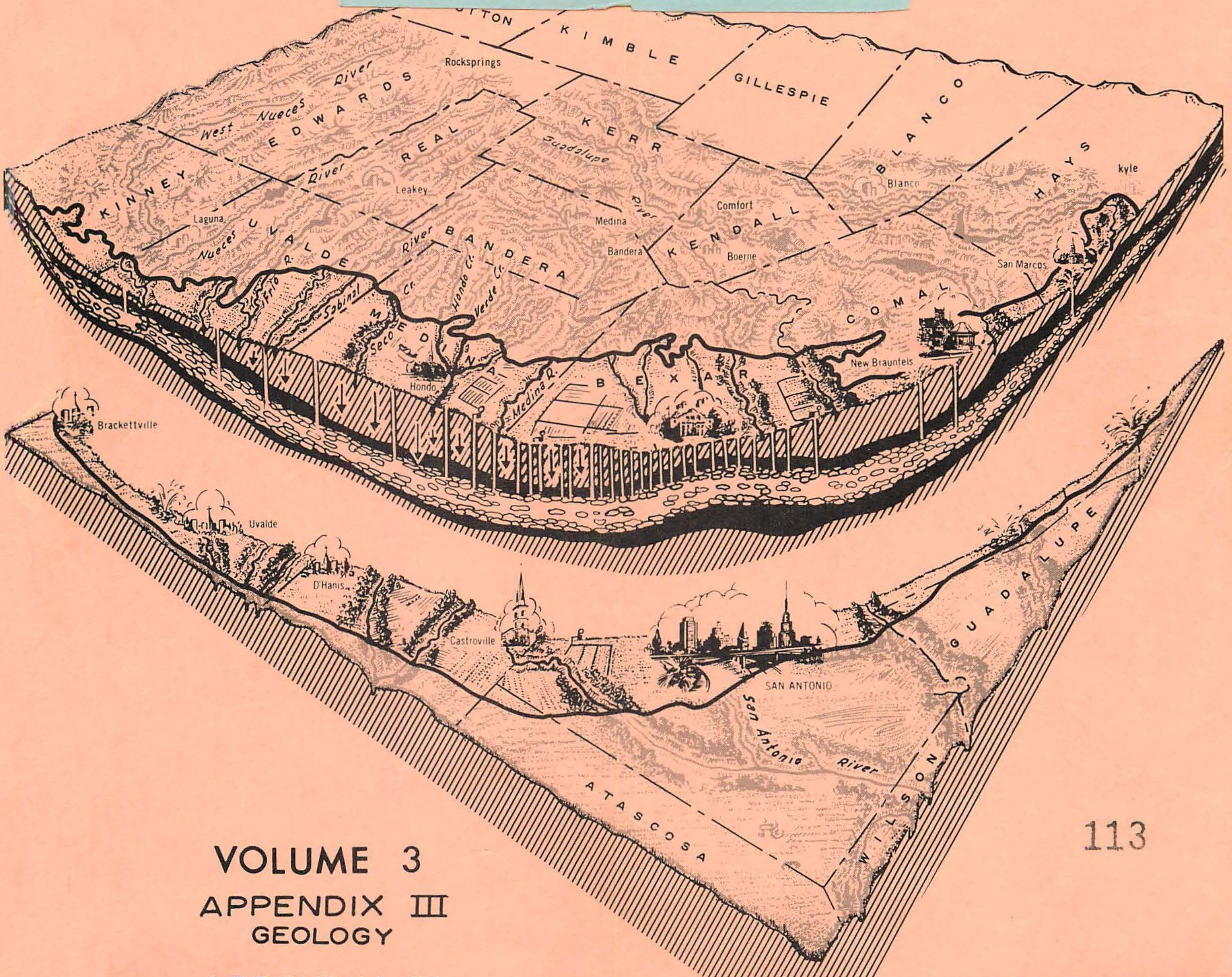
MATTHEWS, NOWLIN, MACFARLANE,
& BARRETT

SURVEY REPORT
ON
EDWARDS UNDERGROUND RESERVOIR

GUADALUPE, SAN ANTONIO AND NUECES RIVERS AND TRIBUTARIES, TEXAS.

