The photographs are approximately true scale.



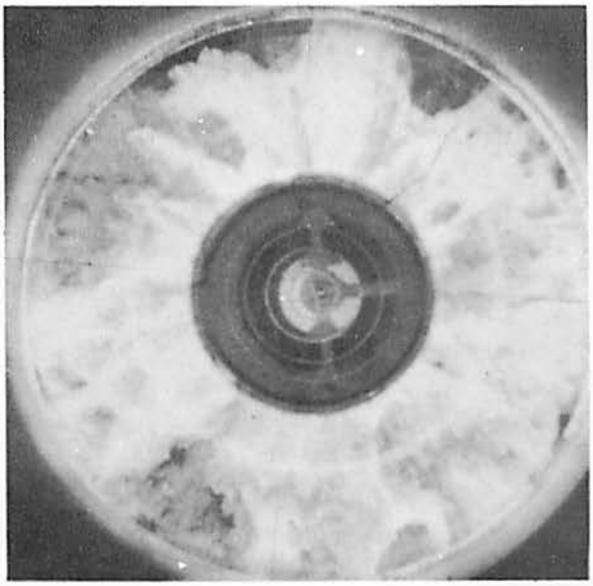
DEPTH 328.0. ARROW IN CENTER OF PHOTO POINTS TO THE NORTH (MAGNETIC). LIMB TO RIGHT OF ARROW DENOTES EAST SIDE. NOTE THE LARGE OPEN FRACTURE ALONG EAST SIDE OF HOLE.



DEPTH 332.4. PRINCIPAL JOINT IS STRIKING NE AND DIPPING ABOUT 45° SE. NOTE THE TWO PIECES OF ROCK IN FRACTURE.



DEPTH 380.0. BROKEN AND FRACTURED LIMESTONE WITH NO ORIENTATION. ANOTHER OPEN FRACTURE ALONG EAST SIDE OF HOLE. ROCK BORDERING FRACTURES AND JOINTS SHOWS EFFECTS OF WEATHERING.



DEPTH 460.3. ROCK IS HIGHLY SOLUTIONED; NOTE OXIDE STAINS AND SOLUTION CAVITIES.

FIGURE 24

BORE HOLE PHOTOS
EDWARDS EXPLORATION BORING

EDWARDS UNDERGROUND RESERVOIR

113. It cannot be definitely concluded, based on the very limited exploration at the dam to date, that leakage from the reservoir can be completely stopped. It is felt, however, that grouting can reduce the leakage from the reservoir. Additional exploration, including a detailed ground-water study to define the water table in the area and extensive testing of the rock upstream from the dam to analyze the effect of the faulting, would be required to determine the feasibility of an extensive grouting program.

114. The losses from the diversion lake, located in the principal recharge area in the Medina River streambed, are so large that even if grouting the Medina Dam were to be found effective it would be necessary to transport the water from the Medina Reservoir across the fault zone in order to obtain any substantial amount of additional water for irrigation.

115. ELECTRIC LOGGING.- Electric logging was performed on exploration borings at most of the dam sites investigated. In addition, through the cooperative assistance of the Geological Survey and a number of private drilling companies, electric logs were obtained on a number of new and old wells throughout the area. All of the information obtained from the logs contributed to the continuing study of the structural geology of the Edwards and associated limestones and the geology and stratigraphy of the area in general. The electric logs were also a significant aid in the correlation of the rock strata and in defining formational contacts.

116. RADIOACTIVE TRACER STUDY.- An investigation of laboratory and other scientific methods available for obtaining additional information regarding movement of underground waters revealed that satisfactory results had been found in somewhat similar circumstances by the "tritium analysis method." This method involves the laboratory analysis of natural water molecules. As commonly known, molecules of water consist of atoms of hydrogen and oxygen. Atoms of an element such as hydrogen appear in two or more forms having the same or very closely related properties. These atoms have the same atomic numbers but different atomic weights. The different forms of the atoms of an element are known as isotopes. Tritium is a radioactive isotope of hydrogen. This natural isotope of hydrogen is present in the atmosphere and in water at all times. Natural tritium is produced by interaction with the atmosphere of cosmic rays from the sun. Its concentration, however, was greatly increased by the nuclear bomb testing program which has been in progress in various parts of the world. This radioactive tritium appears in the water and atmosphere in only minute quantities and is not hazardous to human or animal life. Tritium is not a stable isotope. It has a half life of 12.3 years and upon disintegrating breaks down into helium -3, giving off an extremely low energy beta particle. These are characteristics of tritium that make it valuable in tracing paths of underground waters.

117. The use of natural properties of water molecules in tracer studies is recognized as being superior to the introduction of artificial dyes or other chemicals into the recharge areas of an underground aquifer. Methods have been developed in scientific laboratories to measure the "tritium units" or concentration of the tritium isotope in water. With reference to the Edwards Underground Reservoir study, it was believed that measurement of the tritium concentration in water from streams that recharge the aquifer and in the water that is discharged from the aquifer by wells and springs would reveal to some degree the paths of movement and the time required for the water to travel the length of the underground reservoir. Further investigations of the conditions resulted in a decision to undertake a preliminary sampling and testing program (consisting of 100 water samples) as suggested by Isotopes, Inc., Westwood, New Jersey. A written agreement was consummated with Isotopes, Inc., and the sampling was performed in accordance with the designated time and locations. The samples were forwarded to the laboratory for analyses, correlation of results, and preparation of a report covering the investigation. The report is included in appendix III.

118. The conclusions included in the report indicate that tritium tracer studies can be usefully employed to investigate recharge-discharge problems of underground water storage and determine rates and direction of water movement. Analyses of preliminary samples were limited to natural levels of tritium content and use of equipment capable of measuring the content down to 100 T.U., or tritium units; however, it was found that most of the well samples contained less than 100 T.U. and future analysis will require more sensitive measuring equipment (available in 1964) or the use of enriched samples. More detailed investigations and use of more sensitive measuring equipment has been suggested as a means of obtaining additional information concerning the Edwards Underground Reservoir.

INVESTIGATED PROJECTS

119. GENERAL.- Existing and planned water-resource developments in the Edwards Underground Reservoir area consist of both Federal and non-Federal projects. Among the Federal projects is the Canyon Reservoir on the Guadalupe River, for the purposes of flood control, water conservation, and recreation; the authorized Blieders Creek Reservoir project near New Braunfels for flood control; 5 Soil Conservation Service detention reservoirs on Martinez Creek in the Cibolo Creek watershed; and 13 Soil Conservation Service detention reservoirs on York Creek, San Marcos River watershed. Among the non-Federal projects are Medina Reservoir and Diversion Reservoir on the Medina River for irrigation; and Olmos Reservoir on Olmos Creek in San Antonio for flood control. In formulating a plan of development for the area, full evaluation was made of the effects of the various elements of the plan on the water supply yields of existing and planned improvements in the area. Also, the proposed Cuero Reservoir on the Guadalupe River was considered to be existing in the evaluation of flood control benefits to be credited to proposed projects.

120. OBJECTIVES.- The plan of improvement was formulated with a view to the following objectives: to provide flood protection, where economically feasible, to portions of the rural and urban areas of the Guadalupe, San Antonio, and Nueces River Basins by construction of projects upstream of the Balcones fault zone in the Edwards Reservoir area; to provide an effective means of increasing the recharge of the Edwards Underground Reservoir; to provide additional water conservation storage to meet the projected future water supply requirements and develop to the extent feasible the resources of the Edwards area; and to provide for the development of the fish-wildlife and general recreation potentials in proposed reservoirs.

121. PLANNING CONSIDERATIONS.- Plan formulation studies require that the elements of any plan meet the following conditions: (a) that they be compatible with existing and planned improvements in the three river basins; (b) that there is not a more economical means of accomplishing the same purpose; (c) that the projects proposed in this report be designed to the size, where practicable, that will yield the greatest excess benefits over costs; and (d) that the proposed plan be flexible, in that it may be constructed in steps or expanded as the needs may require.

122. RECHARGE INVESTIGATIONS.- During the period 1935 to 1956 the average annual recharge to the Edwards Underground Reservoir was 423,200 acre-feet. For this same period the average annual discharge from the aquifer was 523,700 acre-feet, with 352,400 acre-feet per year being discharged through major springs along the Balcones fault zone. Pumping during this same period averaged only 171,300 acre-feet.

The excess discharges depleted storage in the underground reservoir by approximately 2,200,000 acre-feet. Consideration of methods to increase the dependable yield of the aquifer for pumping involved: (1) control of the major springs to prevent heavy loss of reservoir storage; and, (2) control of the recharge to the underground reservoir by construction of surface reservoirs on principal streams in the watershed of the aquifer.

a. To control the major springs consideration was given to construction of ring dikes around the springs to equalize the hydrostatic head in the underground reservoir. Comal Springs, the largest of the group, consists of a number of springs issuing from fissures in the Edwards limestone along the base of the Comal Springs fault. The springs extend for about 500 yards along the escarpment in a highly developed area. Because of the intense faulting in the area there could be no assurance that construction of a ring dike along the entire length of the Comal Springs fault where the springs emit would prevent the artesian pressure from increasing and causing springs to break out in a number of other locations. Studies were also made of the feasibility of construction of a grout curtain across a narrow portion of the Edwards Underground Reservoir southwest of Comal Springs. The location would be in an area northeast of San Antonio where the artesian aquifer narrows to approximately five miles in width. From information developed from the exploration boring in this area, as previously described, the top 432 feet of the 482 feet of Edwards and associated limestones penetrated were highly broken and solutioned, with some large cavities in this area. To substantially reduce the flow in this area would require construction of a grout curtain about 5 miles in length, 430 feet in height and to depths below the ground surface as great as 700 feet. In addition to the high cost of such a project, the hydrostatic head within the aquifer would probably prevent successful construction of a grout curtain of this nature. A more detailed discussion is contained in Appendix III, Geology.

b. The base flow of most streams in the Edwards Plateau is lost to the underground reservoir where the streambeds cross the outcrop of the Edwards limestone in the Balcones fault zone. Additional water for recharge, therefore, must come from the floodflows which cannot be absorbed into the underground reservoir as they flow past the loss zone. Following major storms the runoff is frequently greater than the infiltration capacity along the streams and large volumes of water escape beyond the lower edge of the Edwards outcrop. From gage records of the Geological Survey it has been estimated that the infiltration rate along the streams in the Nueces River Basin where they cross the fault zone varies from about 500 to more than 1,000 second-feet. Major storms during the past 30 years have produced peak discharges in the stream channels of the Nueces River Basin in excess of 600,000 second-feet. Along the streams in this basin, which contribute approximately 64 percent of their flow to the natural recharge of the underground reservoir, about 128,000 acre-feet per year of water resources pass the lower edge of the Edwards outcrop. This point on the streams is generally considered to be the downstream limit of the major recharge zone. Of the streams in the San Antonio River Basin only about 8 percent, or 15,900 acre-feet per year, of the average annual resources from the upper areas of the basin pass the lower edge of the Edwards outcrop. Cibolo, Salado, and Leon Creeks and other small tributary streams lose over 90 percent of their flow to the underground reservoir. Medina River, largest of the San Antonio River tributaries, has 93 percent of its resources above the lower edge of the Edwards outcrop impounded in Medina Reservoir. Of the quantity impounded, approximately half is lost to the Edwards aquifer through leakage from the reservoir and its irrigation facilities. In the Guadalupe River Basin only one stream, Dry Comal Creek, is a major contributor to the Edwards aquifer. It loses 71 percent of its flow and has an annual average of only 8,400 acre-feet of its resources passing the outcrop. A small quantity of recharge is realized from the Blanco River, about 10,900 acre-feet per year, with an additional 14,500 acre-feet per year being contributed by adjacent areas. An average of about 74,100 acre-feet per year of water passes the lower edge of the outcrop along this stream and adjacent areas. The Guadalupe River, itself, is a non-contributor to the underground reservoir. Prior to construction of Canyon Reservoir an average of 246,000 acre-feet per year of water crossed Edwards outcrop on this stream with no measurable loss. Table 7 at the end of this section lists the estimated average annual resources and the average annual recharge from each stream in the Edwards Reservoir area. The resources and recharge quantities are shown for the period 1935-1956.

123. From extensive studies and investigations made over the past 65 years by a number of Federal, state, and local governmental agencies, consulting engineers, and ground water hydrologists, and from studies and investigations made by the Corps in connection with this report, it has been concluded that the most practical and effective means of increasing the recharge of the Edwards Underground Reservoir would be to provide surface storage, where feasible, in and upstream from the Balcones escarpment in the recharge area of the aquifer. The surface-water reservoirs would impound floodflows from the watershed areas above the damsites and would provide regulation of the recharge to the underground reservoir. The water would be released from the surface reservoirs at rates not to exceed the infiltration rates along the streams and allowed to enter the underground aquifer through existing natural recharge channels downstream from the dams. In this manner the projects would enable an increased volume of water to be utilized for recharge of the underground reservoir over the life of the projects.

124. SPECIFIC STUDIES.- Preliminary field and office topographic, geologic, and hydrologic studies were made to locate potentially favorable dam and reservoir sites. Preliminary feasibility studies were made on each of the damsites from which selections were made for more detailed investigation and to determine cost and benefit data for each project and project purpose. Economic and water resource, recreation, and fish and wildlife studies were made to determine conservation requirements for the future. Flood control investigations were made in areas known to have a serious flood problem. In addition, preliminary studies were made to determine if provision of hydroelectric power facilities at Federal expense could be justified at any reservoir project under consideration in the drainage area of the Edwards Underground Reservoir. A summary description and analysis of the more detailed investigations in the Nueces, San Antonio, and Guadalupe River Basins is contained in the following paragraphs and sections of the main report, and a detailed analysis is presented in the supporting appendixes I through VI.

a. Economic studies.- An economic base study has been made to measure recent economic growth and to estimate future growth in the Edwards Reservoir area. Projections of industrial development, population, employment, and income have been made to assist in measurement of the probable increase in water resource requirements and the development within the flood plains. A summary of these investigations has been previously described. A detailed analysis is contained in Appendix V, Economic Base Study.

b. Flood control studies and investigations.- Field and office studies and investigations have been made of flood problems in the Edwards Reservoir area. The investigations were extended to include areas downstream in the Gulf Coastal Plain which would be affected by projects within the Edwards area. The studies included an analysis of the flood problems, delineation of areas subject to flooding, and evaluation of the average annual damages and benefits that would accrue from provision of flood-control improvements in the Edwards Reservoir area. Details of the flood-control studies are described in Appendix IV, Flood Control Economics.

c. Geologic investigations.- Geologic conditions at 10 dam sites were investigated for the construction of recharge reservoirs in the Nueces and San Antonio River Basins. The sites chosen for investigation were located on the Nueces, Dry Frio, Frio, and Sabinal Rivers, and on Seco, Hondo, and Cibolo Creeks. Additional investigations were also made at the existing Medina Dam. Six of the sites were located in the Edwards Plateau upstream from the heavy seepage loss areas associated with the Balcones fault zone. These investigated dam sites are situated in areas where the streams have cut through the Edwards and Comanche Peak limestones into the underlying Glen Rose limestone, which formation has generally proven capable of containing water. Core drilling, pressure testing, and other geologic investigations were made at 5 of the 6 sites to determine foundation conditions for proposed structures and to determine if the dams and reservoirs located upstream from the fault zone could be expected to be relatively watertight. Four of the ten recharge project sites are located in or adjacent to the Balcones fault zone and were investigated as "dry-pool" reservoirs, or reservoirs which would not contain permanent storage. Core drilling and pressure testing were performed at one site on Cibolo Creek within the fault zone to investigate the possibility of using this reservoir for "pump-up" storage, or storage pumped into the reservoir from the aquifer when water levels in the underground aquifer were high.

(1) Foundation and other geologic investigations were made at three dam site locations in the Guadalupe River Basin. Projects in this area would not be for recharge purposes but would contain storage for flood-control, conventional water supply, recreation, and fish and wildlife purposes. Investigations were made at two sites on the upper Guadalupe River upstream from the Balcones fault zone and Canyon Reservoir. A selected project would operate in conjunction with the Canyon Reservoir for developing to the extent feasible the total water resources above this project. A third project was investigated in this basin on the Blanco River.

(2) A summary of the results of investigations at Medina Dam was presented in the preceding section of this report and a brief description of the other dam sites is presented in subsequent paragraphs. A detailed description of the geology of the dam sites and the general geology of the area is presented in appendix III.

d. Hydrologic investigations.- Extensive hydrologic investigations have been made to determine the quantity of additional water resources that could be developed for recharge of the Edwards Underground Reservoir and other water conservation purposes by construction of surface reservoirs on the streams of the Edwards Plateau. To determine the best method of regulating the surface reservoirs for recharge of the aquifer three basic plans of operation were investigated. Two of the methods involved holding the water in surface conservation pools and the third method provided for the release of all storage at recharge rates following each runoff period. Studies based on each of the three methods of operation were evaluated to determine the net increase in the spring flow and in the quantity of water available for pumping. These methods of operation and the determination of the most favorable method are discussed in paragraphs 125-128.

(1) Dependable yield and evaporation studies were made for reservoirs located upstream from the Balcones fault zone, which were considered capable of containing permanent conservation pools. For all the projects investigated, flood-control studies were made to determine the storage requirements to control the floods

of record on the individual streams. The investigations also included studies of sediment requirements and structural requirements for the spillway, outlet works, and embankment.

(2) In order to determine the dependable yield of the underground reservoir and to evaluate the effect of the recharge structures on the yield of the aquifer, a number of hydrologic routings of water resources through the underground reservoir were made under existing and modified recharge conditions. The period of routing, 1935-56, was adopted because it represents one complete cycle from a period of high runoff through a period of critical drought. To determine the yield of the Edwards Reservoir which might be associated with various levels of drawdown, routings through reservoir storage were made assuming several constant pumping rates. However, because of the risk of pollution of the Edwards Reservoir by drawing it down below the historical low, a minimum control elevation of 612 feet msl of the water surface of the underground reservoir at San Antonio was used in the evaluation of all recharge plans. The routings were made for a number of combinations of surface reservoirs regulated under the three basic plans of operation.

(3) Additional hydrologic studies were made to determine the effects of investigated reservoirs on yields of downstream existing reservoirs, including Wesley Seale Reservoir (Corpus Christi) on the lower Nueces River. Studies were also made to determine the effects on the yields of downstream reservoirs proposed in Master Plans of the Guadalupe-Blanco River Authority and the Nueces River Conservation and Reclamation District; namely, Cuero Reservoir on the Guadalupe River and Tom Nunn Hill and Cotulla Reservoirs on the Nueces River. The effects of the investigated reservoirs on yields of existing and proposed downstream reservoirs are discussed in paragraph 167. A summary analysis of other hydrologic investigations is contained in subsequent paragraphs and sections of the report and a detailed analysis is presented in Appendix II, Hydrology and Hydraulic Design.

125. PLANS OF OPERATION FOR RECHARGE RESERVOIRS.- For operation studies on investigated recharge reservoirs, four project sites were used and these sites were located upstream of the Edwards outcrop in areas considered to be relatively watertight. The reservoir projects were Montell on the Nueces River, Concan on the Frio River, Sabinal No. 2 on the Sabinal River, and Hondo on Hondo Creek.