AS SENT TO CHIEF OF ENGINEERS



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U. S. ARMY ENGINEER DISTRICT, FORT WORTH
CORPS OF ENGINEERS
FORT WORTH, TEXAS
AND
EDWARDS UNDERGROUND WATER DISTRICT
SAN ANTONIO, TEXAS

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SUMMARY

Studies have been conducted in the "San Antonio Area" to devise effective means of accomplishing the recharge and replenishment of the Edwards Underground Reservoir as a part of the plan for flood control, water conservation, and other related water uses. Geological investigations for this study have been directed toward three principal phases: (1) to locate and explore suitable dam and reservoir sites on the important rivers and streams in the Nueces, San Antonio, and Guadalupe River Basins; (2) to study the geology of the Edwards and associated limestones aquifer in particular and the regional geology in general; (3) to study the water movement in the Edwards Underground Reservoir.

Consideration of methods to increase the dependable yield of the Edwards Underground Reservoir for pumping involved: (1) Control of the major springs to prevent heavy losses of underground reservoir storage; and (2) control of recharge to the aquifer by the construction of surface reservoirs on the principal streams in the area that contribute recharge to the underground reservoir.

Approximately 67 percent of the discharge from the Edwards Underground Reservoir, during the period from 1935 to 1956, has been through major springs along the **Balcones** fault zone. Therefore, to control the major springs,consideration was given to the construction of ring dikes around the springs to equalize the hydrostatic head in the underground reservoir. The problems involved in such an undertaking, however, can be realized when one of the areas is examined. For example, 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 a distance of 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 length of the Comal Springs fault where the springs emit would prevent the artesian pressure from increasing and causing breakouts in a number of other locations. Studies were also made of the feasibility of constructing a grout curtain across the Edwards Underground Reservoir southwest of Comal Springs at a location where the reservoir narrows to about 5 miles in width. Information developed from the Edwards core boring, located in this general area, shows the top 432 feet of the 482 feet of Edwards and associated limestones penetrated to be highly broken and solutioned. Therefore, to substantially reduce the flow in this area, a grout curtain about 5 miles in length with depths up to 700 feet would be required. 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.

From gage records of the U. S. 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

cubic feet per second along the Sabinal River to about 1,000 cubic feet per second along the Nueces River. Major storms in the last 30 years have produced peak discharges in the stream channels of the Nueces River Basin in excess of 600,000 cubic feet per second. The base flow of most streams in the Edwards Plateau is lost to the underground reservoir where the streams 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 aquifer as they flow over the loss zone. This can only be provided by constructing dams on the major rivers and creeks upstream from the fault zone. It has been determined, however, that the high evaporation rate in this region would prevent the efficient and effective recharge of the Edwards Underground Reservoir by the storage of these floodwaters in permanent conservation pools.

Geological investigations were conducted on the major streams of the Edwards Plateau prior to selecting dam sites for detailed foundation exploration. These investigations showed that, with very few exceptions, the sedimentary rocks of the Glen Rose, Edwards, and Comanche Peak formations which outcrop in the streambed and along the canyon walls are all structurally suitable as a foundation for proposed structures. Therefore, selection of the final location for the reservoir projects was not limited by foundation conditions, but instead was based on requirements of the proposed reservoirs. Reservoirs considered for permanent conservation pool were located upstream of the heavy loss areas associated with the Balcones fault zone. Reservoir leakage, however, does not present a problem in construction of projects for flood control and recharge only. For this reason one project was located in the fault zone. Where any dam is located in an area of known faulting the alignment of the structure should be adjusted, where possible, to avoid major faults that may be discovered during the detailed preconstruction exploration.

Streams in the Edwards Plateau carry a considerable volume of suspended solids, especially during flood stages, and it is reasonable to assume that a portion of this material is deposited into openings through which recharge water infiltrates. The construction of a dam across these streams would cause a large percentage of the stream-transported material to be deposited on the reservoir floor. This sediment cover may reduce to a small degree the overall recharge capabilities of the bedrock. However, recharge to the aquifer is primarily through a system of interconnecting open joints and channels in the rock which extend across the streambed into the canyon walls. Siltation would not affect leakage along these rocks which comprise the rim of the reservoirs. Medina Dam and Diversion Dam, constructed in the fault zone on the Medina River, have been in operation for 50 years, and there is no evidence that leakage from the reservoir has declined during this period.