126. Three basic methods of operation of the four reservoirs were investigated. Under one method of operation, the water would be retained in the surface reservoirs during periods when the water level in the underground aquifer was high and when rainfall and runoff from the uncontrolled areas kept the underground reservoir replenished. During periods of drought, when the water level in the underground reservoir is drawn down to some predetermined level and the natural recharge is small, the water would be released from the surface reservoirs to enter the aquifer to provide a dependable volume of water

during the remaining years of the drought period to maintain, as a minimum, the water level in the underground reservoir at the predetermined elevation. Under this method of operation approximately 974,000 acre-feet of water would be impounded in the four reservoirs. Assuming no evaporation losses, these four reservoirs would increase the average annual recharge from these streams by about 72,000 acre-feet per year. However, by impounding this large quantity of water in surface reservoirs in this semiarid region and making no releases from the reservoirs except flood releases and recharge only during the critical drought approximately 63,000 acre-feet of water resources would be lost by evaporation each year. The operation of the four projects under this plan would result in a net recharge to the aquifer of 9,000 acre-feet per year. In addition, water levels in the underground reservoir would average from 4 to 7 feet lower during most years of operation except during the latter years of a severe drought. Because of the lowered water levels in the aquifer, springflow would be substantially reduced throughout the entire period of operation without a significant increase in the quantity of water that could be pumped from the aquifer. For these reasons this method of operation was eliminated from further consideration.

127. Under the second method of operation, a constant release would be made of the dependable yield of the surface reservoirs for continuous recharge of the underground reservoir. By operation of the reservoirs in this manner the evaporation loss would be reduced to about 54,000 acre-feet per year, and the net recharge from the four reservoirs would average 18,000 acre-feet per year. The construction of Hondo Reservoir and operating it in this manner would actually reduce the existing recharge from this stream by 2,400 acre-feet per year.

128. The high evaporation rate in this region prevents the efficient and effective recharge of the Edwards Underground Reservoir by storage of floodwaters in permanent conservation pools. Because of the high and urgent demands for water in the Edwards area and the high evaporation losses the third method of operation would be to release the water from the surface reservoirs as quickly as possible at a rate equal to the infiltration rate of the streams. The operation of "dry-pool" reservoirs would enable the development of maximum water resources at the dam sites with a minimum loss of the resources to evaporation. The net increase in recharge from the four reservoirs would average 72,000 acre-feet per year under this method of operation.

129. SUMMARY OF PLAN FORMULATION STUDIES.- Studies were made of all streams crossing the fault zone in the three river basins to determine the quantity of water that would be available for recharge of the Edwards aquifer. The principal areas in the watershed of the Edwards Underground Reservoir where additional water resources could be developed lie within the Guadalupe River Basin and the western portion of the Nueces River Basin.

a. In the Guadalupe River Basin it was found that construction of projects would have little or no effect on the underground reservoir. However, projects for purposes other than recharge were studied and it was found that Dam No. 7 Reservoir on the Guadalupe River for water conservation and Cloptin Crossing Reservoir on the Blanco River for flood control, water conservation, fish and wildlife, and general recreation could be economically justified. Cloptin Crossing and Dam No. 7 Reservoirs were studied because they represent a part of the water resources physically available above the fault zone. Cloptin Crossing Reservoir is proposed for construction primarily because it is fully justified as a Federal project for flood control, recreation, and fish and wildlife purposes. Water conservation storage potential was computed for both of these reservoirs in order to present the complete picture of both the surface and ground-water resources which are physically possible of development within this study area.

b. Since only a very small percentage of the water resources of the San Antonio River Basin passes the lower edge of the Edwards outcrop, and since there are no appreciable flood damages in this area, no additional water resource development could be justified in this basin at this time.

c. On major streams of the Nueces River Basin three reservoirs to contain joint-storage for flood control and recharge were found to be economically justified. These three are the Montell Reservoir on the Nueces River, Concan Reservoir on the Frio River, and Sabinal Reservoir on the Sabinal River.

130. As can be seen on table 7 and discussed in paragraph 122, Recharge Investigations, the recharge from the streams is very effective under natural conditions and for many of the smaller streams a relatively small quantity of water crosses the loss zone that could be made available for recharge purposes. The high cost of construction and the small quantities of water available precluded thorough investigation and development of these smaller streams at this time. It is also conceivable that in the operation of reservoirs on the larger streams by withholding releases for a day or two during storms that more of the runoff from the uncontrolled areas will enter the aquifer than does under existing conditions, particularly from streams adjacent to the projects. After a period of operation of the reservoirs a determination can then be made of their effect on the runoff from the uncontrolled areas and small retardation type structures may become economically feasible at that time.

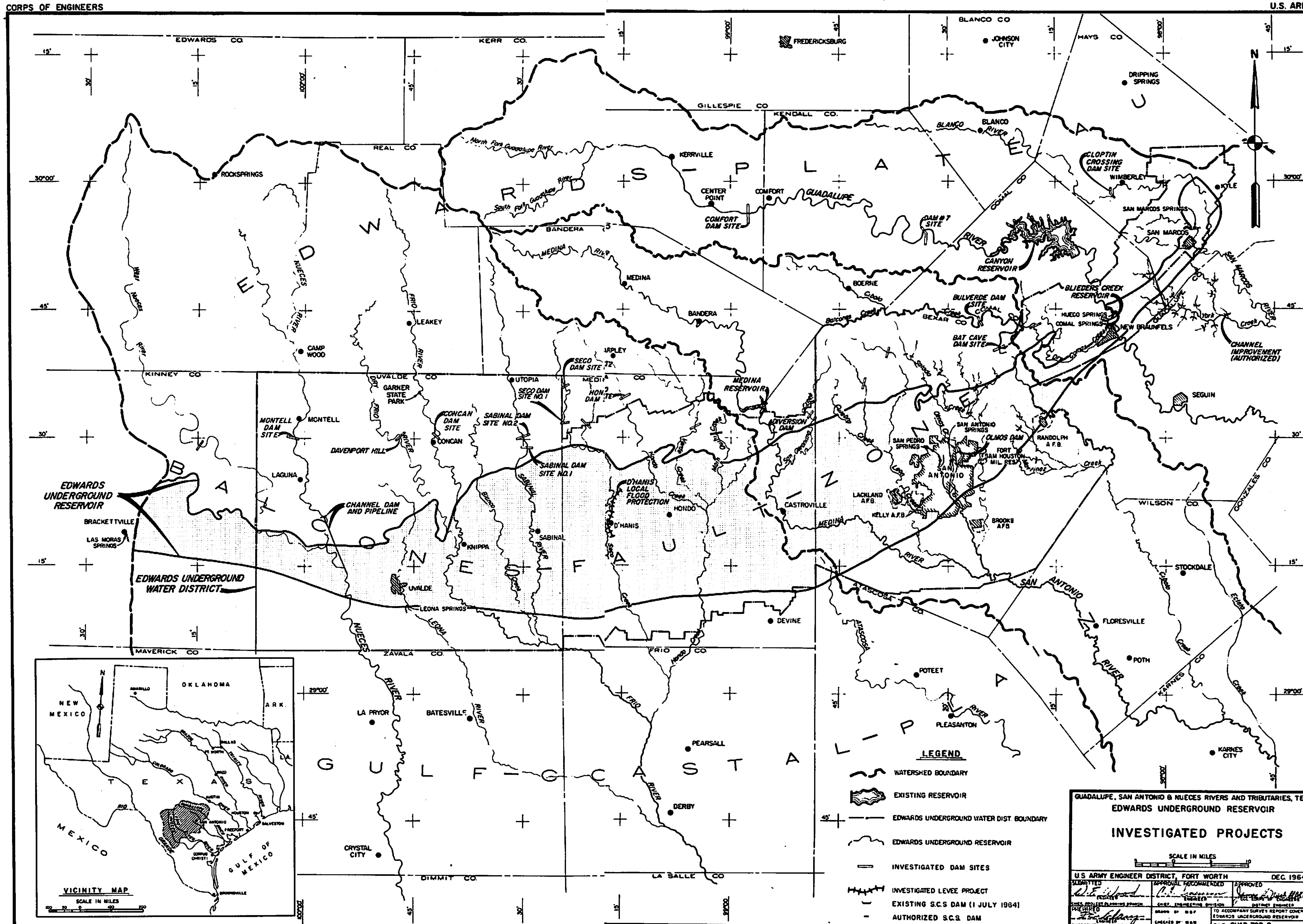
131. A description of the proposed projects is contained in the following section of this report. The methods and procedures used in selection of the projects and in determining the project purposes and allocated storages are fully described in Appendix I, Project Formulation and Appendix II, Hydrology and Hydraulic Design.

TABLE 7

RECHARGE PROJECT INVESTIGATIONS

Stream***	Estimated average annual resources above lower edge of Edwards outcrop (ac-ft)*	Estimated average annual recharge (ac-ft)*: Existing conditions	Modified conditions	Increase due to reservoir projects****	Average annual runoff at lower edge of Edwards outcrop*: Existing conditions	Modified conditions	Drainage area** (sq. mi.): Total	Controlled
GUADALUPE RIVER BASIN								
Blanco River and adjacent area	99,500	25,400	25,400	0	74,100	24,200(1)	514	307
Guadalupe River	…46,000	0	0	0	246,000	74,100(2)	1,510	1,425
Dry Comal Creek	…8,900	20,500	21,800	1,300	8,400	7,100	98	16
SUBTOTAL - Guadalupe River Basin	…74,400	45,900	47,200	1,300	328,500	105,400		
SAN ANTONIO RIVER BASIN								
Cibolo Creek	…58,900	54,100	58,500	4,400	4,800	400	258	238
Salado Creek	…24,400	21,400	24,400	3,000(3) ✓	3,000	0	118 ✓	118
Leon and San Geronimo Creek	…29,300	27,600	28,900	1,300	1,700	400	152	84
Medina River	…4,300	42,700	63,600	20,900(4) ✓	6,400(5)	17,700(6)	630 ✓	613
SUBTOTAL - San Antonio River Basin	…6,900	145,800	175,400	29,600	15,900	18,500		
NUECES RIVER BASIN								
Verde Creek	…8,700	14,600	17,000	2,400	4,100	1,700	108	63
Hondo Creek	…3,500	18,300	22,200	3,900	5,200	1,300	136	95
Tributary areas	…3,700	10,700	11,400	700	3,000	2,300	79	19
Seco Creek	…5,400	12,000	14,200	2,200	3,400	1,200	89	59
Sabinal River	…3,900	17,600	33,400	15,800	16,300	500	214	210
Blanco and Hackberry Creeks	…4,100	2,100	2,100	-	2,000	2,000	26	-
Little Blanco Creek	…2,500	1,300	1,300	-	1,200	1,200	16	-
Frio River	…5,000	40,000	61,500	21,500	25,000	3,500	432	391
Two Tributaries	…2,700	1,700	1,700	-	1,000	1,000	18	-
Dry Frio River	…7,000	17,100	25,400	8,300	9,900	1,600	140	117
Leona River	…6,800	4,300	4,300	-	2,500	2,500	35	-
Deep Creek	…3,500	2,200	2,200	-	1,300	1,300	18	-
Nueces River	…8,700	64,400	91,000(7)	26,600(7)	34,300	3,400	784	707
Indian Creek	…6,400	4,200	4,200	-	2,200	2,200	51	-
Four Tributaries	…7,700	5,000	5,000	-	2,700	2,700	61	-
West Nueces River	…2,800	16,000	26,600	10,600	13,800	3,200	905	700
SUBTOTAL - Nueces River Basin	3…2,400	231,500	323,500(7)	92,000(7)	127,900	31,600		
TOTAL - Edwards Reservoir Area	9…,700	423,200	546,100(7)	122,900(7)	472,300	155,500		

* The annual resources, recharge and runoff …xclusive of springflow) at the lower edge of the Edwards outcrop are averages for the period 1935-56.
** The drainage area at lower edge of the Edw…ds outcrop, as indicated on plates 2 and 3, appendix II.
*** Location of dam sites shown on plate 5.
**** Increase in recharge creditable to investi…ted reservoir project as shown on plate 5 and in table 7, appendix I.
(1) Reduced by estimated net inflow of 49,900 …-ft/yr to Cloptin Crossing Reservoir.
(2) Reduced by estimated net inflow of 171,900 …c-ft/yr to Dam No. 7 - Canyon Reservoir system.
(3) Using 16 SCS structures on Salado Creek (1…2 Work Plan).
(4) Based on extrapolation of data by John J. …ndertulip, "Surface Runoff That Passes the Lower Edge of the Edwards Limestone Outcrop Between the Nueces River and the Blanco River." (No release for irrigat…n)
(5) Does not include approximately 45,200 ac-f…yr combined loss to evaporation and use for irrigation.
(6) Assuming no use for irrigation. Does not …clude approximately 13,000 ac-ft/yr loss to evaporation.
(7) Does not include 4,300 ac-ft/yr (4 mgd) to…e delivered to downstream areas.


GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
INVESTIGATED PROJECTS
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE GUAD. 707-2
LEGEND
WATERSHED BOUNDARY
EXISTING RESERVOIR
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
INVESTIGATED DAM SITES
INVESTIGATED LEVEE PROJECT
EXISTING S.C.S. DAM (1 JULY 1964)
AUTHORIZED S.C.S. DAM
VICINITY MAP
SCALE IN MILES
NEW MEXICO
OKLAHOMA
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF COASTAL PLAIN
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
EDWARDS CO.
KERR CO.
REAL CO.
BANDERA
KINNEY CO.
UVALDE CO.
MEDINA CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
DIMMIT CO.
LA SALLE CO.
GILLESPIE CO.
KENDALL CO.
BLANCO CO.
HAYS CO.
COMAL CO.
BEXAR CO.
WILSON CO.
GONZALES CO.
ATASCOSA CO.
KARNES CO.
ROCKSPRINGS
LEAKEY
CAMP WOOD
MONTELL
LAGUNA
CONCAN
GARNER STATE PARK
UTOPIA
BRACKETTVILLE
LAS MORAS SPRINGS
KNIPPA
UVALDE
LEONA SPRINGS
SABINAL
D'HANIS
HONDO
CASTROVILLE
DEVINE
KERRVILLE
CENTER POINT
COMFORT
BOERNE
MEDINA
BANDERA
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
WIMBERLEY
KYLE
SAN MARCOS SPRINGS
SAN MARCOS
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
SEGUIN
SAN ANTONIO
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
RANDOLPH A.F.B.
FORT SAM HOUSTON MIL. RES.
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
PEARSALL
DERBY
LA PRYOR
BATESVILLE
CRYSTAL CITY
MONTELL DAM SITE
DAVENPORT HILL
CONCAN DAM SITE
SABINAL DAM SITE NO. 2
SABINAL DAM SITE NO. 1
SECO DAM SITE NO. 1
SECO DAM SITE
HONDO DAM SITE
CHANNEL DAM AND PIPELINE
D'HANIS LOCAL FLOOD PROTECTION
MEDINA RESERVOIR
DIVERSION DAM
OLMOS DAM
COMFORT DAM SITE
DAM #7 SITE
CANYON RESERVOIR
BULVERDE DAM SITE
BAT CAVE DAM SITE
BLIEDERS CREEK RESERVOIR
CLOPTIN CROSSING DAM SITE
CHANNEL IMPROVEMENT (AUTHORIZED)
NUECES RIVER
FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
SAN ANTONIO RIVER
ATASCOSA RIVER
LEONA
HONDO
North Fork Guadalupe River
South Fork Guadalupe River
30°00'
29°00'

132. PROPOSED PLAN.- To provide controlled recharge storage for the underground reservoir, additional water supply storage and recreation facilities for the people of the Edwards Reservoir area, and to provide flood protection for the downstream areas of the Guadalupe and Nueces River Basins, the following plan of improvement is proposed:

a. For authorization and construction by the Federal Government.-

(1) Montell Reservoir on the Nueces River for flood control, water supply, recharge, and for recreation and fish and wildlife purposes, including a channel dam and a pipeline for water supply to downstream areas of the Nueces River Basin.

(2) Concan Reservoir on the Frio River for flood control, recharge, and recreation purposes.

(3) Sabinal Reservoir on the Sabinal River for flood control, recharge, and recreation purposes.

(4) Cloptin Crossing Reservoir on the Blanco River for flood control, water conservation, and for recreation and fish and wildlife purposes.

b. For construction by local interests.- Dam No. 7 Reservoir on the Guadalupe River for water conservation.

The following paragraphs describe in more detail elements of the proposed plan. The general location of the projects is shown on plate 6. Pertinent data on the earth and rock-fill embankments, outlet works, spillways, reservoir storages, land requirements, relocations, and design floods are presented in table 8. A complete analysis of the project formulation studies is presented in appendix I.

133. MONTELL RESERVOIR.- The proposed Montell Dam would be constructed at river mile 401.6 on the Nueces River, about 20 miles northwest of Uvalde. The structure would consist of an earth and rock-fill dam with an outlet works and an uncontrolled spillway. The reservoir would have a total controlled storage of 252,300 acre-feet, consisting of 239,300 acre-feet of joint-storage for 50-year flood control and recharge; 1,000 acre-feet of conservation storage for water supply; and 12,000 acre-feet of storage for sediment reserve. A small permanent pool of 2,200 acre-feet, consisting of 1,000 acre-feet of conservation storage and 1,200 acre-feet of sediment reserve, would be maintained to provide a safe yield of 4,300 acre-feet per year (4 million gallons per day). Water in the permanent pool would

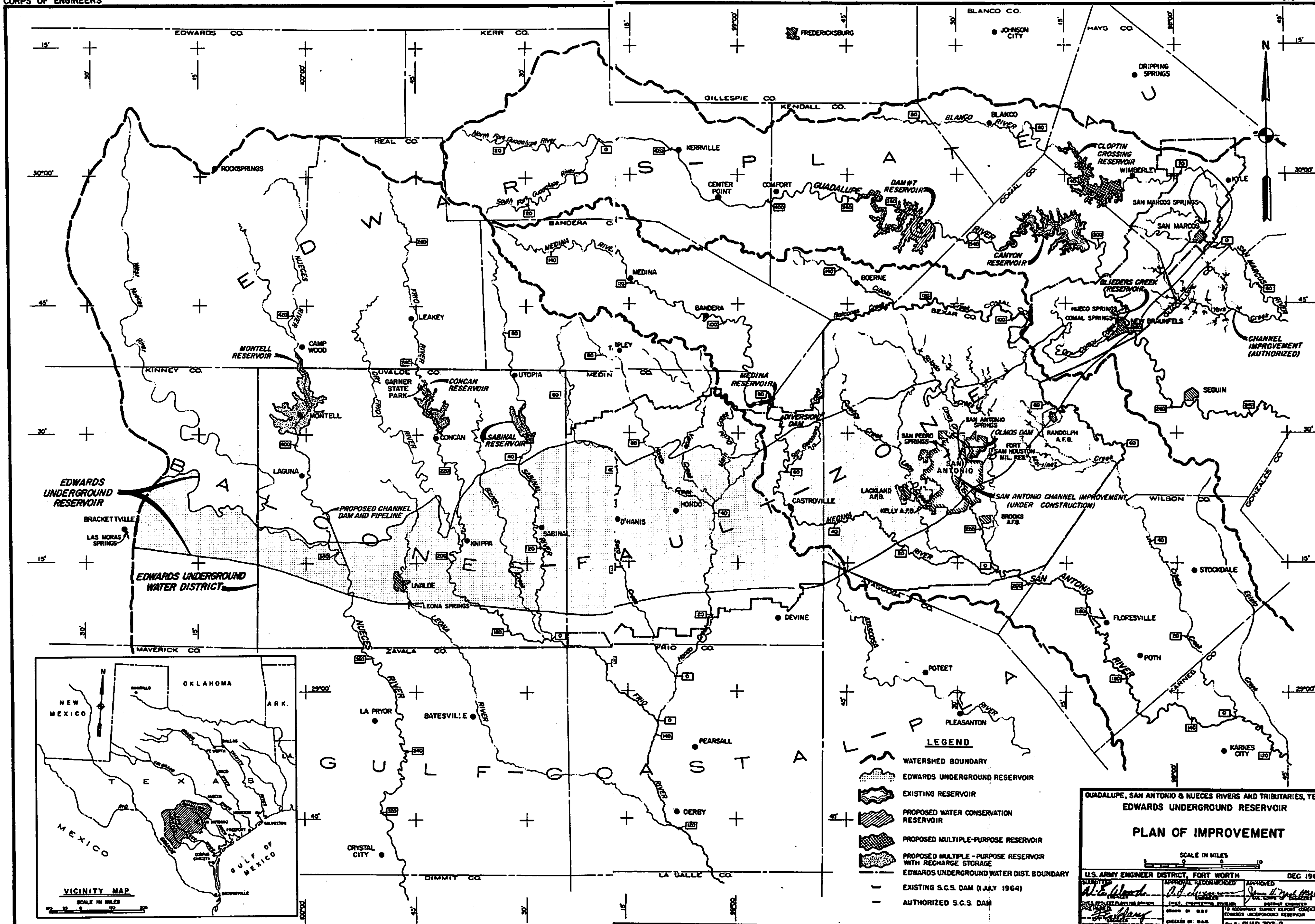
be confined mostly within the channel of the Nueces River. The joint storage provided in the project would increase the average annual recharge to the underground reservoir by about 26,600 acre-feet.