Based upon economic, hydrologic, and geologic investigations, the following projects, shown on plate 34, Plan of Improvement, have been found to be economically justified:

a. For authorization and construction by the Federal Government:

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

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

All of the dams will be located on sedimentary rocks suitable for construction of the proposed structures. Montell and Cloptin Crossing will be founded on the Glen Rose limestone. Concan will be founded on Glen Rose limestone in the valley and on the left abutment, but will rest on the Comanche Peak and basal Edwards on the right abutment. Sabinal Dam site will be located in the Balcones fault zone on the Comanche Peak and Edwards limestones. Dam No. 7 will be founded on the lower member of the Glen Rose limestone and the Travis Peak formation. Montell Dam site will be constructed across a broad, alluvium-filled valley about 2 miles south of Montell. A cutoff trench will be required through the 45 feet of pervious alluvium covering the bedrock. Faulting was not discovered at the dam site itself, but several wide fracture zones and faults were discovered in the reservoir. One such fracture zone, located north of the right abutment, shows some evidence of solutioning and may require additional exploration to determine its leakage potential. Concan Dam site is located on the Frio River about 1-1/2 miles north of Concan. Exploration has shown the bedrock to be suitable for the proposed structure although some faulting was encountered. The right abutment has been downfaulted about 70 feet with respect to the left abutment. Future exploration must be directed to locate the areas of intense faulting in the vicinity of the site. The proposed Sabinal Dam is located on the Sabinal River about 11 miles north of Sabinal. The site is situated in a narrow canyon about one-half mile downstream from the Woodward Cave fault which has a stratigraphic displacement of about 175 feet. Since the site is located in the Balcones fault zone, additional exploration will be required to locate all of the faults which could possibly affect the structure foundation. Cloptin Crossing is located on the Blanco River about 2 miles southwest of Wimberley. Limited exploration has shown the foundation rock to be suitable, free of any major structural disturbances. Dam No. 7 will be located on the Guadalupe River 11 miles northeast of Boerne. The limestone and dolomite rocks are satisfactory as structure foundations. Relatively high grout takes are anticipated on the left abutment where joint planes are well developed and solutioning has occurred. Reservoir leakage is not expected to be significant.

The injection system of artificial recharge, whereby waters are introduced into an aquifer by means of wells, caves, crevices, and other openings, has been used in Uvalde County since the early 1950's. The injection structures generally consist of low concrete dams located a short distance downstream from grate-covered openings in the bedrock. Recharge structures of this general type have been constructed on Indian Creek, Leona River, Dry Frio River, and the Sabinal River north and northeast of Uvalde. However, because of the lack of stream gage stations and strategically located recorder wells in the Edwards and associated limestones, attempts to evaluate the benefits derived from these small recharge structures have not been completely successful. Some flood waters that would otherwise escape are diverted into the Edwards and associated limestones aquifer, but just how much, or whether expenditures necessary to capture this water are justified, is not known. Although the proposed plan of improvement will provide for the capture and control of available recharge water on three of the major streams, there are some areas, such as Seco Creek, where large flood control and recharge structures could not be justified, but where the small retention-type structures would possibly be effective. If at a later date such structures are found to be necessary and economically justified, care will have to be exercised in locating them where it is certain the water will find its way into the Edwards Underground Reservoir.

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INTRODUCTION

1. PURPOSE AND SCOPE.- The purpose of this report is to update existing information and to present new data obtained during the geologic investigation of the Edwards Underground Reservoir. The objective of the investigation outlined in the plan of survey was to devise effective means of accomplishing the recharge and replenishment of the Edwards Underground Reservoir as part of plans for flood control, water conservation, and other related water uses in the Nueces, San Antonio, and Guadalupe River Basins of Texas. This report details the geology of the area which comprises the Edwards Underground Reservoir; the results of the foundation and reservoir investigation for eight dam sites; and the results of special geologic investigations.

2. LOCATION.- The area covered by this report comprises some 6400 square miles located in south-central Texas in the upper limits of the Nueces, San Antonio, and Guadalupe River Basins. The Edwards Underground Reservoir, the area's most valued natural water resource, lies along the southern boundary of this area. The Reservoir lies between the cities of Brackettville in Kinney County and Kyle in Hays County where hydraulic divides or barriers control the waterflow in the "San Antonio Area." The centerline 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. The northern boundary for the artesian aquifer is located at the southern edge of the Edwards Plateau, and the southern boundary corresponds to the so-called "bad-water" line in the ground water zone. The "bad-water" line is an arbitrary line used to divide the water in the Underground Reservoir into that with less than 1000 ppm dissolved solids and that with more than 1000 ppm dissolved solids. Three formations, considered as a single hydrological unit and commonly referred to as the Edwards and associated limestones, make up the aquifer. They are, from oldest to youngest, the Comanche Peak, Edwards, and Georgetown. The Edwards and associated limestones average between 350 and 500 feet thick in the artesian zone between the outcrop area and the "bad-water" line.

3. PREVIOUS INVESTIGATIONS.- Because of its importance to economic and industrial development in the San Antonio area, the Edwards limestone reservoir has been one of the most intensively studied aquifers in Texas. Many investigations have been made of the geologic and

hydrologic character of this underground reservoir since 1900. In recent years extensive studies have been conducted by private consultants and by U. S. Geologic Survey in cooperation with the Texas Water Commission, San Antonio City Water Board, San Antonio City Public Service Board, Bexar County Metropolitan Water District, and the Edwards Underground Water District. In 1949, the San Antonio 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 Bexar, Bandera, Comal, Edwards, Hays, Kinney, Medina, Real, and Uvalde Counties), paying particular attention to the Edwards limestone aquifer. Information contained in these and other publications has been utilized freely for preparation of this report and is referenced in the accompanying bibliography.

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4. PHYSIOGRAPHY.- The study area lies within two physiographic provinces, the Edwards Plateau and the West Gulf Coastal Plain, which are separated by a variable width zone of faulting known as the Balcones fault zone. The area to the north of the fault zone, locally referred to as the "hill country", is situated in the Edwards Plateau section of the Great Plains province. Its principal characteristics are those of a young plateau with a mature margin of moderate to strong relief. Principal streams, near their headwaters, have cut narrow canyons into Lower Cretaceous limestone strata which comprise the plateau and, as they progress south and southeast toward the southern margin of the plateau, they meander and have formed very broad, alluvium-filled valleys. Vegetation, consisting of shrubs, scrub oak, cedar, and chaparral trees, covers the valley bottoms and hillsides, but is conspicuously absent in the undissected uplands. The West Gulf Coastal Plain section of the Coastal Plains province lies south of the Balcones fault zone and features a young to mature coastal plain. The area is generally flat and featureless except for occasional low hills formed by shallow intrusive plugs.

5. Although local relief is usually less than 500 feet, the elevation in the study area varies from slightly less than 400 feet in the coastal plain to over 2200 feet in the plateau area.

6. LITHOLOGY AND WATER-BEARING PROPERTIES OF FORMATIONS.- Plate 1 shows the areal distribution of the Edwards and associated limestones, formations younger and older than the Edwards and associated limestones, and traces of major faults in the study area. Table 1 shows the geologic formations in the study area with a brief summary of their lithologic characteristics and water-bearing properties.

a. Pre-Cretaceous rocks.- Rocks of pre-Cretaceous age do not crop out in the study area. Drillers' logs of wells which have penetrated these strata indicate they include schist, slate, black limestone, and sandstone at variable depths. In the study area these Paleozoic rocks are not generally considered as being water productive.

b. Cretaceous system.- At the end of the Paleozoic era the sea retreated from central Texas and the land remained above sea level during the Triassic and Jurassic periods. In early Cretaceous time the sea advanced once more, depositing a wedge of sedimentary rocks on an eroded Paleozoic land surface. Based on the work of others, these rocks have been divided into three series which are, from oldest to youngest, the Coahuila of Mexico, the Comanche, and the Gulf.