134. In addition to the Montell Dam and Reservoir, a low channel dam would be constructed at about river mile 387, about 14 miles downstream from the reservoir. From the channel dam a gate-controlled 24-inch pipeline would be constructed to extend downstream across the "loss zone" on the Nueces River a distance of about 8.5 miles to the vicinity of Tom Nunn Hill, about river mile 376.5. The pipeline would transport 4,300 acre-feet per year (4 mgd) by gravity flow to the area.

135. The 1,000 acre-feet of conservation storage in Montell Reservoir, along with the channel dam and pipeline facilities would provide the equivalent dependable yield of the Tom Nunn Hill Reservoir, a project proposed in the master plan of the Nueces River Conservation and Reclamation District. By obtaining this quantity of water from the Montell project, in lieu of the construction of Tom Nunn Hill Reservoir, the Reclamation District would realize an estimated net saving in excess of $297,600 annually. The Montell and Tom Nunn Hill Reservoirs are discussed further in paragraph 167 and a complete analysis of the Nueces River studies is presented in Appendix I, Project Formulation.

136. The plan of operation adopted for the project provides for the release of all inflows after each rain, with exception of that required to maintain the small permanent pool. The maximum rate of release will be approximately 1,000 second-feet, the estimated infiltration rate of the stream in the Edwards outcrop area. The storage required to control the 50-year flood has been increased slightly to allow for the withholding of releases for 2 days. It is anticipated that the withholding period will allow a greater percentage of runoff from the uncontrolled area to infiltrate into the aquifer before regulated releases are commenced.

137. Recreation development is proposed for the Montell project at two separate areas, at the dam and reservoir and at the channel dam 14 miles downstream. The facilities at the reservoir would include overlook facilities, park and picnic areas, an access road to the water and a boat ramp. In the vicinity of the channel dam, an area known as Chalk Bluff, additional overlook facilities, park and picnic areas, an access road and foot trails to the river are proposed. Water for the pipeline to the Tom Nunn Hill area will be ponded behind this channel dam. Additional water released from the Montell Reservoir will flow over the channel dam and recharge the underground reservoir in the Edwards outcrop area downstream from the channel dam. The flow at the channel dam would range from 6 to 1,000 second-feet with flows in excess of 6 second-feet occurring about 99 percent of the time. The recharge operation of the project and the constant flow of the stream will provide a scenic attraction for sightseeing, picnicking, camping,


GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
PLAN OF IMPROVEMENT
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE: GUAD. 707-2
LEGEND
WATERSHED BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EXISTING S.C.S. DAM (1 JULY 1964)
AUTHORIZED S.C.S. DAM
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF COASTAL PLAIN
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
MONTELL RESERVOIR
CONCAN RESERVOIR
SABINAL RESERVOIR
MEDINA RESERVOIR
DIVERSION DAM
CLOPTIN CROSSING RESERVOIR
DAM #7 RESERVOIR
CANYON RESERVOIR
BLIEDERS CREEK RESERVOIR
CHANNEL IMPROVEMENT (AUTHORIZED)
OLMOS DAM
SAN ANTONIO CHANNEL IMPROVEMENT (UNDER CONSTRUCTION)
PROPOSED CHANNEL DAM AND PIPELINE
EDWARDS CO.
KERR CO.
REAL CO.
BANDERA CO.
GILLESPIE CO.
KENDALL CO.
BLANCO CO.
HAYS CO.
COMAL CO.
BEXAR CO.
KINNEY CO.
UVALDE CO.
MEDINA CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
ATASCOSA CO.
WILSON CO.
GONZALES CO.
KARNES CO.
DIMMIT CO.
LA SALLE CO.
ROCKSPRINGS
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
KERRVILLE
CENTER POINT
COMFORT
BLANCO
WIMBERLEY
KYLE
SAN MARCOS SPRINGS
SAN MARCOS
BOERNE
MEDINA
BANDERA
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
SEGUIN
LEAKEY
CAMP WOOD
UTOPIA
GARNER STATE PARK
MONTELL
CONCAN
LAGUNA
TARPLEY
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
SAN ANTONIO
LACKLAND A.F.B.
KELLY A.F.B.
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CASTROVILLE
HONDO
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SABINAL
KNIPPA
UVALDE
LEONA SPRINGS
BRACKETTVILLE
LAS MORAS SPRINGS
DEVINE
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
LA PRYOR
BATESVILLE
PEARSALL
KARNES CITY
DERBY
CRYSTAL CITY
NUECES RIVER
FRIO RIVER
DRY FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
SAN ANTONIO RIVER
ATASCOSA RIVER
LEONA RIVER
WEST NUECES RIVER
North Fork Guadalupe River
South Fork Guadalupe River
Cibolo Creek
Salado Creek
Cypress Creek
Seco Creek
Hondo Creek
York Creek
Ecleto Creek

and fishing. A further analysis of this water resource development with its recreational attraction is contained in paragraphs 168-170 of this report and in Appendix VI, Recreation and Fish and Wildlife.

138. CONCAN RESERVOIR.- The Concan Reservoir is proposed for construction by the Federal Government at river mile 226.2 on the Frio River to provide joint-storage for 50-year flood control and recharge of the Edwards Underground Reservoir. The total controlled storage proposed for this project is 149,000 acre-feet, which includes 7,800 acre-feet of reserve storage for 100-year sedimentation. The structure would consist of an earth and rock-fill dam with an uncontrolled spillway and an outlet works through the dam.

139. Provision of the 141,200 acre-feet of joint-storage in the reservoir will contain the flood of record on this stream. This storage will also develop the maximum water resources of the stream above the dam site.

140. The plan of operation proposed for this project provides for release of all inflows after each rain. The rate of release has been tentatively planned at 750 second-feet, the estimated infiltration rate of the stream in the Edwards outcrop area. No permanent storage would be provided in the reservoir. The storage required for 50-year flood control has been increased slightly to permit 2-day withholding before regulated releases are commenced. Operation of the reservoir under this plan would increase the average annual recharge from this stream by approximately 21,500 acre-feet.

141. Although no permanent pool will be maintained at the Concan project, recreation development has been included as a part of the project plans. The Frio River is a perennial stream and will have flow most of the time, except during periods of severe drought. For the 39-year period prior to 1963 the average flow of the stream in this area was 96 second-feet. Only during the critical drought, 1947-56, the Frio River in this area had no recorded flow for about five months. In addition, large quantities of floodwater will be stored in the reservoir for considerable periods of time. The release of these floodwaters to recharge the underground reservoir will provide a scenic attraction for sightseers. For these reasons sufficient overlook, park and picnic facilities for the general public are proposed for inclusion in the project.

142. SABINAL RESERVOIR.- The Sabinal Dam and Reservoir is proposed for Federal construction at river mile 42.3 on the Sabinal River. The proposed location is just inside the upstream limits of the Edwards outcrop in the Balcones fault zone. The reservoir would

contain 89,100 acre-feet of joint-storage for 50-year flood control and recharge and 4,200 acre-feet of reserve storage for 100-year sedimentation. The joint-storage would be sufficient to control the flood of record on this stream without spills. This storage would also develop the maximum water resources of the stream above the dam site and would contribute 15,800 acre-feet per year of additional recharge to the Edwards aquifer.

143. The structure would consist of an earth and rock-fill dam with a gated spillway in the river channel controlled by six 40' x 30' tainter gates. The structure would be founded on the Edwards limestone, which is considered to be good foundation rock. Leakage along joint systems, similar to that at Medina Dam, is expected but should present no problem in construction or stability of the structure.

144. No permanent pool will be maintained in the Sabinal Reservoir. All inflows will be released after each rain at a rate tentatively established at 500 second-feet, the estimated infiltration rate of the streambed in the Edwards outcrop area.

145. Although no permanent storage is to be maintained in the reservoir, recreation development has been included in the proposed plan for the project. Approximately 25 percent of the time the Sabinal River will not have flow at the dam site even though during the 20-year period of record prior to 1963 the average rate of flow of the stream in this area was 37 second-feet. The greatest attraction to the public, however, will occur at times when large quantities of floodwater have been stored in the reservoir and are being released to recharge the underground aquifer in the immediate proximity of the dam.

146. Because of the anticipated interest of the general public in the flood control and recharge operations of the project, sufficient overlook, park, and picnic areas for the public are proposed.

147. CLOPTIN CROSSING RESERVOIR.- A multiple-purpose reservoir for flood control, water conservation, and recreation and fish and wildlife is proposed for Federal construction on the Blanco River at the Cloptin Crossing site, river mile 32.5. The project would contain 119,900 acre-feet of flood control storage, 274,900 acre-feet of water conservation storage, and 9,200 acre-feet of storage for sediment accumulation. It has been found that providing 75-year frequency flood control storage in the Cloptin Crossing Reservoir will produce the greatest excess benefits over costs in reducing flood damages downstream and this amount of flood-control storage is included in the proposed project. The flood of record has a frequency of approximately once in 25 years.

148. The provision of 274,900 acre-feet of conservation storage in the Cloptin Crossing Reservoir would fully develop the resources of the Blanco River watershed upstream from the dam site and would provide a dependable yield of 38 million gallons per day (42,700 ac.ft./yr).

149. The structure proposed for the Cloptin Crossing Dam would consist of an earth and rock-fill embankment with an uncontrolled spillway and an outlet works through the dam. Full development of basic recreation facilities would be accomplished at this project. The facilities would include additional lands, parking areas, access roads, boat ramps, and picnic areas. To assure maximum utilization of all the reservoir lands and facilities for general recreation, fishing and hunting, and to protect and enhance the fish and wildlife resources of the area, an adequate zoning plan will be developed during the advance planning phase of the four projects recommended for Federal authorization and construction.

150. DAM NO. 7 RESERVOIR.- The Dam No. 7 Reservoir could be constructed by local interests when it becomes evident that the underground reservoir is no longer capable of meeting the water supply needs of the area. The location of the proposed project is at river mile 351.3 on the Guadalupe River, the site selected by the Guadalupe-Blanco River Authority. The reservoir proposed for this site would have a total controlled storage of 658,000 acre-feet at elevation 1,247 feet, the top of the conservation pool. Since the Canyon Dam, 48 miles downstream, has been designed to control all floods of record originating above this project, additional flood storage in Dam No. 7 Reservoir could not be justified. Storage space of 17,500 acre-feet should be provided for deposition of sediment over a 100-year period.

151. The project is designed to operate in conjunction with Canyon Reservoir to develop the resources above Canyon Dam to the fullest extent feasible. The provision of 640,500 acre-feet of conservation storage in Dam No. 7 Reservoir would produce a dependable yield for the Canyon-Dam No. 7 system of 127 million gallons per day (142,700 ac.ft./yr). This is an increase of 41 mgd (46,400 ac.ft./yr) over that yield determined for the Canyon Reservoir without upstream development.

152. The structure proposed for the Dam No. 7 site is an earth and rock-fill embankment with an uncontrolled spillway and an outlet works through the dam.

TABLE 8

PERTINENT DATA
PROPOSED RESERVOIRS
PLAN OF IMPROVEMENT
EDWARDS UNDERGROUND RESERVOIR AREA

	MULTIPLE PURPOSE RESERVOIRS			
	Montell Reservoir	Cloptin Crossing Reservoir	Concan Reservoir	Sabinal Reservoir
DRAINAGE AREA				
Square miles	707	307	391	210
SPILLWAY DESIGN FLOOD				
Peak inflow, cfs	893,900	414,900	992,500	381,800
Volume, acre-feet	821,300	353,000	489,400	249,000
Volume, inches	21.78	21.56	23.47	22.23
Peak outflow, cfs	581,000(1)	196,400(1)	433,000(1)	270,600

RESERVOIR	Montell Elev.(2) (feet)	Montell Area (acres)	Montell Capacity (ac-ft)	Montell Capacity (inch)	Cloptin Crossing Elev.(2) (feet)	Cloptin Crossing Area (acres)	Cloptin Crossing Capacity (ac-ft)	Cloptin Crossing Capacity (inch)	Concan Elev.(2) (feet)	Concan Area (acres)	Concan Capacity (ac-ft)	Concan Capacity (inch)	Sabinal Elev.(2) (feet)	Sabinal Area (acres)	Sabinal Capacity (ac-ft)	Sabinal Capacity (inch)
Top of dam	1371.0	-	-	-	1023.0	-	-	-	1399.5	-	-	-	1244.0	-	-	-
Maximum design water surface	1366.0	10,180	333,100	14.14	1017.5	9,600	573,000	35.00	1394.2	5,670	200,600	13.46	1238.8	3,860	135,200	12.07
Top of flood control pool and spillway crest	1331.0(3)	6,200	252,300	6.69	998.0	7,730	404,000	24.67	1366.5(3)	3,830	149,000	7.15	1225.5(3)(5)	2,990	93,300	8.33
Top of conservation pool	1237.0	260	2,200	0.06	980.5	6,060	283,400	17.31	-	-	-	-	-	-	-	-
Sediment storage - Total	1331.0	-	12,000	0.32	998.0	-	9,200	0.56	1366.5	-	7,800	0.37	1226.5	-	4,200	0.37
Sediment storage - Conservation Pool	1237.0	-	1,200	0.03	980.5	-	8,500	0.52	-	-	-	-	-	-	-	-

	Montell Reservoir	Cloptin Crossing Reservoir	Concan Reservoir	Sabinal Reservoir
STORAGE SUMMARY				
Flood control, ac-ft	239,300(4)	119,900	141,200(4)	89,100(4)
Water conservation, ac-ft	1,000	274,900	-	-
Sediment, ac-ft	12,000	9,200	7,800	4,200
Total	252,300	404,000	149,000	93,300
DAM				
Type	Earth and rock fill	Earth and rock fill	Earth and rock fill	Earth and rock fill
Total length, feet	7,360	7,520	2,955	2,150
Embankment section:				
Type	Earth and rock fill	Earth and rock fill	Earth and rock fill	Earth and rock fill
Total length, feet	7,360	7,520	2,955	1,500
Height above streambed, feet	158.0	200.0	164.0	114.0
Freeboard, feet	5.0	5.5	5.3	5.2
Crown width, feet	30	30	30	30
Side slopes:				
Upstream	1 on 3.5	1 on 3.5	1 on 3.5	1 on 3.0
Downstream	1 on 3.0	1 on 3.0	1 on 3.0	1 on 3.0
SPILLWAY				
Type	Broadcrested	Broadcrested	Broadcrested	Gated
Net length, feet	960	760	1,030	240
Gates:				
Type	-	-	-	Tainter
Number	-	-	-	6
Size (width x height)	-	-	-	40' x 30'
Spillway discharge, cfs:				
Maximum design water surface	570,600	187,200	425,300	270,600
OUTLET WORKS				
Type	Gate-controlled conduit	Gate-controlled conduit	Gate-controlled conduit	Gate-controlled sluices
Number of conduits	1	1	1	2
Dimensions	15' diameter	13' diameter	13' diameter	3'-0" x 6'-0"
Invert elevation, feet	1216.0	855.0	1240.0	1130.0
Control	3 - 5'-8" x 12' tractor-type gates	2 - 6' x 13' tractor-type gates	2 - 6' x 13' tractor-type gates	2 - 3' x 6' slide gates
RELOCATIONS				
Roads and highways:				
U. S. highways, miles	-	-	0.3	-
State highways, miles	10.5	-	-	-
F.M. highways, miles	-	-	-	6.0
State park roads, miles	-	-	0.2	-
County roads, miles	1.8	1.3	6.3	-
Access roads, miles	4.5	-	-	-
Bridges, feet	390	400	100	-
Utilities:				
Power lines, miles	27	2.0	5.0	8.7
Telephone lines, miles	20	2.0	5.0	8.7
Cemetery graves	340	-	-	-
LANDS				
Dam and reservoir				
Clearing, acres	260	3,750	-	-
Land acquisition:				
Fee simple, acres	700	8,390	400	400
Flood easement, acres	6,140	-	3,960	3,000
(Guide taking line)	(1336.0)	(1003.0)	(1371.5)	(1229.5)
Recreation				
Clearing, acres	80	2,420	30	30
Land acquisition:				
Fee simple, acres	100	2,210	10	10
PIPELINE AND CHANNEL DAM				
Channel dam height (feet)	6			
Pipeline				
Diameter (inches)	24			
Length (miles)	8.5			
Control	Gate valve			

(1) Includes discharge through outlet works as follows: 10,400 (Montell); 9,200 (Cloptin Crossing); 7,700 (Concan)
(2) All elevations refer to mean sea level.
(3) Top of controlled storage - joint storage for flood control and recharge purposes.
(4) Joint-storage for flood control and recharge.
(5) Top of controlled storage and top of gate elev. 1226.5; spillway crest elev. 1196.5.

153. YIELD OF THE EDWARDS UNDERGROUND RESERVOIR.- Construction of Montell, Concan and Sabinal Reservoirs in the Nueces River Basin and operation of the projects as previously outlined will result in a net increase in recharge to the Edwards aquifer of 63,900 acre-feet per year (57 million gallons per day). The average annual recharge for the period 1935-56, 423,200 acre-feet, would be increased by the projects to 487,100 acre-feet, as shown in table 9.

154. The yield of the underground reservoir cannot, over a long period of time, exceed the average annual recharge. Because of the nature of the aquifer, this yield is realized through discharges from both wells and springs. The major springs along the southern limits of the Balcones fault zone are natural outlets for the Edwards Reservoir and are uncontrolled. Rate of flow from these springs is dependent on the water level in the underground reservoir. The reservoir might be drawn down to some point at which no springflow would occur and the entire recharge would then be available for pumpage. In this case, if pumpage never exceeded the average recharge during any part of the hydrologic cycle, the dependable yield during the critical drought period would be the average recharge. This, however, is based on the premise that the level of the reservoir would be drawn down far enough that even during periods of exceptionally high recharge, the reservoir would not fill to the spring outlets, and consequently no springflow would occur.