(1) Equivalents of Coahuila Series of Mexico.- The Hosston and Sligo formations form a wedge of sedimentary rock overlying the Paleozoic basement complex. These formations, correlatable with the Coahuila series which outcrops in Mexico, occur only in the subsurface of the study area. They are composed chiefly of sandstone, shale, and limestone which reportedly reach a maximum thickness of about 1100 feet in Bexar County.1/* The Sligo formation is not considered water-bearing, but some of the Hosston sandstones in Bexar County reportedly yield a small to moderate quantity of potable water. Because the formations are generally penetrated only by oil tests, which are not concerned with ground water, very little is known about the water-bearing capabilities of the rocks.

(2) Comanche series.- Rocks comprising the Comanche series have been divided into three groups which are, from oldest to youngest, the Trinity, Fredericksburg, and Washita. The Travis Peak formation of the Trinity group is the oldest outcropping formation in the study area.

(a) Trinity group.- The Trinity group consists of two formations which are, in ascending order, the Travis Peak and Glen Rose formations.

1. Travis Peak formation.- Rocks comprising the Travis Peak formation have been divided into three members; the Sycamore sand member, the Cow Creek limestone member, and the Hensell member. The formation does not crop out in Uvalde, Medina, or Bexar Counties but its subsurface equivalent, represented by the Pearsall formation, is found overlying the Hosston formation at depth. In the northwest part of Comal County, rocks assigned to the Cow Creek and Hensell members crop out in the Guadalupe River valley. The Geological Survey 6/ reports the Sycamore member does not crop out and is probably not present in the subsurface in the county. All the members

*The numbers 1/, etc., pertain to specific references in the bibliography at the end of this appendix