155. A limiting factor, however, in determining the safe yield for pumping is the presence of the water of poor quality along the southern and southeastern limits of the Edwards Reservoir in the Balcones fault zone. It is not known to what elevation the water level in the underground reservoir can be lowered before the poor quality water would be drawn into the important well fields in the San Antonio area. The volume of water which would move from the bad water zone is also unknown, and consequently the overall effect of the lowering of the water level cannot be predicted. Contamination of a portion of the reservoir would probably render that area useless as a source of fresh water for the future.16/ It is considered that, in view of the possible consequences of contamination, the water level should not be lowered appreciably beyond its historic low point, or elevation 612 msl at San Antonio.

156. For analyzing the effect of the increased recharge on yield and water levels of the underground reservoir, hydrologic routings were made of the recharge through reservoir storage in the aquifer for the period 1935-62. The routings were made under existing and modified conditions of recharge. As graphically shown on figure 25, the safe yield for pumping may be increased from 234,000 to 263,000 acre-feet per year (235 million gallons per day) without depleting storage in the

underground reservoir below elevation 612 at San Antonio. This represents an increase of 29,000 acre-feet per year (26 mgd). The remainder of the increased recharge, 34,900 acre-feet per year (31 mgd) under this plan of operation would be discharged from the aquifer principally through the major springs. Approximately 4,000 acre-feet per year of this additional springflow would be discharged from Leona Springs in the Nueces River Basin, 13,300 acre-feet from San Antonio and San Pedro Springs in the San Antonio River Basin, and 17,600 acre-feet from Hueco, Comal and San Marcos Springs in the Guadalupe River Basin. The total average annual springflow for the period 1935-56 was 352,400 acre-feet. Under assumed conditions of constant pumping of 234,000 acre-feet per year during this same period, the average annual springflow would be about 292,900 acre-feet. With the recharge projects in operation this quantity would be increased to 327,800 acre-feet.

157. The computed safe yield for pumping under modified conditions of recharge, 263,000 acre-feet per year (235 mgd) represents an average during each year of the period 1935-56. If this yearly average is not exceeded this quantity of water would be available during a recurrence of the critical drought, as experienced during the period 1947-56, without depleting the reservoir below the historic low. In the absence of an alternative source of water supply this quantity should not be exceeded.

158. Provision of an alternative surface water supply, sufficient to meet the demands of the area during a critical drought, would enable greater quantities of water to be pumped from the aquifer during wet years and in the early years of a drought period. However, the water level in the underground reservoir would drop to the historic low a number of years prior to the end of the drought, the time depending on the extent of pumping and the existing climatic conditions. For the remaining years of the drought, the dependable yield of the underground reservoir would be only that inflow during the driest year, which in 1956 totaled 44,000 acre-feet. If this small quantity were exceeded during the drought it is believed that water levels in the aquifer would drop rapidly below the historic low and the danger of contamination of the fresh water source would be significantly increased.

159. With an alternative source to provide a water supply for the critical drought period it is conceivable that the pumping during wet years could be substantially increased to utilize the full quantity of additional recharge provided by Montell, Concan and Sabinal Reservoirs, 63,900 acre-feet per year (57 million gallons per day).

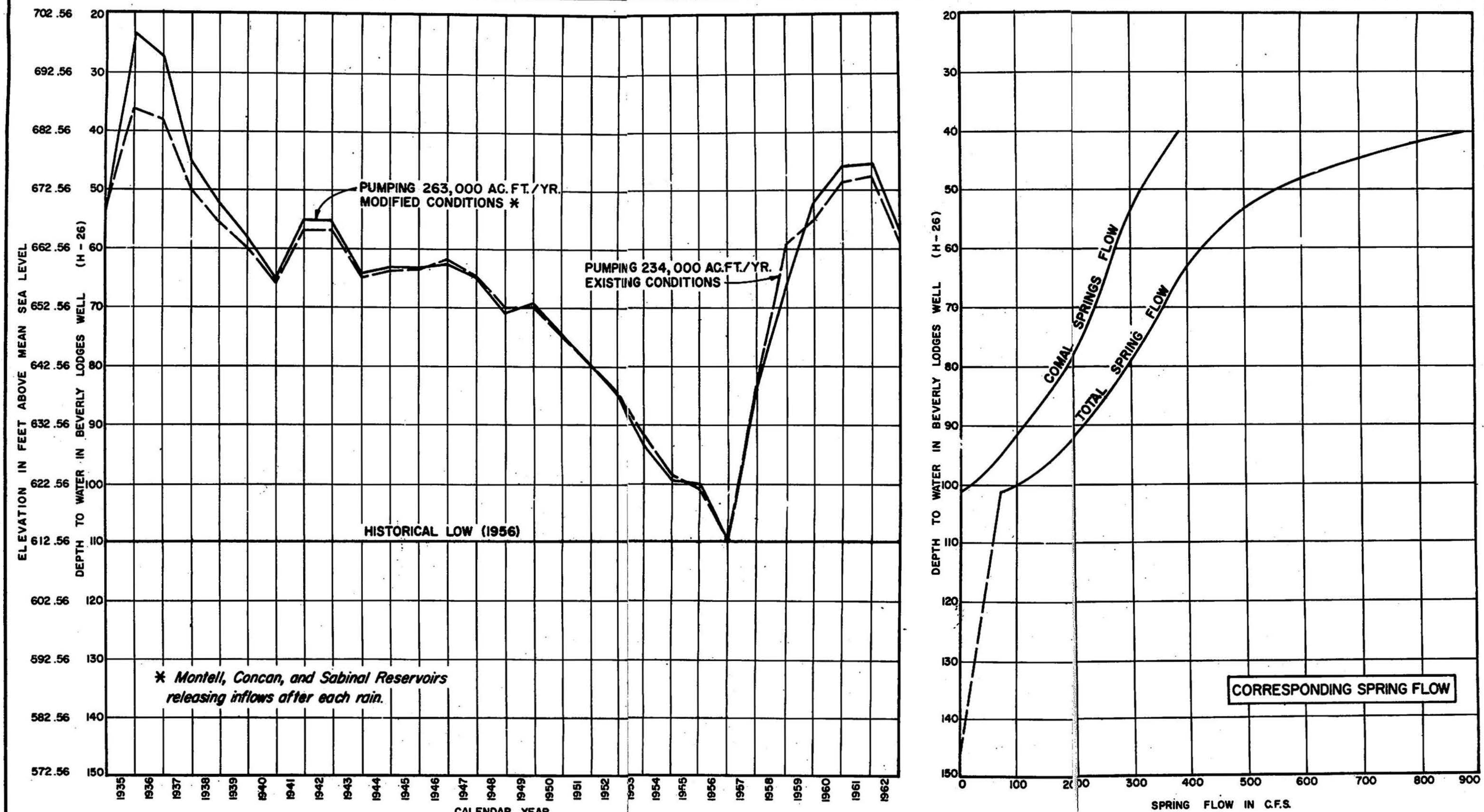
160. Water levels in the underground reservoir will be higher over the life of the recharge projects, particularly during periods when large volumes of water are induced into the aquifer. The water

TABLE 9

PHYSICAL EFFECTS OF THE PLAN

Stream***	Estimated average annual resources above lower edge of Edwards outcrop (ac-ft)*	Estimated average annual recharge (ac-ft)*: Existing conditions	Estimated average annual recharge (ac-ft)*: Modified conditions	Estimated average annual recharge (ac-ft)*: Increase due to reservoir projects	Average annual runoff at lower edge of Edwards outcrop*: Existing conditions	Average annual runoff at lower edge of Edwards outcrop*: Modified conditions	Drainage area** (sq. mi.): Total	Drainage area** (sq. mi.): Controlled
GUADALUPE RIVER BASIN								
Blanco River and adjacent area	99,50	25,400	25,400	0	74,100	24,200(1)	514	307
Guadalupe River	246,00	0	0	0	246,000	74,100(2)	1,510	1,425
Dry Comal Creek	28,90	20,500	20,500	0	8,400	8,400	98	--
SUBTOTAL - Guadalupe River Basin	374,40	45,900	45,900	0	328,500	106,700		
SAN ANTONIO RIVER BASIN								
Cibolo Creek	58,90	54,100	54,100	0	4,800	4,800	258	--
Salado Creek	24,40	21,400	24,400(3)	3,000(3)	3,000	0	118	118
Leon and San Geronimo Creeks	29,30	27,600	27,600	0	1,700	1,700	152	--
Medina River	94,30	42,700	42,700	0	6,400(4)	6,400(4)	630	613
SUBTOTAL - San Antonio River Basin	206,90	145,800	148,800	3,000(3)	15,900	12,900		
NUECES RIVER BASIN								
Verde Creek	18,70	14,600	14,600	0	4,100	4,100	108	--
Hondo Creek	23,50	18,300	18,300	0	5,200	5,200	136	--
Tributary areas	13,70	10,700	10,700	0	3,000	3,000	79	--
Seco Creek	15,40	12,000	12,000	0	3,400	3,400	89	--
Sabinal River	33,90	17,600	33,400	15,800	16,300	500	214	210
Blanco and Hackberry Creeks	4,10	2,100	2,100	0	2,000	2,000	26	--
Little Blanco Creek	2,50	1,300	1,300	0	1,200	1,200	16	--
Frio River	65,00	40,000	61,500	21,500	25,000	3,500	432	391
Two Tributaries	2,70	1,700	1,700	0	1,000	1,000	18	--
Dry Frio River	27,00	17,100	17,100	0	9,900	9,900	140	--
Leona River	6,80	4,300	4,300	0	2,500	2,500	35	--
Deep Creek	3,50	2,200	2,200	0	1,300	1,300	18	--
Nueces River	98,70	64,400	91,000(5)	26,600(5)	34,300	3,400	784	707
Indian Creek	6,40	4,200	4,200	0	2,200	2,200	51	--
Four Tributaries	7,70	5,000	5,000	0	2,700	2,700	61	--
West Nueces River	29,80	16,000	16,000	0	13,800	13,800	905	--
SUBTOTAL - Nueces River Basin	359,40	231,500	295,400(5)	63,900(5)	127,900	59,700		
TOTAL - Edwards Reservoir Area	940,70	423,200	490,100(3)(5)	66,900(3)(5)	472,300	179,300		

* The annual resources, recharge and runoff (exclusive of springflow) at the lower edge of the Edwards outcrop are averages for the period 1935-56.
** The drainage area at lower edge of the Edwards outcrop, as indicated on plates 2 and 3, appendix II.
*** Location of dam sites shown on plate 6
(1) Reduced by estimated net inflow of 49,900 ac-ft/yr to Cloptin Crossing.
(2) Reduced by estimated net inflow of 171,900 ac-ft/yr to Dam No. 7 - Canyon Reservoir system.
(3) Using 16 SCS detention structures on Salado Creek (1962 Work Plan), for increase of 3,000 ac-ft/yr.
(4) Does not include approximately 45,200 ac-ft/yr combined loss to evaporation and use for irrigation.
(5) Does not include 4,300 ac-ft/yr (4 mgd) to be delivered to downstream areas.



NOTE:
For Hydrologic Routing above EL. 682, Springflow Curves were extended.

FIGURE 25
EFFECTS OF CONSTANT PUMPAGE ON WATER LEVELS IN THE EDWARDS UNDERGROUND RESERVOIR
MONTELL, CONCAN, & SABINAL RESERVOIRS IN OPERATION

levels under modified recharge conditions would range from 1 to 13 feet higher and would average approximately two feet higher over the period of routing 1935-56.

161. EFFECTS OF SURFACE STORAGE FOR DEPENDABLE WATER SUPPLY.- Three reservoir projects are proposed in the plan of improvement to provide conservation storage for purposes other than recharge. The projects are Montell, Cloptin Crossing and Dam No. 7. Montell Reservoir would contain 1,000 acre-feet of conservation storage to supply 4,300 acre-feet per year to the Nueces River Conservation and Reclamation District. Construction of Cloptin Crossing and Dam No. 7 Reservoirs, as previously described, would provide a total of 915,400 acre-feet additional conservation storage in the Edwards area. Cloptin Crossing Reservoir would fully develop the upstream resources of the Blanco River and provide a dependable yield of 38 million gallons per day (42,700 acre-feet per year). Dam No. 7 Reservoir would develop to the fullest extent feasible the resources of the Guadalupe River upstream from Canyon Dam. The Canyon-Dam No. 7 Reservoir system would have a dependable yield of 127 mgd (142,700 acre-feet per year). This is an increase of 41 mgd (46,400 acre-feet per year) over the yield determined for the existing Canyon Reservoir without upstream development. The Cloptin Crossing and Dam No. 7 Reservoir projects could supplement the ground-water supply and prevent its rapid depletion if area-wide agreement on development of water resources can be obtained.

162. FUTURE WATER DEMANDS AND SUPPLY.- The projected water demands of the Edwards area are shown in table 10 and figure 26. If only the recharge reservoirs (Montell, Concan and Sabinal) are provided and the plan to limit the pumping rate from the underground reservoir to 263,000 acre-feet per year (235 mgd) is adopted, then the ground-water and surface-water resources would meet the projected needs of the Edwards area as indicated in the following tabulation:

NUECES AND SAN ANTONIO RIVER BASINS

Need	Sufficient to the year
Municipal and Rural	1996
Municipal, Rural, Industrial, and Thermal Power	1979
Municipal, Rural, Industrial, Thermal Power and Irrigation	(1)
Municipal, Rural, Industrial, Thermal Power, Irrigation, and Water Quality	(1)

(1) Total projected demand cannot be met.

163. If Dam No. 7 and Cloptin Crossing Reservoirs are constructed in addition to the recharge reservoirs to supplement the ground-water and surface-water resources of the Edwards Reservoir area the plan would then meet the projected needs of the area as follows:

TOTAL AREA

Need	Sufficient to the year
Municipal and Rural	2036
Municipal, Rural, Industrial, and Thermal Power	2014
Municipal, Rural, Industrial, Thermal Power, and Irrigation	2001
Municipal, Rural, Industrial, Thermal Power, Irrigation, and Water Quality	1980

164. As indicated in the above tabulations, development of the water resources of the Edwards Reservoir area as justified in the plan of improvement will not meet the anticipated future demands within the area to the year 2075, even with drastic curtailment of use. To meet the anticipated future water demands beyond these dates will require more adequate use of return flows and development of additional water supplies outside the Edwards Reservoir area. Because of the limitations imposed by the authorization for this report, no overall basin water supply plan has been investigated for the three river basins.

165. FLOOD CONTROL.- The construction of Montell, Concan, and Sabinal Reservoirs to contain 469,600 acre-feet of joint-storage for flood control and recharge purposes would provide 50-year frequency flood protection for developments along the Nueces, Frio and Sabinal Rivers from floods originating on the Edwards Plateau upstream from the dam sites. The largest portion of the benefits will be creditable to Montell Reservoir and will be derived from protection of the urban and extensive agricultural developments along the Nueces River, particularly in the "winter garden" area downstream from the Balcones fault zone in the vicinity of La Pryor, Crystal City and Cotulla. Additional benefits will also be realized in areas further downstream, including the cities of Tilden and Three Rivers. The flood control value of the proposed Montell, Concan, and Sabinal Reservoirs is

TABLE 10

WATER REQUIREMENTS AND RESOURCES

Item	Nueces River Basin	San Antonio River Basin	Guadalupe River Basin	Total Area
	Year 1962 Water Use in M.G.D. (1)			
Municipal and Rural	6.1	139.7	6.6	152.4
Industrial and Power	1.6	19.8	0.5	21.9
Irrigation	35.3	29.4	0.3	65.0
TOTAL	43.0	188.9	7.4	239.3
	Year 2025 Water Requirements in M.G.D. (2)			
Municipal and Rural	19.9	479.3	46.0	545.2
Industrial and Power	8.7	135.7	15.3	159.7
Irrigation	58.5	60.6	43.8	162.9
Quality Control	-	250.0	-	250.0
TOTAL	87.1	925.6	105.1	1,117.8
	Year 2075 Water Requirements in M.G.D. (2)			
Municipal and Rural	29.3	819.9	72.9	922.1
Industrial and Power	13.7	217.9	30.0	261.6
Irrigation	58.5	60.6	43.7	162.8
Quality Control	-	406.0	-	406.0
TOTAL	101.5	1,504.4	146.6	1,752.5
	Year 2025 Water Resources in M.G.D.			
San Marcos Spring	-		36.0	36.0
Edwards Underground Aquifer	235.0*		-	235.0
Other Ground Water	4.0		18.0	22.0
Montell Reservoir	4.0		-	4.0
Canyon-Dam No. 7 Reservoir System	-		127.0	127.0
Cloptin Crossing Reservoir	-		38.0	38.0
Streamflow	9.0		23.0	32.0
Return Flow	103.0		24.0	127.0
TOTAL	355.0		266.0	621.0
	Year 2075 Water Resources in M.G.D.			
San Marcos Spring	-		36.0	36.0
Edwards Underground Aquifer	235.0*		-	235.0
Other Ground Water	5.0		28.0	33.0
Montell Reservoir	4.0		-	4.0
Canyon-Dam No. 7 Reservoir System	-		127.0	127.0
Cloptin Crossing Reservoir	-		38.0	38.0
Streamflow	7.0		10.0	17.0
Return Flow	126.0		40.0	166.0
TOTAL	377.0		279.0	656.0

*Includes recharge from Montell, Concan and Sabinal Reservoirs.

(1) Determined by the Geological Survey; use from the aquifer.
(2) Determined by the Public Health Service; demands of the 14 counties.

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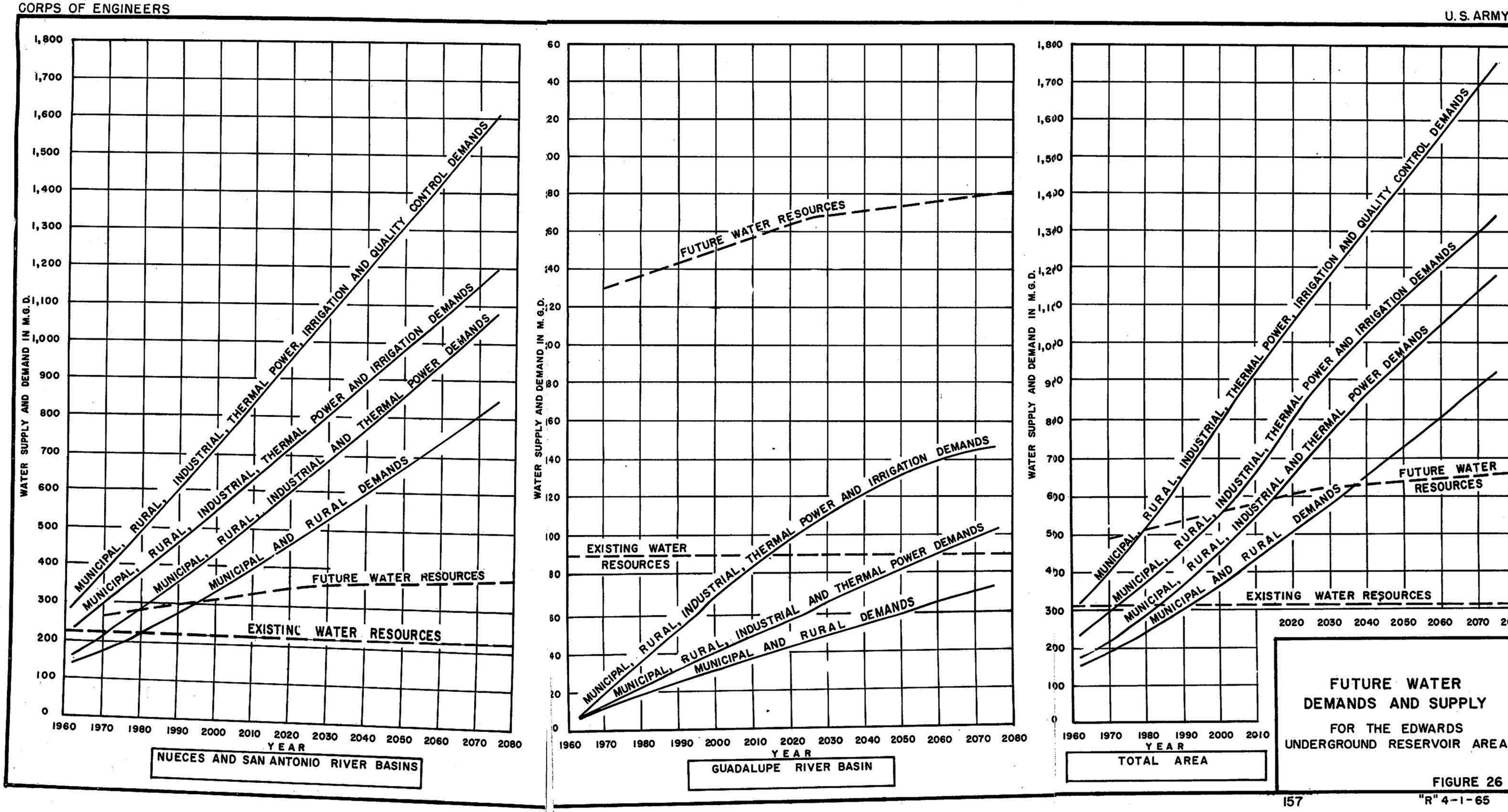


FUTURE WATER DEMANDS AND SUPPLY FOR THE EDWARDS UNDERGROUND RESERVOIR AREA

FIGURE 26

shown on the following tabulation:

	Joint-storage reservoirs		
	Montell	Concan	Sabinal
Average annual damages, dollars (1)	716,100	302,600	308,100
Annual damages prevented, dollars (1)	232,000	25,600	19,700
Annual damages prevented, percent	32.4	8.5	6.4
Average annual benefits dollars (2)	602,100	59,300	46,300
Flood protection frequency	50 yr	50 yr	50 yr

(1) Under 1964 conditions of economic development.
(2) Includes benefits allowable for future development.

The prolonged release of floodwaters from the reservoirs at a reduced rate will result in a higher degree of infiltration of these waters into the Edwards Underground Reservoir resulting in benefits to water supply not included above.

166. The provision of 119,900 acre-feet of flood control storage in Cloptin Crossing Reservoir will provide 75-year frequency flood protection to the agricultural lands, transportation and utility facilities and other improvements along the river valley of the Blanco River downstream from the dam site. It will also provide protection to the city of San Marcos from floods originating on the Blanco River upstream from the dam site. In addition, the project will provide substantial flood protection to downstream areas of the San Marcos and Guadalupe Rivers, including the city of Gonzales, from floods originating on the Blanco River. The flood-control value of the proposed Cloptin Crossing Reservoir is shown in the following tabulation:

Average annual damages, dollars (1)	1,080,000
Annual damages prevented, dollars (1)	226,000
Annual damages prevented, percent	20.9
Average annual benefits, dollars (2)	659,000
Flood protection frequency (Blanco River)	75 yr.

(1) Under 1964 conditions of economic development.
(2) Includes $163,300 credit for reduction of flood control storage requirements in Cuero Reservoir plus an allowance for future development.

167. EFFECTS OF PLAN ON YIELD OF DOWNSTREAM RESERVOIRS.-

a. Nueces River Basin.- The master plan of the Nueces River Conservation and Reclamation District[17] includes the proposed construction of Concan and Sabinal Reservoirs on the Frio and Sabinal Rivers, respectively, for recharge of the Edwards Underground Reservoir. The District has indicated that these recharge projects would have only a negligible effect on downstream water rights. The master plan also recommends construction of the Tom Nunn Hill and the Cotulla Reservoirs and the enlargement of Wesley Seale Reservoir. The size of the projects at Tom Nunn Hill and Cotulla were based upon the maximum development consistent with the prior water rights of the city of Corpus Christi pertaining to Wesley Seale Reservoir. It was recommended in the master plan that Tom Nunn Hill and Cotulla Reservoirs be constructed with conservation capacities of 50,000 and 300,000 acre-feet, respectively, and that the conservation storage capacity in the existing Wesley Seale Reservoir be enlarged from 300,000 to 500,000 acre-feet.

(1) The plan of development for the Edwards Reservoir area has been formulated in consonance with the improvements proposed in this master plan. Although Montell Reservoir is proposed in lieu of Tom Nunn Hill Reservoir, storage in the Montell project, with the channel dam and pipeline facilities included, would furnish to the Reclamation District the dependable yield of the Tom Nunn Hill project, determined to be 4,300 acre-feet per year. Based on the cost of a single purpose water supply reservoir at the Montell site, water could be delivered to the area at an estimated cost of 6.9 cents per 1000 gallons, some 21.0 cents per 1000 gallons cheaper than the estimated cost of water from the Tom Nunn Hill project, computed on a dependable yield basis. In the event an additional quantity of water is desired

for the Crystal City area the additional water could be made available from the Montell Reservoir for approximately 12 cents per 1000 gallons ($39/acre-feet). The pipeline across the fault zone could also be extended further downstream from the Tom Nunn Hill area at a cost of about $50,000 per mile. Enlarging the Montell Reservoir to provide 10,000 acre-feet per year of dependable yield for downstream water supply purposes would decrease the recharge from the proposed project by approximately 18 percent.

(2) Substituting Montell Reservoir in the Tom Nunn Hill - Cotulla - Wesley Seale Reservoir system for Tom Nunn Hill Reservoir would not have an adverse effect on the yield of Wesley Seale Reservoir.

(3) Examination of the resources of the Cotulla Reservoir indicates that under natural conditions the Nueces River loses large quantities of water to the Edwards Underground Reservoir as the stream crosses the outcrop of the Edwards limestone in the Balcones fault zone. In addition, the river loses flow to the gravels and sand formations downstream from the fault zone. It is estimated that under existing conditions, flow occurring at the Montell Dam site at the rate of 14,000 acre-feet per month would be lost in transit through the fault zone and the gravel and sand formations downstream from the fault zone, and no part of such flow would reach the Cotulla Reservoir. Similarly, it is estimated that under natural conditions a flow of 60,000 acre-feet per month at the Montell Dam site would be reduced to only 10,000 acre-feet at the Cotulla site. It is estimated that if Tom Nunn Hill Reservoir had been in operation during the critical drought period, 1947-56, the September 1955 storm would have produced the only runoff in the upper basin during this period which would have reached the Cotulla Reservoir, approximately 16,100 acre-feet. If Montell Reservoir were constructed in lieu of Tom Nunn Hill Reservoir, this flow would not have reached the Cotulla Reservoir. It is considered, however, that the probability of the recurrence of a flood of the magnitude of the September 1955 flood (largest for peak discharge since 1854) during some future critical drought period is so remote that it should be disregarded in establishing reservoir size or yield. This flood was produced from a storm centered over a small area in the upper Nueces River Basin. If this flood were disregarded, construction of Montell Reservoir in lieu of Tom Nunn Hill Reservoir would not have an adverse effect on the yield of either of the two downstream reservoirs as presented in the master plan.

50,000 Ac/mo Loss

b. Guadalupe River Basin.- The plan of development for the Guadalupe River Basin is set forth in the "Supplement to the Initial Plan of Development of the Guadalupe-Blanco River Authority," dated May 1961.18/ This master plan provides for the construction of Cloptin Crossing Reservoir, but at a smaller size than that proposed in this report. The master plan also provides for construction of Dam No. 7 Reservoir in case excessive leakage is experienced at Canyon Reservoir; however, it would provide less storage than the project proposed in this report.

(1) Yield studies were made for the two sizes of projects at each of the Cloptin Crossing and Dam No. 7 Reservoir sites and for Canyon and Cuero Reservoirs. These studies determined that the critical drought period at each of the above reservoirs occurred during the period from June 1947 through February 1957. During this period there would be no reservoir spills from the Cloptin Crossing and Dam No. 7 projects as proposed in the master plan and, consequently, the increase in size of the upstream projects could not decrease the inflow to Cuero Reservoir during its critical period. For this reason the yield of the Cuero Reservoir as presented in the master plan would not be affected by the increase in the conservation capacity of the Cloptin Crossing and Dam No. 7 Reservoirs as proposed in this report.

(2) If the Montell, Concan, and Sabinal Reservoirs in the Nueces River Basin were constructed and operated to recharge the Edwards Underground Reservoir, and if the plan were adopted to limit the pumping from the aquifer to 263,000 acre-feet per year, the additional springflow from the Comal, Hueco, and San Marcos Springs in the Guadalupe River Basin would increase the average annual resources of Cuero Reservoir by 17,600 acre-feet.

168. RECREATION - FISH AND WILDLIFE.- The springs, caverns and clear running streams of the Edwards Underground Reservoir area have been a tremendous attraction for over two centuries. All the major cities in the area were founded in the vicinity of major springs, including San Antonio, New Braunfels, San Marcos and Uvalde. Municipal and private parks and other recreation improvements have been developed at all the major springs and caverns in the area. In addition, Garner State Park on the Frio River, upstream of the proposed Concan Reservoir, has been developed by the Texas Parks and Wildlife Department. At this park a channel dam forms a reservoir with a water surface of approximately ten acres. However, because of the scenic beauty of this area, the clear running streams and extensive recreation development, this park receives an estimated average annual visitation of 900,000. Also, eight recreation parks have been developed at the newly constructed Canyon Reservoir. One of the parks is a model recreation area for reservoir projects in the Fort Worth District.

169. To supplement existing recreation developments in the Edwards Reservoir area, it is proposed that land and facilities be provided at the Montell, Concan, Sabinal and Cloptin Crossing Reservoirs for general recreation and fish and wildlife purposes.

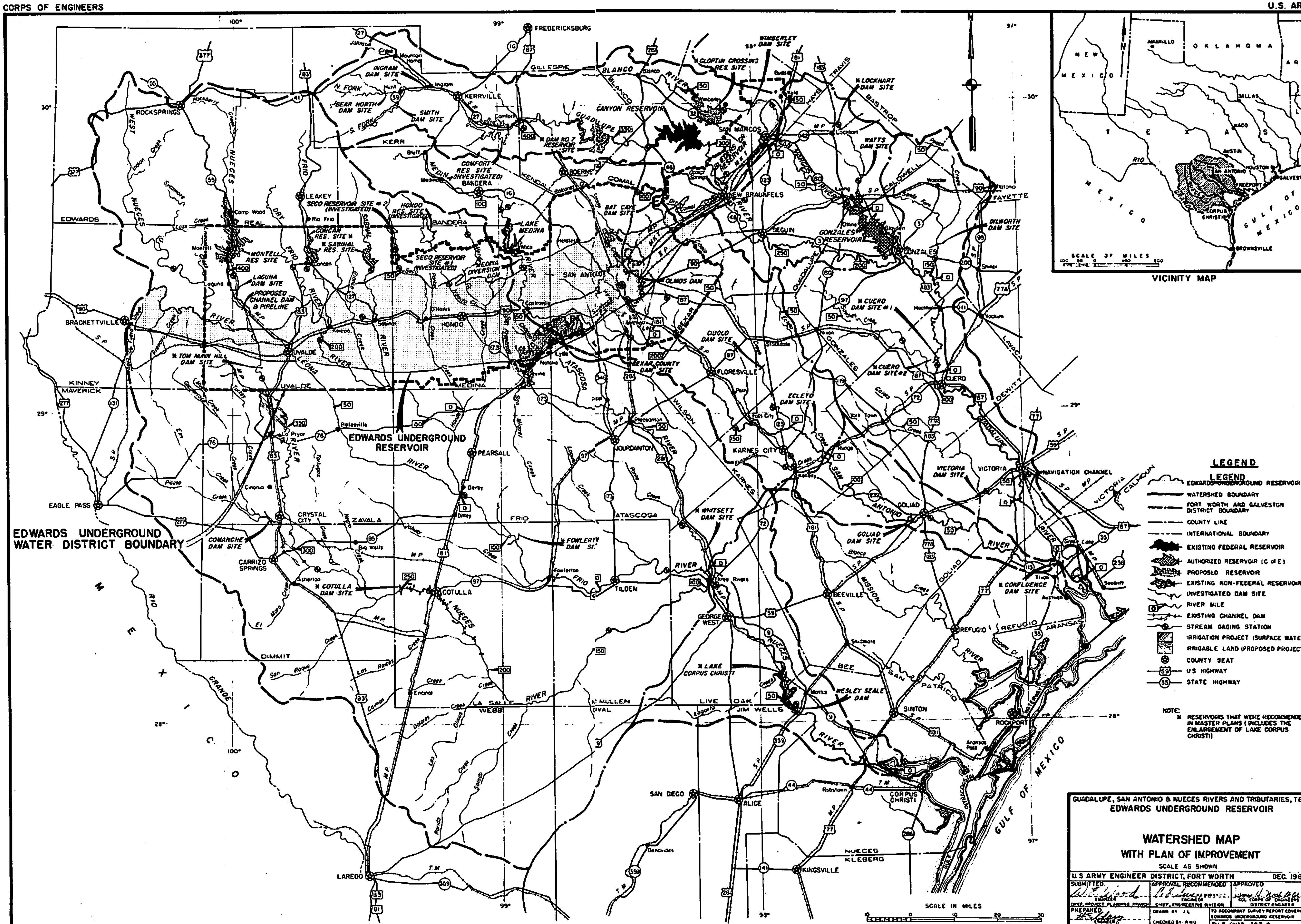
The flood control operation of all the projects and the recharge operations of the Montell, Concan and Sabinal Reservoirs would provide an additional scenic attraction for sightseers. The low-flow of the Nueces River would also be enhanced along a 14-mile reach between the Montell Dam and a channel dam to be constructed immediately upstream from the Edwards outcrop on this stream. The additional recharge water to be provided by the three reservoirs would enhance all the major springs along the Balcones fault zone, as described in paragraph 156. Of particular significance would be the increase in springflow in the city of San Antonio, estimated to average about 13,300 acre-feet annually. San Antonio and San Pedro Springs have flowed only intermittently in recent years, and the flow of the scenic San Antonio River through the city has been maintained by wells in Brackenridge Park, commercial and industrial wells, and local flood runoff. 4/

170. The recreation lands and facilities proposed in this report would provide recreational opportunities for an additional 2,560,000 visitors annually. Of this total, about 1,700,000 visitors are expected to participate in general recreational activities and about 860,000 visitors in fishing and hunting. The proposed recreational development would complement, but not compete with, those recreational attractions existing in the area. If recreation lands and facilities were provided at the Dam No. 7 Reservoir, this project would attract an estimated additional 4,800,000 visitors.

171. Inundation of reservoir lands will result in loss of bottomland habitat for big and upland game, particularly deer. Because of the small populations of wild turkey and small fur-bearing animals, they are not expected to be appreciably affected by the proposed projects. The reservoirs with conservation storage will attract to some degree certain waterfowl during migration, such as mallards, pintails, blue-winged teals, green-winged teals, and coots. Mourning dove populations are expected to continue to be plentiful in the Cloptin Crossing Reservoir area. The Cloptin Crossing and Montell Reservoirs would be clear, attractive impoundments which would provide high quality fish habitat, primarily for largemouth bass, catfish, and white crappie. The fish habitat along the Nueces River between the Montell Dam and the proposed channel dam would also be enhanced by the constant release to be made from the Montell Reservoir. A more detailed description of the effects of the proposed plan on the fish and wildlife resources of the Edwards Reservoir area is presented in a report of the Bureau of Sport Fisheries and Wildlife, attached to appendix VI.

FIGURE 27

SAN ANTONIO RIVER
IN THE
CITY OF SAN ANTONIO



VICINITY MAP
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT BOUNDARY
GULF OF MEXICO
LEGEND
EDWARDS UNDERGROUND RESERVOIR
WATERSHED BOUNDARY
FORT WORTH AND GALVESTON DISTRICT BOUNDARY
COUNTY LINE
INTERNATIONAL BOUNDARY
EXISTING FEDERAL RESERVOIR
AUTHORIZED RESERVOIR (C of E)
PROPOSED RESERVOIR
EXISTING NON-FEDERAL RESERVOIR
INVESTIGATED DAM SITE
RIVER MILE
EXISTING CHANNEL DAM
STREAM GAGING STATION
IRRIGATION PROJECT (SURFACE WATER)
IRRIGABLE LAND (PROPOSED PROJECT)
COUNTY SEAT
U S HIGHWAY
STATE HIGHWAY
NOTE:
RESERVOIRS THAT WERE RECOMMENDED IN MASTER PLANS (INCLUDES THE ENLARGEMENT OF LAKE CORPUS CHRISTI)
SCALE IN MILES
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
WATERSHED MAP
WITH PLAN OF IMPROVEMENT
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2

ECONOMIC EVALUATION OF THE PROPOSED PLAN

172. GENERAL.- Economic studies of the proposed reservoirs were made to determine that (a) the annual benefits exceeded the annual charges for the project and its separate and joint project purposes; (b) each unit of the project is proposed at the size, where practical, that produces the greatest excess benefits over costs; and (c) the entire plan is the most practical and feasible means of accomplishing the project purposes.

173. COSTS.- The estimates of first cost include all initial expenditures for physical construction of the project, lands and damages, relocations, reservoir clearing, engineering and design, and supervision and administration. The first costs and annual charges, based on July 1964 price levels, for all projects recommended for authorization are shown in table 11. The annual charges for the proposed projects include interest and amortization of Federal and non-Federal investments at an interest rate of 3-1/8 percent for a 100-year period, operation and maintenance costs, and annual equivalent costs of major replacements.

174. BENEFITS.- Benefits which would be expected to accrue from the recommended projects have been estimated on the basis of a useful project life of 100 years. Those benefits which are expected to accrue from future flood plain development have been reduced to an average annual equivalent value by compound interest methods. The estimates of average annual benefits for the projects recommended for authorization are described below and are shown in table 11 by projects and purposes.

a. Reduction in flood damages.- The average annual benefits for flood damage reduction accruing to the various projects were determined by use of discharge-damage and discharge-frequency relationships. The average annual damages of $2,406,800 under 1965 conditions of economic development in the flood plain would be reduced by the 4 proposed flood control reservoirs to $1,903,500 for benefits of $503,300. An allowance to reflect the economic trends and future development anticipated in the flood plain during the period 1975 to 2075 would increase these annual flood-control benefits to a total of $1,366,400. The reservoirs are designed to prevent all future floods immediately below the dam sites up to a frequency of once in 50 years at the Montell, Concan and Sabinal Reservoirs and once in 75 years at the Cloptin Crossing Reservoir. However, the flood plain areas over which the average annual damages are considered are very extensive and the reduction of damages indicated reflects the average reduction over the entire flood plain area with the degree of protection diminishing downstream as the uncontrolled drainage area increases.

b. Water supply.- Benefits for water supply were computed on the basis of the cost of providing the same quantity and quality of water by the cheapest alternative means. The estimated cost of the alternate project was based on non-Federal financing and interest rates for the proposed publicly-owned project. Additional benefits were credited to Montell Reservoir for the water provided to downstream areas in lieu of the non-Federal Tom Nunn Hill Dam and Reservoir. The four reservoir projects proposed for construction by the Federal Government have been credited with water supply benefits of $3,168,700 as determined by the Public Health Service and shown in table 11. The Dam No. 7 Reservoir, proposed for construction by local interests, would accrue an additional $1,617,000 in water supply benefits annually. For a complete analysis see the report by the Public Health Service attached to appendix I.

c. Recreation.- Benefits for recreation were computed on the basis of estimated annual attendance in visitor-days at each project, using a value of $0.50 per visitor-day for a variety of recreational activities including picknicking, swimming, boating, camping, sight-seeing, hiking, fishing, and hunting. Recreation benefits for fishing and hunting were computed on the basis that 35 percent of the total visitation would be for these purposes, 34.65 percent for the purpose of fishing, and 0.35 percent for the purpose of hunting. It was estimated that the average visit for fishing should have an additional value of $0.50, and the average visit for hunting an additional value of $1.00. Total benefits from these recreational activities are estimated at $1,414,300, as shown in table 11. For a complete discussion of the recreational potentialities see appendix VI.

175. ECONOMIC JUSTIFICATION.- Comparison of annual benefits with annual costs, as presented in table 11, indicates that each proposed project is economically justified individually and as a unit in the system. A complete analysis of the economic justification of each project is presented in Appendix I, Project Formulation. Though the projects have been justified by monetary benefits alone, they would also provide important intangible benefits to the economy of the region.

176. The flood control effects of the Montell, Concan, Sabinal and Cloptin Crossing projects would reduce the threat to lives and stabilize the economy of the area subject to flooding downstream from these projects. The general recreation and fish and wildlife aspects of the projects would improve the social well-being of a great number of the people living in the general area.

177. Providing additional recharge to the underground reservoir would help maintain higher water levels in the Edwards aquifer throughout the life of the recharge projects and would allow increased pumping from the underground reservoir without reducing the water level below the historical low, thereby averting possible contamination. The average flow of important springs along the Balcones escarpment would be increased, thereby assuring a more dependable water supply to cities,

industries, and farms in their areas of influence. Higher water levels in the aquifer would assure a more economical pumping operation for all users, both large and small. Many of these benefits are intangible and have not been evaluated in monetary terms, but it is evident that they are of major economic significance and would materially supplement the justification of the projects recommended for authorization. The benefits to be derived from the plan, however, are dependent upon the use of a supplemental surface water supply and limitation on pumpage withdrawal throughout the reservoir area.

TABLE 11

FIRST COSTS, ANNUAL CHARGES, ANNUAL BENEFITS, AND BENEFIT-COST RATIO
PROPOSED PROJECTS
EDWARDS UNDERGROUND RESERVOIR AREA
(July 1964 price level)
(Interest rate 3-1/8% - Amortization, 100 years)
(in thousand dollars)

	Montell	Concan	Sabinal	Cloptin Crossing	Totals
FIRST COSTS	32,545.0(1)	15,650.0	11,413.0	24,440.0	84,048.0
ANNUAL CHARGES	1,237.5(2)	599.5	440.6	1,035.7	3,313.3
ANNUAL BENEFITS	1,802.4	889.6	659.9	2,597.8	5,949.7
Flood Control	(602.1)	(59.3)	(46.3)	(659.0)	(1,366.7)
Water Supply	(1,098.8)	(816.8)	(600.1)	(653.0)	(3,168.7)
Recreation	(101.5)	(13.5)	(13.5)	(1,285.8)	(1,414.3)
BENEFIT-COST RATIO	1.5	1.5	1.5	2.5	1.8

(1) Includes $900,000 estimated first cost of channel dam and pipeline.

(2) Includes $46,000 for annual charges of channel dam and pipeline.

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176. COST ALLOCATION TO PROJECT PURPOSES.- Cost allocation studies were made for the proposed Montell, Concan, Sabinal and Cloptin Crossing Reservoirs to determine the equitable distribution of the costs to the various project purposes. The allocations were made by the Separable Cost-Remaining Benefits Method. For the Montell and Cloptin Crossing projects, allocations were made between the purposes of flood control, water conservation, fish and wildlife, and general recreation. The costs of the channel dam and pipeline proposed in connection with the Montell Reservoir project are specific costs for water supply purposes and are added to the allocated water supply cost of the reservoir. For the Concan and Sabinal projects, allocations were made between the purpose of flood control, water conservation and recreation. The total project costs allocated in this manner for the four reservoir projects are presented in table 12.

177. APPORTIONMENT OF COSTS AMONG INTERESTS.- The apportionment of construction, operation, maintenance, and replacement costs between Federal and non-Federal interests have been made for the four reservoir projects based on existing laws, policies, and procedures established to govern construction of public works. A cost apportionment summary is presented in table 13.

178. The costs allocated to flood control in the proposed projects are apportioned to the Federal Government in accordance with the general policy established in the Flood Control Act of 1936, Public Law 738, 74th Congress, as amended. The apportionments are made to the Federal Government because of the widespread and general nature of the benefits associated with the flood control effects of the reservoir projects.

179. The portion of the allocated water supply cost of Montell, Concan, and Sabinal Reservoirs assigned to recharge the Edwards Underground Reservoir has been apportioned both to the Federal Government and to local interests. As described in previous sections of this report, the largest military complex in the Southwest is located within the Edwards Reservoir area in and around the city of San Antonio. The military installations pumped 13.5 million gallons per day (15,100 acre-feet-per-year) directly from the underground reservoir in 1962. This quantity represented about 5.5 percent of the total water pumped from the aquifer in 1962. For the period 1955-62 the percentages of water used by the military were virtually the same as those for 1962, and it is assumed that future military water requirements will continue on this same trend. Since the military installations will share with local interests in the benefits to be derived from the recharge reservoirs, 5.5 percent of the allocated water supply cost of the projects assigned to recharge of the Edwards aquifer have been apportioned to the Federal Government.

180. The cost of Montell and Cloptin Crossing Reservoirs allocated to conventional water supply (including costs for the pipeline and channel dam) is the responsibility of non-Federal interests, in accordance with the provisions of the Water Supply Act of 1958, Public Law 500, 85th Congress, as amended.

181. Recreation is considered to be a project purpose of the Concan and Sabinal Reservoirs, and both general recreation and fish and wildlife recreation are considered to be project purposes of the Montell and Cloptin Crossing Reservoirs. The facilities to be provided have been developed in consonance with Senate Document 97, 87th Congress, 2d Session. Costs for recreation lands and facilities allocated to the Federal Government are within the limits established by H. R. 9032, introduced on November 6, 1963, and printed on pages 20092 through 20095 of the Congressional Record for that date.

TABLE 12

SUMMARY OF COST ALLOCATIONS
PROPOSED PROJECTS

Project and Purpose	Allocations: First Costs	Allocations: Annual Charges	Annual Benefits	B/C Ratio	Allocated water supply cost per 1,000 gallons
MONTELL RESERVOIR					
Flood Control	$10,873,000	$ 403,200	$ 602,100	1.5	-
Water Conservation:	20,007,000	758,300	1,098,800	1.5	-
Reservoir:	(19,107,000)	(712,300)	(1,052,800)	1.5	-
Recharge	(18,560,000)	(680,100)	(1,010,500)	1.5	0.078
Downstream Supply	(547,000)	(32,200)	(42,300)	1.3	0.023
Pipeline System	(900,000)	(46,000)	(46,000)	1.0	0.056*
Recreation - Fish and Wildlife	1,665,000	76,000	101,500	1.3	-
TOTAL	32,545,000	1,237,500	1,802,400	1.5	
CONCAN RESERVOIR					
Flood Control	1,189,000	55,100	59,300	1.1	-
Water Conservation (Recharge)	14,234,000	531,400	816,800	1.5	0.076
Recreation	227,000	13,000	13,500	1.0	-
TOTAL	15,650,000	599,500	889,600	1.5	
SABINAL RESERVOIR					
Flood Control	898,000	42,800	46,300	1.1	-
Water Conservation (Recharge)	10,288,000	384,900	600,100	1.6	0.075
Recreation	227,000	12,900	13,500	1.0	-
TOTAL	11,413,000	440,600	659,900	1.5	
CLOPTIN CROSSING RESERVOIR					
Flood Control	7,628,000	292,800	659,000	2.2	-
Water Conservation	9,461,000	359,700	653,000	1.8	0.026
Recreation - Fish and Wildlife	7,351,000	383,200	1,285,800	3.4	-
TOTAL	24,440,000	1,035,700	2,597,800	2.5	
TOTAL - PROPOSED PROJECTS	$84,048,000	$3,313,300	$5,949,700	1.8	

18,560,000
14,234,000
10,288,000
43,082,000

*For water conservation storage in the reservoir plus the pipeline system.

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TABLE 13

APPORTIONMENT OF COSTS
PROPOSED PROJECTS
(in 1000 dollars)

Project and Purpose	First Cost			Operation, Maintenance and Replacement of Parts Cost		
	Federal	Non-Federal	Total	Federal	Non-Federal	Total
MONTELL RESERVOIR						
Flood Control	10,873.0	-	10,873.0	19.2	-	19.2
Water Conservation:						
Reservoir:						
Recharge	1,021.0*	17,539.0	18,560.0	1.4*	23.2	24.6
Downstream supply	-	547.0	547.0	-	12.8	12.8
Pipeline System	-	900.0	900.0	-	16.6	16.6
Recreation - Fish and Wildlife	1,665.0	-	1,665.0	17.2	-	17.2
TOTAL	13,559.0	18,986.0	32,545.0	37.8	52.6	90.4
CONCAN RESERVOIR						
Flood Control	1,189.0	-	1,189.0	13.7	-	13.7
Water Conservation (Recharge)	783.0*	13,451.0	14,234.0	2.0*	34.0	36.0
Recreation	227.0	-	227.0	5.1	-	5.1
TOTAL	2,199.0	13,451.0	15,650.0	20.8	34.0	54.8
SABINAL RESERVOIR						
Flood Control	898.0	-	898.0	12.0	-	12.0
Water Conservation (Recharge)	566.0*	9,722.0	10,288.0	1.8*	30.3	32.1
Recreation	227.0	-	227.0	5.1	-	5.1
TOTAL	1,691.0	9,722.0	11,413.0	18.9	30.3	49.2
CLOPTIN CROSSING RESERVOIR						
Flood Control	7,628.0	-	7,628.0	27.3	-	27.3
Water Conservation	-	9,461.0	9,461.0	-	30.4	30.4
Recreation - Fish and Wildlife	7,351.0	-	7,351.0	127.3	-	127.3
TOTAL	14,979.0	9,461.0	24,440.0	154.6	30.4	185.0
TOTAL PROPOSED PROJECTS	32,428.0	51,620.0	84,048.0	232.1	147.3	379.4

*Represents 5.5% of the allocated costs to recharge purposes. All water resources developed by Concan and Sabinal Reservoirs and 86% (26,600 ac.ft./yr) of the water resources developed by Montell Reservoir are indicated for recharge purposes. The remaining 14% (4,300 ac.ft./yr) of water resources developed by Montell Reservoir is indicated for municipal and industrial water supply for downstream areas in the Nueces River Basin.

LOCAL COOPERATION

182. LOCAL COOPERATION IN THE PLAN.-

a. Basic principles.- The division of project costs between Federal and non-Federal interests is based on the allocation of costs to the project purposes in accordance with presently applicable laws and regulations governing cost-sharing practices.

b. Non-Federal responsibilities.- In accordance with the Water Supply Act of 1958 and the Federal Water Pollution Control Act Amendments of 1961, all construction, operation and maintenance, replacement, and interest costs incurred by the Federal Government and allocated to water supply are to be repaid by local interests, except 5.5 percent of those costs pertaining to recharge of the Edwards Underground Reservoir. No payment is required for the costs allocated to future water supply until such time as the project is first used for that purpose, except for the payment of interest charges on the unpaid balance after the interest free period, which shall not exceed 10 years. The construction costs, including interest during construction and interest on the unpaid balance, may be paid in a lump sum or in equal annual payments within the life of the project, but not to exceed 50 years after water supply use is initiated. In addition, annual payments must be made for the operation and maintenance costs allocated to water supply, beginning with the first use of storage for water supply, plus payment of applicable replacement costs when incurred. The above requirements are equally applicable to provisions for additional water supply and at such time that portions of reservoir storage are converted to meet long-term demands. Project costs allocated to recreation have been apportioned to the Federal Government and are within limits of the cost-sharing policy adopted by the Administration and outlined in H.R. 9032, 88th Congress. In addition to the foregoing, responsible local interests will be required to furnish assurances satisfactory to the Secretary of the Army that they will:

(1) Enter into a contract prior to initiation of the construction work and in accordance with repayment provisions of the Water Supply Act of 1958, as amended, to reimburse the Federal Government for that portion of the construction costs allocated to water supply and apportioned to non-Federal interests, including the channel dam and pipeline in connection with the Montell Reservoir project. The percent of the total project first costs and operation and maintenance costs apportioned to local interests are presently estimated as follows:

Project	First Costs	O&M
Montell Reservoir	58.34%	58.19%
Concan Reservoir	85.95%	62.04%
Sabinal Reservoir	85.18%	61.59%
Cloptin Crossing Reservoir	38.71%	16.43%

(2) Obtain without cost to the United States all water rights necessary for operation of the projects in the interest of conventional water supply and recharge to the underground reservoir.

183. VIEWS OF LOCAL INTERESTS.- The Edwards Underground Water District, the State agency designated by the Governor of Texas to cooperate with the Corps in this study, has coordinated the review of this report by other interested State and local agencies and by the major military commands within the Edwards area. Copies of the draft of the report were sent by the Edwards Underground Water District to the commanding officers at Fort Sam Houston, Randolph Air Force Base and Kelly Air Force Base; and to the interested river authorities, city water boards and improvement districts. The views of the Edwards Underground Water District and the comments received from other local interests are summarized in the following subparagraphs. The letters containing the comments are presented in appendix VII.

a. Edwards Underground Water District.- By letter dated March 23, 1965, the Edwards Underground Water District stated that in signing the cooperative report it expresses its full approval of the proposed plan of improvement for the comprehensive development of the water resources of the Edwards area and will endeavor to provide the necessary local cooperation.

b. San Antonio River Authority.- In its letter to the Edwards Underground Water District dated February 10, 1965, the Authority stated that further investigations should be made to determine if the water level in the underground reservoir could be safely lowered below elevation 612 feet. The Authority stated that some equitable program of regulation should be achieved. This regulation should apply to both artificial recharge and pumping withdrawals. The Authority referred to the agreement between the Authority and the Guadalupe-Blanco River Authority which contemplates the construction of the Cloptin Crossing Reservoir and possible development of a site upstream from Canyon Reservoir.

c. Guadalupe-Blanco River Authority.-

(1) By letter to the Edwards Underground Water District

dated January 22, 1965, the Authority stated it had only a casual interest in the three recharge reservoirs proposed for construction in the Nueces River Basin since they are outside the boundaries of the Authority. The Authority, however, doubted their economic justification for water conservation. The Authority also stated that it has a real and continuing interest in the Cloptin Crossing and Dam No. 7 Reservoir projects proposed for construction in the Guadalupe River Basin but expressed belief that the report gives no consideration to existing water rights in its treatment of these projects. The Authority stated that, in its opinion, since Dam No. 7 and Cloptin Crossing Reservoirs were not for recharge purposes that their inclusion in this survey report exceeded the authorization of Congress under which the report was prepared, and requested the report be revised to eliminate them. The Authority further stated, however, that if the Cloptin Crossing Reservoir were constructed to its optimum size and operated for the benefit of the Guadalupe River Basin in conjunction with downstream water rights, it is a desirable and justified project. Furthermore, if presented in a separate report dealing with the water supply and flood-control problems of the Guadalupe River Basin the project would have the full support of the Guadalupe-Blanco River Authority.

(2) In its letter the Authority quoted only the first portion of authorizing law which pertained to the recharge of the Edwards Underground Reservoir. Public Law 86-645 states that the study should be made with a view to devising an effective means of accomplishing the recharge and replenishment of the Edwards Underground Reservoir as a part of plans for flood control and water conservation in the Nueces, San Antonio, and Guadalupe River Basins of Texas.

d. Zavala-Dimmit Counties Water Improvement District No. 1.- In its letter to the Edwards Underground Water District dated March 25, 1965, the District expressed the wish to reserve the right to be free to either support or oppose the Montell Reservoir project. The District stated that its plan for basin development provides for two reservoirs for the replenishment of ground waters; that all the water of the Nueces River proper is solely needed for Corpus Christi and multiple uses upstream; and that if a substantial quantity of water is available above the Montell site, this water should be available to reservoirs included in the approved master plan.

e. Bexar-Medina-Atascosa Counties Water Improvement District No. 1.- By letter dated March 15, 1965, the District notified the Edwards Underground Water District that it had no comment to make on the report.

f. Bexar Metropolitan Water District.- In its letter (undated) to the Edwards Underground Water District the Bexar Metropolitan Water District expressed the wish to postpone its comments until it has had a chance to review the proposed State water plan.

g. Nueces River Conservation and Reclamation District.- By letter dated April 7, 1965, the District stated that it was opposed to construction of the Montell, Concan and Sabinal Reservoirs as proposed in the report. The District expressed belief that Tom Nunn Hill Reservoir, as proposed in its Master Plan, would better serve the irrigation needs of the "winter garden" area along the Nueces River. The District stated that Uvalde County desires 10,000 acre-feet of permanent storage in Concan Reservoir for recreation and the consideration of a more economical spillway and outlet works at this project. It was the opinion of the District that the Concan and Sabinal Reservoirs were not justified at this time, based on a value of water for irrigation purposes within the District.

COORDINATION WITH OTHER AGENCIES

184. GENERAL.- Since studies were first initiated for this report, close coordination has been maintained with the Edwards Underground Water District. Semi-annual progress reports on the study have been made by representatives of the Fort Worth District at regular meetings of the Board of Directors of the Water District. In the interim, plans and investigations have been coordinated through additional conferences and correspondence.

185. On November 29, 1960, the Texas Water Commission and the regional offices of other possibly interested Federal agencies were advised of the Fort Worth District's Fiscal Year 1961 general investigations program, including the initiation of studies on recharging of the Edwards Underground Reservoir. The agencies were requested to advise the Fort Worth District of their interest in the area and the survey study, and to furnish information on available basic data in their possession which may be useful to the Corps during the course of the investigations. Further requests were made to all interested Federal, State, and local agencies at the public hearing held in San Antonio, Texas, on December 7, 1961. In response to the requests, extensive quantities of basic information and reports containing results of previous investigations were received from U. S. Geological Survey, Texas Water Commission, Soil Conservation Service, San Antonio City Water Board, Ground-Water Hydrologist W. F. Guyton, and others. Direct liaison on the working level, as well as at field-agency head level, was established and maintained throughout the course of this investigation with several of the above agencies, the Public Health Service, the Bureau of Sport Fisheries and Wildlife, and the Geological Survey. Funds were allotted to several Federal agencies to prepare special reports or secure data for use in the investigations. These special investigations are described in the following paragraphs.

186. PUBLIC HEALTH SERVICE.- On November 30, 1962, the Public Health Service, U. S. Department of Health, Education and Welfare, was requested to determine the need and value of reservoir storage for purposes of municipal and industrial water supply and water quality control. It was also requested that consideration be given to the quality of the water available for recharge to the underground reservoir. The limits of the study area, as established by the authorizing law, were to include the fourteen counties across the northern portions of the Guadalupe, San Antonio and Nueces River Basins within the Edwards Reservoir area. The Public Health Service report is presented as an attachment to appendix I.

187. BUREAU OF SPORT FISHERIES AND WILDLIFE.- On December 6, 1962, the Bureau of Sport Fisheries and Wildlife, Fish and Wildlife Service, U. S. Department of the Interior, was requested to prepare a report on the Edwards Underground Reservoir area in cooperation with

the Corps of Engineers under authority of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.). The Bureau was requested to determine the effects of the proposed improvements on the fish and wildlife aspects of the area included in the authorized study. Close coordination has been maintained with the Fort Worth office, Branch of River Basins Studies, during preparation of this report. The report prepared by the Bureau is included as an attachment to appendix VI.

188. GEOLOGICAL SURVEY.- On July 18, 1962, the Ground-Water Branch of the Geological Survey, U. S. Department of the Interior, was requested to provide assistance in preparation of geologic maps of several dam and reservoir sites under investigation. Emphasis was placed on location of any zones of faulting, caves or other loss zones that could contribute to reservoir leakage, including the presence of any member of the Edwards and associated limestones. Assistance was also requested for aid in interpretation and correlation of gamma logs of mechanically logged wells and other information obtained from core boring and oil well data, and aid in planning and execution of radioactive tracer studies.

189. On February 21, 1963, the Surface Water Branch of the Geological Survey was requested to make a low-flow survey, or seepage investigation, in the upper reaches of the proposed Cloptin Crossing Reservoir on the Blanco River.

190. Close field-level coordination with the Austin and San Antonio offices of the Geological Survey has been maintained throughout the period of study.

191. SOIL CONSERVATION SERVICE.- During the investigation, the Soil Conservation Service, U. S. Department of Agriculture, furnished work plans and other data regarding its program of runoff and waterflow retardation and soil-erosion prevention in the Guadalupe and San Antonio River Basins. The existing and planned improvements in the Edwards Reservoir area have been described in previous sections of this report.

192. FEDERAL POWER COMMISSION.- During preparation of the report, the Federal Power Commission was advised of various projects under consideration in the Edwards Reservoir area. The Commission was requested to furnish the Corps with unit capacity and energy values based on privately-financed alternative steam electric system compared to a Federally-financed hydroelectric system, the cost per kilowatt of the alternative thermoelectric generating plant, and a statement of utilization of the hydro-capacity to supply the area power demands.

193. BUREAU OF RECLAMATION.- The Bureau in conjunction with its "Texas Basins Project" investigation requested that the Fort Worth District of the Corps of Engineers determine the flood control storage requirements and benefits applicable to certain reservoirs under consideration by the Bureau. The projects studied by the Corps for the Bureau were Cuero Reservoir (Stage II) in the Guadalupe River Basin and Cibolo Reservoir in the San Antonio River Basin.

194. REVIEW OF REPORT BY OTHER AGENCIES.- Copies of this report have been forwarded to other Federal agencies at field level and to the Texas Water Commission for their preliminary views and comments. Letters from these agencies and the replies by the District Engineer where appropriate are presented in Appendix VII of this report. The comments contained in the letters from other agencies are summarized briefly in the following subparagraphs:

a. Bureau of Public Roads.- By letters dated January 8 and 14, 1965, the Bureau of Public Roads stated that the report had been reviewed and the Bureau had no comment.

b. Bureau of Outdoor Recreation.- The Bureau of Outdoor Recreation, by letter dated January 8, 1965, expressed satisfaction with the analysis of the recreation problems of the study area as presented in the report. The Bureau indicated that it would have no specific comments to offer concerning the proposed projects until the pending Nationwide Outdoor Recreation Plan and the Statewide Outdoor Recreation Plan of the State of Texas have been developed.

c. Southwestern Power Administration.- By letter dated January 18, 1965, the Southwestern Power Administration stated that the proposed improvements would not affect its interests. However, it was suggested that in further studies of reservoir projects in the region the hydroelectric power potential be considered in both conventional and pumped storage projects.

d. Federal Power Commission.- As described in its letter dated January 20, 1965, the Federal Power Commission made a detailed study to determine the feasibility of inclusion of hydroelectric power facilities as a part of the development of the projects proposed in this report. The Commission concurred in the conclusions reached by the Corps that provision of these facilities at Federal expense could not be justified. It was noted that operation of recharge reservoirs as proposed in the report would increase the springflow and thus increase the power production at the series of small existing hydroelectric stations on the Guadalupe River.

e. Public Health Service.- The Public Health Service, by letter dated January 21, 1965, noted several minor inconsistencies in data presented in the report. In addition, the Service has suggested several public health safeguards for inclusion in development of preconstruction plans for the reservoir and recreation areas. It further recommended that a postimpoundage vector control survey be conducted to determine additional measures needed to provide adequate public health safeguards.

f. Soil Conservation Service.- By letters dated January 21 and 28, 1965, the Soil Conservation Service noted several minor errors in the presentation of data pertaining to its reservoir projects. The Service indicated the value placed on the recharge water was higher than it would generally estimate, but was not considered unreasonable since the total resources are needed in the San Antonio area.

g. Forest Service.- By letter dated January 20, 1965, the Forest Service expressed belief that the role of land treatment combined with floodwater-retarding structures was not adequately reflected in the report.

h. Bureau of Sport Fisheries and Wildlife.-

(1) By letter dated January 22, 1965, the Bureau of Sport Fisheries and Wildlife expressed concern that the benefits for fishing and hunting used in this report were considerably in excess of those determined by the Bureau. The Bureau expressed belief that sport fishing from the projects would decline after the early years of impoundment and that the projects would provide no hunting benefits. The Bureau requested that the recommendations contained in its report (pertaining to preconstruction plans and reservoir management) be incorporated and discussed in the Corps report.

(2) The Corps estimates of benefits are based on experienced visitor use at comparable operating Corps reservoirs throughout the area and are considered conservative. In developing the estimates, consideration was given to present population density, predicted population increases during project life, and competition to be satisfied from existing and other proposed reservoirs.

i. Geological Survey.- By letter dated January 25, 1965, the Geological Survey concurred in recommendations presented in the report concerning an expansion of the existing program for obtaining basic hydrologic data on the surface-water and ground-water resources of the area. The Survey made additional suggestions concerning hydrologic instrumentation that should be established during construction of the reservoir projects. It also presented additional information concerning current programs of study and mapping, history of investigations, and data on quality of water.

j. National Park Service.- The National Park Service, in its letter dated January 25, 1965, expressed satisfaction that the planning for recreation as presented in the report had been given careful study. The Service concurred in statements presented in the report that, prior to construction of Concan Reservoir, protective works at Garner State Park must be developed and coordinated with the Texas Parks and Wildlife Department. Notification was requested well in advance of construction in order that it could program site surveys and excavations required in the Archeological Salvage program.

k. Bureau of Reclamation.-

(1) In its letter dated January 29, 1965, the Bureau of Reclamation indicated the possibility that control of withdrawals from the Edwards Underground Reservoir may not be obtainable, that the increase in safe yield for pumping provided by the recharge reservoirs would be modest, and that the unit cost of the projects would be relatively high. The Bureau also stated that adequate consideration had not been given to downstream water rights and needs, and that a considerable portion of the yield of Cloptin Crossing Reservoir would be obtained at the expense of yield at the Cuero Reservoir. In addition, a few items were noted that should be clarified in the report.

(2) Regarding downstream water rights and needs, full consideration was given to the master plans of other agencies for development of water resources within the area of influence of the Edwards Underground Reservoir.

l. Bureau of Mines.- In its letter dated April 2, 1965, the Bureau stated that projections in the report of the total value of mineral production for the study area appeared to be optimistic and the gain in employment conservative, based on these projections. The Bureau indicated that the proposed plan would have no adverse affect on the mineral resource development in the area. The Bureau recommended that a field investigation and report by petroleum and mining engineers be made prior to construction planning.

m. The Texas Water Commission.- By letter dated February 3, 1965, the Texas Water Commission expressed satisfaction with the treatment given a very complex hydrologic problem and stated that the report reflects a thorough analysis. The Commission suggested rewording the recommendations to read that responsible local interests would be designated by the State to provide the necessary local cooperation. The rewording of the recommendations would require that local interests obtain the necessary water rights in connection with the projects. The Commission also stated that local interests and/or the State may desire to consider modification of the projects during preconstruction planning. Inclosed with the letter from the Texas Water Commission were letters from the Texas Highway Department and the Parks and Wildlife Department. The Texas Highway Department expressed belief that the report contains appropriate language and adequate provisions in the estimated costs to promote orderly development of the proposed projects and related highway relocations. It was contemplated, however, that adjustments in costs of relocations may be necessitated during the final planning stage. The Parks and Wildlife Department stated that the Department had cooperated with the Bureau of Sport Fisheries and Wildlife in preparation of the Bureau's report to be included in appendix VI, and that it had no further comment.

IMPLEMENTATION OF THE PLAN

195. SCHEDULE FOR PROJECT DEVELOPMENTS.- The selection of the time sequence and order of development for the various elements in the plan are based on the projected time patterns of water resource demands. While projected demands are based on the best information currently available, it is recognized that their dependability and accuracy lessen with the length of the period of projection. After completion of construction of each phase of development, definition of needs should be re-examined before continuing with the next phase of development. Such re-examination could result in some modification in the use of projects previously constructed as well as in improvements planned for subsequent construction. Present proposals for initial Federal participation are limited to those elements of the plan that current and projected needs indicate should be constructed in the next 10 to 15 years. To meet the immediate needs of the area, the following order of construction is proposed:

a. The initial phase should include construction of Cloptin Crossing and Montell Reservoir projects which have been selected for the following reasons:

(1) These projects would afford immediate protection to the flood plains of the Blanco, San Marcos, Guadalupe, and Nueces Rivers where present flood damages are the greatest.

(2) They would provide 75,100 acre-feet per year (67 mgd) of additional water resources, of which 26,600 acre-feet per year are indicated for recharge of the Edwards Underground Reservoir.

(3) They would provide 7,320 acres of additional water surface and appropriate recreation facilities, the major portion of which would be provided at Cloptin Crossing Reservoir which is located in an area of concentrated population.

b. Following completion of Montell and Cloptin Crossing Reservoirs, construction should begin on the Concan and Sabinal Reservoirs. Based on projected future demands, all four of the projects will be needed by the year 1975.

c. Four or five years after completion of the above-named reservoirs construction should begin on Dam No. 7 Reservoir. Estimates of future demands indicate this project will be needed by the year 1980.

196. Future water demands and the above order of construction are based on full utilization of all return flows in the area.

DISCUSSION AND CONCLUSIONS

197. DISCUSSION.- The protection and preservation of the Edwards Underground Reservoir is of utmost importance to the continued growth and prosperity of this south Texas region. This natural water resource is one of the finest of its kind in the United States. Since so many cities, towns, military installations, industries, farms, and ranches in three river basins depend on the Edwards aquifer for their only source of water supply, the preservation of this resource becomes a common problem to the more than 850,000 citizens residing in this area.

198. Of primary importance is the control of withdrawals from the aquifer. Pumping from the aquifer should be limited to a safe quantity that would not deplete the resource. This would also avoid the danger of polluting the high quality artesian water with hydrogen sulfide or saline water, a situation that is believed could result from pressure differentials that would be caused by uncontrolled and sustained heavy pumping from the reservoir.

199. Since citizens of all three river basins, the Guadalupe, San Antonio, and Nueces, share in the benefits of the Edwards Underground Reservoir, the 14 counties in the watershed of the aquifer were considered as a unit in formulating a water supply plan. Any plan that would enhance the dependable yield of the Edwards Reservoir or would provide a supplemental source of water to prevent the depletion of the aquifer would benefit citizens in all three river basins.

200. The construction of Montell, Concan, and Sabinal Reservoirs, as proposed in this report, would furnish an additional quantity of water for pumping, would keep higher water levels in the aquifer, and would enhance the springflow from major springs along the southern limits of the Balcones escarpment, particularly in the Guadalupe and San Antonio River Basins. The Montell, Concan, and Sabinal projects would store large quantities of flood flows to be released immediately after storms to minimize evaporation losses from the reservoirs and at a rate to more efficiently recharge the underground aquifer. In addition, by holding back the high main stem discharges for a brief period following storms, these reservoirs would permit the recharge of a greater percentage of the runoff from the downstream uncontrolled area. The Montell Reservoir, together with the channel dam and pipeline, would also furnish a quantity of water at an economical price for use in the Tom Nunn Hill area. Since increasing conservation storage in the projects at the Cloptin Crossing and Dam No. 7 sites would not affect the dependable yield of the Cuero Reservoir as determined by the Guadalupe-Blanco River Authority, these upper Guadalupe reservoirs could be used to supplement the Edwards Underground Reservoir and other surface and ground-water resources of the area.

201. In consonance with the principles of comprehensive planning, the feasibility of providing flood control storage and facilities for fish and wildlife and general recreation was determined for each project investigated. The provision of the flood control storage in Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs would serve to reduce the threat to lives and destruction to property in the area downstream from these projects. The recreation and fish and wildlife facilities proposed for development in this report would provide recreational opportunities for a total of over 2,560,000 visitors annually. Surface water reservoirs in the Edwards Plateau (which is widely known for its scenic beauty) would be significant assets to the state. The plan of operation for Montell Reservoir provides for the constant release of four million gallons per day to downstream areas of the Nueces River Basin. This constant stream flow would greatly enhance the use of the stream for fishing, camping, and general recreation along a 14-mile reach of the river between Montell Reservoir and the proposed channel dam.

202. Additional information on the plan of improvement called for by Senate Resolution 148, 85th Congress, adopted January 28, 1958, is contained in a supplement to this report.

203. CONCLUSIONS.- The comprehensive plan for the preservation and recharge of the Edwards Underground Reservoir as a part of plans for flood control and water conservation in the Nueces, San Antonio, and Guadalupe River Basins of Texas provides for the full development of the water and related land resources to meet the immediate and long-range needs to approximately the year 2000. The projects recommended for authorization for immediate construction by the Federal Government are those found necessary for the orderly development of the water and related land resources consistent with the present and projected economic conditions of this south Texas region. The projects are multiple-purpose in scope and are well justified both individually and as a system and each purpose served by the projects is fully justified. Projects recommended for authorization for immediate construction include Montell Reservoir on the Nueces River, Concan Reservoir on the Frio River, Sabinal Reservoir on the Sabinal River, and Cloptin Crossing Reservoir on the Blanco River. The Dam No. 7 Reservoir project is considered as a part of the comprehensive plan to fully develop the water resources available upstream from the natural recharge areas in the Balcones fault zone but not recommended for authorization or construction by the Federal Government at this time. Although a comprehensive plan may develop projects embracing even those purposes for which a high degree of responsibility remains with non-Federal entities, it appears that in accordance with existing policy the Corps should not undertake construction of those projects in which purposes traditionally considered as a Federal responsibility are not justified and which local levels of government or private

enterprise could logically be expected to develop to a degree consistent with proper development of the resources of the region. It is considered that the Dam No. 7 Reservoir project may be constructed by the Federal Government if future analysis indicates a Federal responsibility in the project or by local interests for water supply if such needs develop in advance of possible Federal participation in the project.

RECOMMENDATIONS

204. RECOMMENDATIONS.- On the basis of studies made and conclusions reached in connection with this report, the District Engineer recommends:

a. That the comprehensive plan be recognized as a plan for the full development and beneficial public use of the water and related land resources of the upper Guadalupe, San Antonio, and Nueces River Basins and that a plan of improvement for the Edwards Underground Reservoir area be authorized to provide for construction of the following:

(1) Montell Reservoir on the Nueces River for flood control, water supply, recharge, and for recreation and fish and wildlife purposes, including a channel dam and a pipeline for water supply to downstream areas of the Nueces River Basin.

(2) Concan Reservoir on the Frio River for flood control, recharge, and recreation purposes.

(3) Sabinal Reservoir on the Sabinal River for flood control, recharge, and recreation purposes.

(4) Cloptin Crossing Reservoir on the Blanco River for flood control, water supply, recreation, and fish and wildlife purposes.

b. That the foregoing be accomplished with such changes and modifications as, in the discretion of the Chief of Engineers, may be advisable at estimated Federal costs as follows:

(1) Total Federal construction costs of $84,048,000 or a total net Federal construction cost of $32,428,000 after reimbursement by local interests of a portion of the project costs allocated to water conservation.

(2) Total Federal annual maintenance and operation costs of $379,400 or a total net Federal annual cost of $232,100 after reimbursement by non-Federal interests of a portion of the maintenance and operation costs allocated to water conservation.

c. That prior to initiation of construction responsible local interests designated by the State of Texas give assurances satisfactory to the Secretary of the Army that they will:

(1) Reimburse the Federal Government for that portion of the construction costs allocated to water supply and apportioned to non-Federal interests in accordance with the repayment provisions of the Water Supply Act of 1958, as amended, including the cost of the channel

dam and pipeline in connection with the Montell Reservoir. These costs are presently estimated as shown below:

Reservoir	Allocated cost to water supply (local interests share)			
	Construction costs		Annual O&M costs	
	Amount (dollars)	Percent	Amount (dollars)	Percent
Montell	18,986,000	58.34	52,600	58.19
Reservoir	(18,086,000)	(55.57)	(36,000)	(39.82)
Channel dam and pipeline	(900,000)	(2.77)	(16,600)	(18.37)
Concan	13,451,000	85.95	34,000	62.04
Sabinal	9,722,000	85.18	30,300	61.59
Cloptin Crossing	9,461,000	38.71	30,400	16.43

51,620,000
900,000
50,720,000

(2) Obtain without cost to the United States all water rights necessary for operation of the projects in the interest of conventional water supply and recharge to the underground reservoir.

PAUL W. JAHN
Chairman, Board of Directors
Edwards Underground Water District

F. P. KOISCH
Colonel, CE
District Engineer

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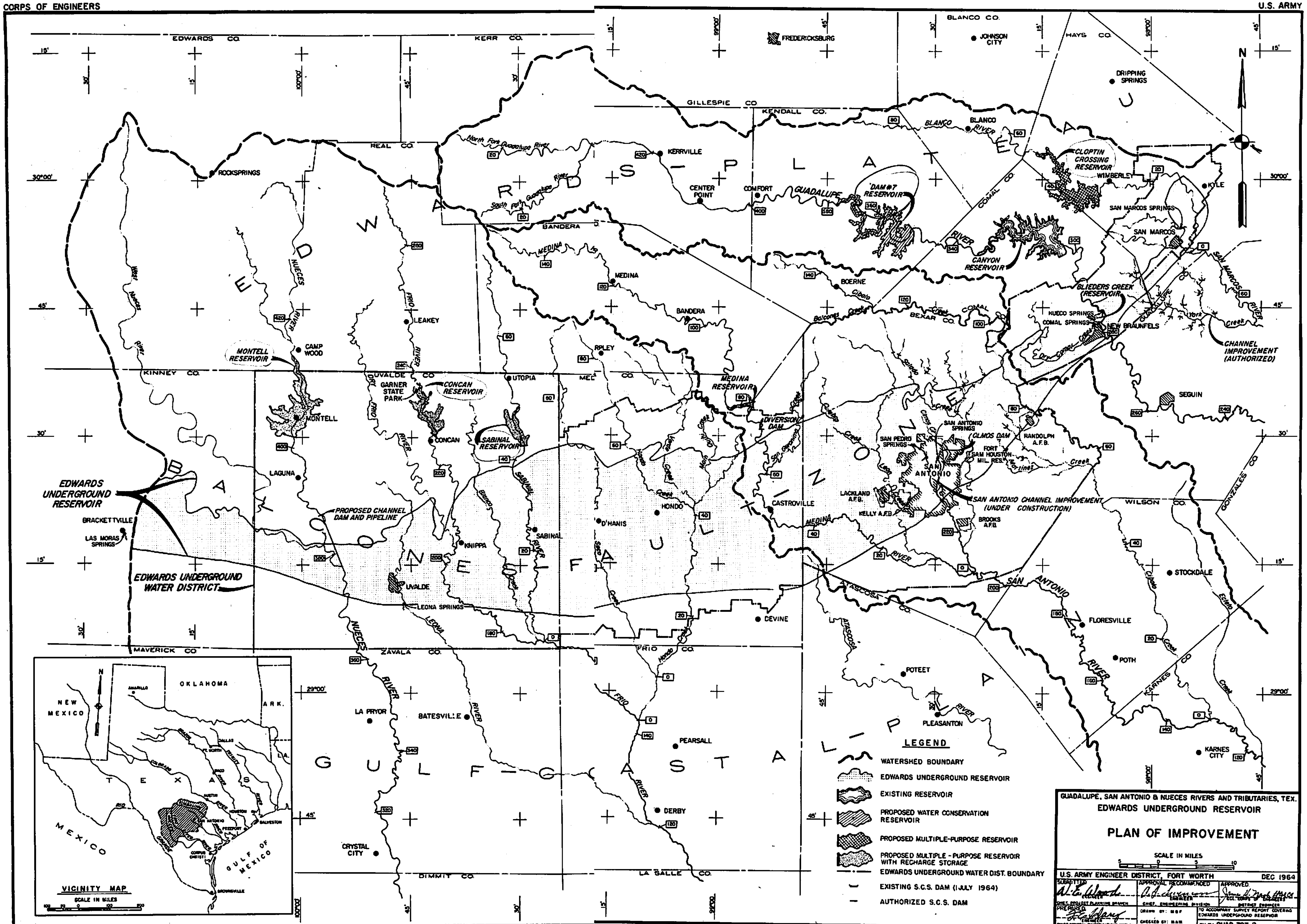
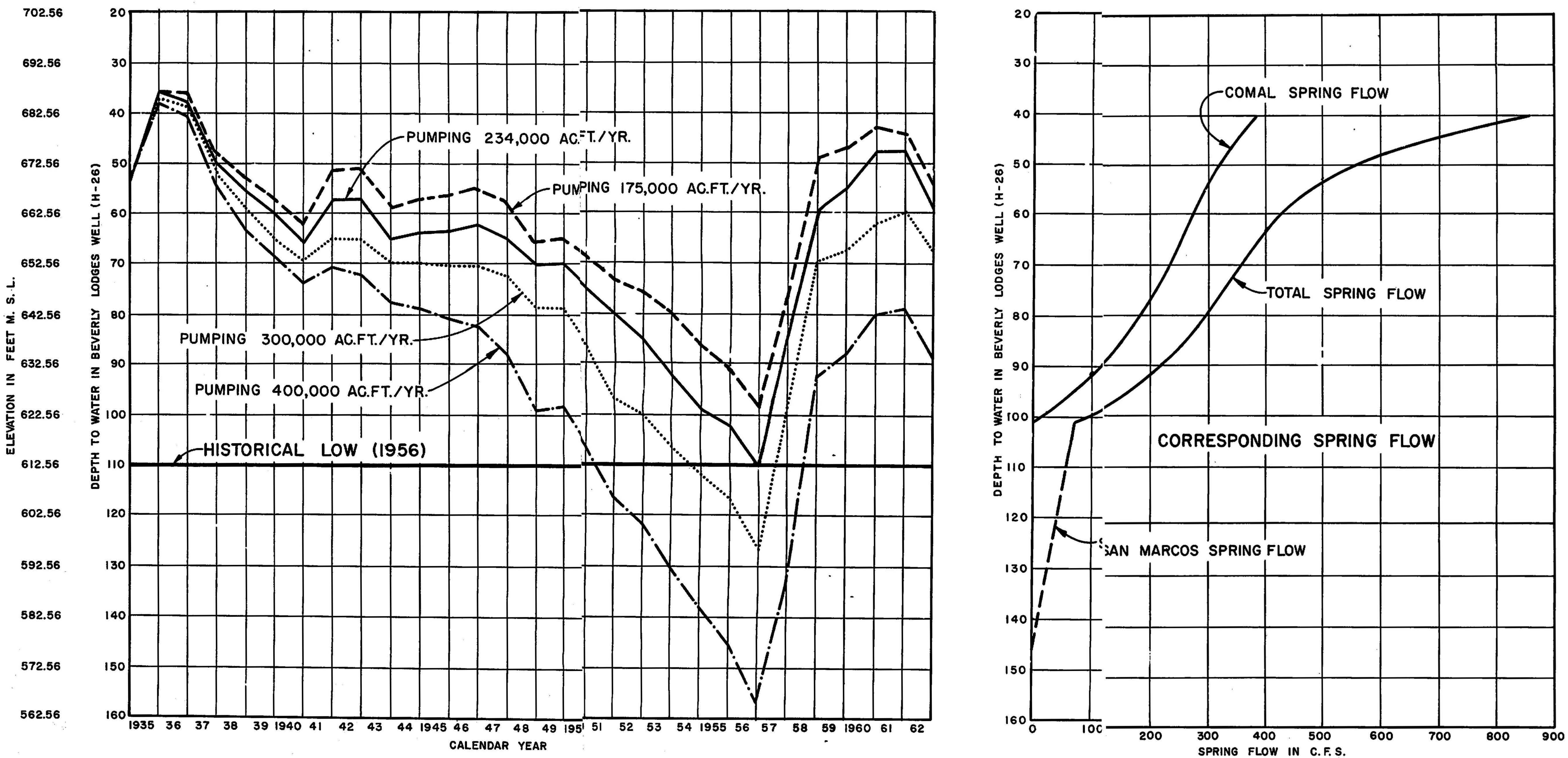
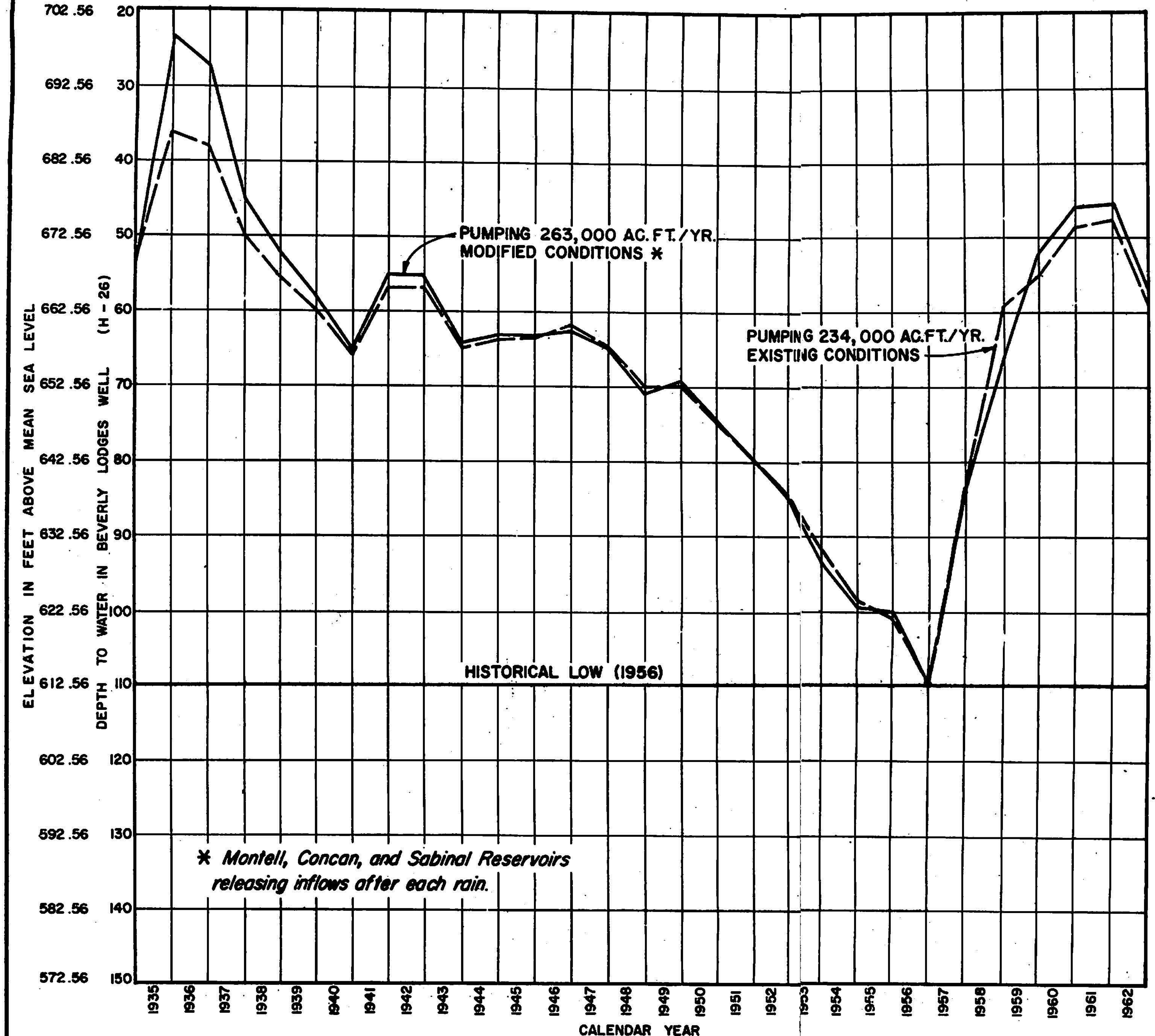
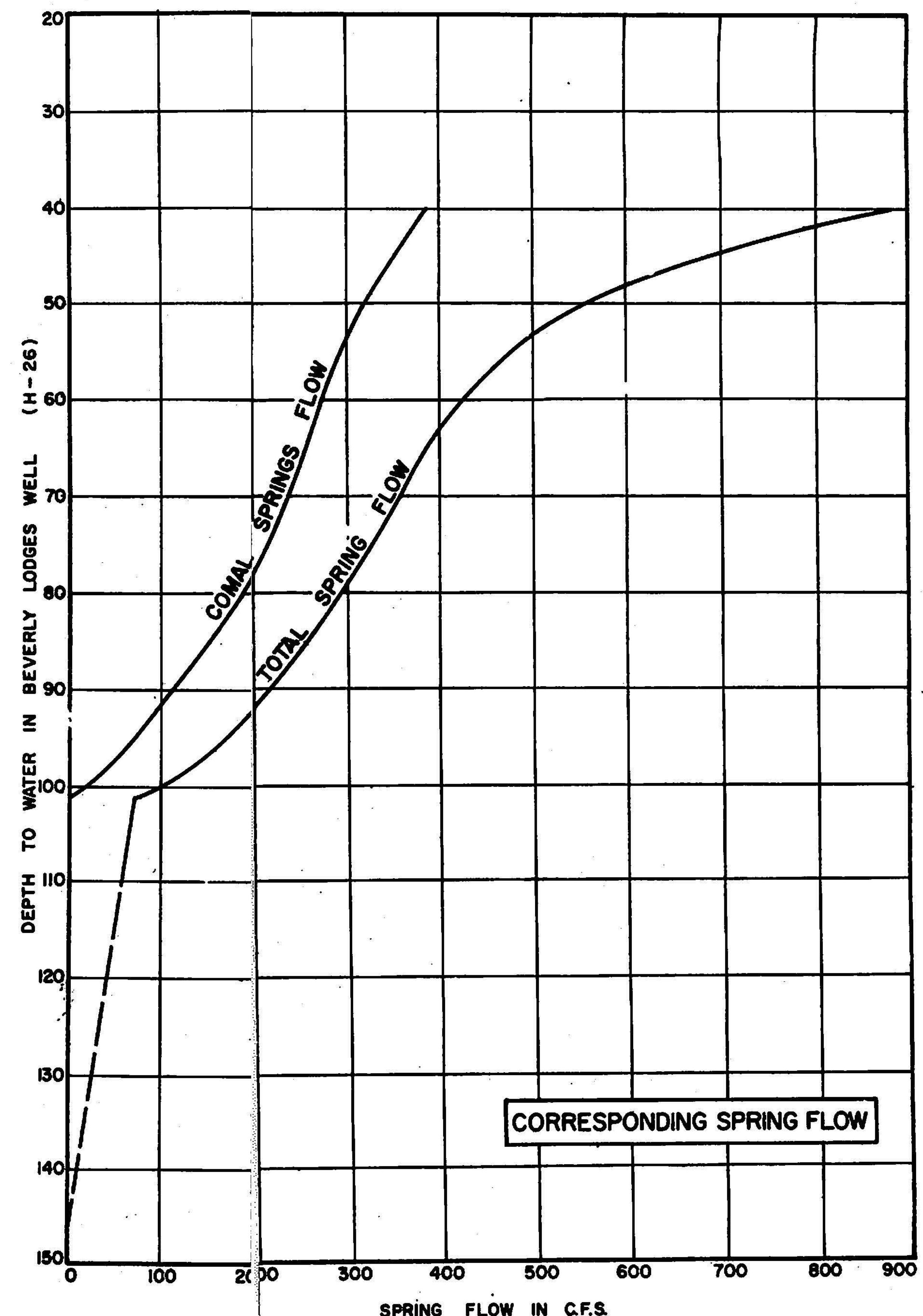

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
PLAN OF IMPROVEMENT
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
FILE: GUAD. 707-2
LEGEND
WATERSHED BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EXISTING S.C.S. DAM (1 JULY 1964)
AUTHORIZED S.C.S. DAM
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF COASTAL PLAIN
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
MONTELL RESERVOIR
CONCAN RESERVOIR
SABINAL RESERVOIR
MEDINA RESERVOIR
DIVERSION DAM
OLMOS DAM
CANYON RESERVOIR
DAM #7 RESERVOIR
CLOPTIN CROSSING RESERVOIR
GLIEDERS CREEK RESERVOIR
CHANNEL IMPROVEMENT (AUTHORIZED)
SAN ANTONIO CHANNEL IMPROVEMENT (UNDER CONSTRUCTION)
PROPOSED CHANNEL DAM AND PIPELINE
SAN ANTONIO
NEW BRAUNFELS
SAN MARCOS
UVALDE
HONDO
CASTROVILLE
KERRVILLE
VICINITY MAP
SCALE IN MILES



NOTE:
For hydrologic routings above El. 682.0 spring flow curves were extended.

FIGURE 19
EFFECTS OF CONSTANT PUMPAGE ON WATER LEVELS IN THE EDWARDS UNDERGROUND RESERVOIR - EXISTING CONDITIONS

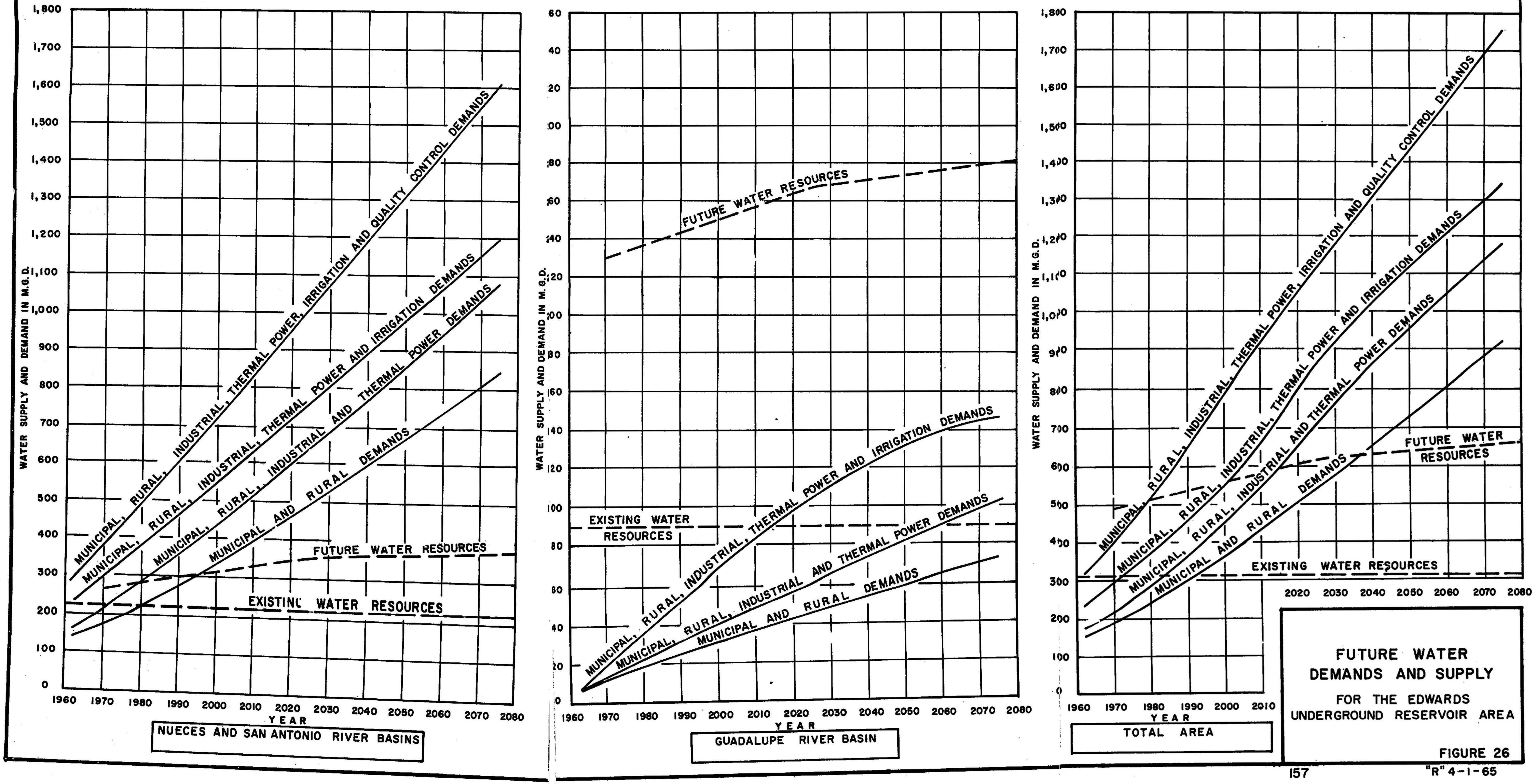




NOTE:
For Hydrologic Routing above EL. 682, Springflow Curves were extended.

FIGURE 25
EFFECTS OF CONSTANT PUMPAGE ON WATER LEVELS IN THE EDWARDS UNDERGROUND RESERVOIR
MONTELL, CONCAN, & SABINAL RESERVOIRS IN OPERATION

"R" 4-1-65



FUTURE WATER DEMANDS AND SUPPLY

FOR THE EDWARDS UNDERGROUND RESERVOIR AREA

FIGURE 26

"R" 4-1-65