TABLE I - GEOLOGIC FORMATIONS OF THE SAN ANTONIO AREA

SYSTEM	SERIES	GROUP OR AGE	FORMATION	APPROXIMATE MAXIMUM THICKNESS (FEET) UVALDE COUNTY	MEDINA COUNTY	BEXAR COUNTY	COMAL COUNTY	HAYS COUNTY	CHARACTER OF ROCKS	WATER BEARING PROPERTIES	REMARKS
Quaternary	Recent		Alluvium	0-20	0-30	0-20	0-15	0-30	Silt, sand, clay and gravel	Locally yields small supplies. Generally not dependable	Confined to stream beds.
	Pleistocene		Leona	0-93	0-65	0-90	0-50	0-50	Silt, sand and gravel.	Yields small to large supply of water.	Terraces between stream beds and upper or Uvalde gravel.
Tertiary	Pliocene(?)		Uvalde gravel	0-20	0-30	0-30	0-15	0-20	Silt and coarse, flinty gravel.	Not known to yield water.	Found at various levels capping hills and stream divides.
	Eocene	Claiborne	Mount Selman formation	Absent	100	200	Absent	Absent	Sandstone and shale, or clay with limonite and calcite concretions.	Furnishes good supply of water in Frio County.	Outcrops only in southern part of counties.
			Carrizo sand	50 ≠	300	600	Absent	Absent	Coarse to medium-grained sand and sandstone; locally crossbedded	Yields small to large supply of water.	Outcrops in southern part of counties and thickens to south.
		Wilcox	Indio formation	200 ≠	710	1070	Absent	Absent	Thin-bedded, clayey sandstone and shale. Contains lignite and calcareous concretions.	Yields small to moderate supply of variable quality water.	Found in southern part of counties.
	Paleocene	Midway	Wills Point formation	Absent	Absent	490	Absent	Absent	Arenaceous clay with arenaceous and calcareous concretions.	Not known to yield water.	Outcrops as two belts across southern part of Bexar County.
			Kincaid formation	25	155	Absent	Absent	Absent	Clay, siltstone, sandstone and limestone; thin conglomerate or glauconite at base.	Not known to yield water.	Thickens in direction of dip.
Cretaceous	Gulf	Navarro	Kemp clay	Absent	Absent	535	Absent	300	Mostly clay and marl from Bexar County east. Escondido consists of sandstone with inter-bedded shale and clay, some limestone.	Not a suitable quality water producer.	Undifferentiated from Taylor marl in Hays County.
			Escondido formation	285 ≠	740	Undif-ferentiated		Undif-ferentiated			
			Corsicana marl	Absent	55						
			Taylor marl	Absent	150	540	300 ≠	300	Nodular, locally chalky marl and calcareous clay.	Generally not a water producer. Yields small amount in Hays County.	Forms rounded hills with clayey soils.
			Anacacho limestone	470	530	355	Undif-ferentiated	Absent	Grades from marly chalk in Medina County to limestone with bentonitic clay in Uvalde County.	May locally yield small amount of generally poor quality water.	Interbedded limestones to west contain asphalt.
			Austin chalk	580	290	210	150	200	Limestone and argillaceous, chalky limestone.	Yields small to moderate amount of water.	Thickens to west in Uvalde County.
			Eagle Ford shale	240	65	40	25	30	Calcareous and sandy shales and argillaceous, flaggy limestone.	Not known to yield potable water.	Thickens to west in Uvalde County.
	Comanche	Washita	Buda limestone	100	110	80	70	60	Hard, massive limestone.	Generally not water-bearing except for small quantities in Uvalde and Bexar Counties.	Contains calcite veinlets in western counties.
			Grayson shale	120	95	60	55	60	Blue-gray clay or marly shale. Weathers yellow	Yields no water.	Identified by abundant "rams' horns" (Exogyra arietina).
			Edwards and associated limestone: Georgetown limestone	400	75	65	25	50	Hard, massive limestone, sometimes cherty.	Principal aquifer in San Antonio area. Yields large quantities of good quality water for municipal, irrigation and industrial uses. Generally not differentiated in wells	Thickens considerably to west.
		Fredericks-burg	Edwards and associated limestone: Kiamichi formation	210	Absent	Absent	Absent	Absent	Flaggy, cherty limestone, some dolomite and petroliferous shale.		Not identified east of Uvalde County.
			Edwards and associated limestone: Edwards limestone	100	620	600 ≠	500	400	Hard, massive, sometimes dolomitic limestone; contains chert nodules.		Massive bluff-former.
			Edwards and associated limestone: Comanche Peak limestone	90	45	40	40	40	Hard, nodular limestone, sometimes argillaceous.		Similar to Edwards except not cherty.
			Walnut clay	Not recognized	42	20	15	15	Fossiliferous, argillaceous and arenaceous limestone and clay.	Generally not water-bearing.	Slope former.
		Trinity	Glen Rose limestone: Upper member; Lower member	1530	1175	1200	1500	900	Alternating beds of hard limestone and soft, argillaceous limestone. Sometimes arenaceous and gypsiferous. More massive at base.	Yields small to moderate supply of variable quality water. Basal part of lower member locally yields high quantity of water in Hays County.	In outcrop, forms stair step type topography.
			Travis Peak formation (Pearsall of subsurface): Hensell member	440 Undif-ferentiated	650 Undif-ferentiated	180 Undif-ferentiated	300 Undif-ferentiated	85	Fine-grained sand, siltstone and marly limestone.	Yields small to moderate amounts of fair to poor quality water.	Only outcrops in Comal and Hays Counties. Sycamore probably absent in Comal County.
			Travis Peak formation (Pearsall of subsurface): Cow Creek limestone member					70	Massive detrital limestone		
			Travis Peak formation (Pearsall of subsurface): Sycamore sand member					50	Conglomerate and sand.		
	Coahuila (Mexico)	Nuevo Leon and Durango (Mexico)	Sligo formation	210	208	1100 Undif-ferentiated	Not identified	200	Limestone, sandstone and shale.	Not known to yield potable water.	Not exposed.
			Hosston formation	910	440		?	500	Sandstone, shale and limestone.	Not known to yield potable water except in Bexar County.	Not exposed.
Pre-Cretaceous									Slate, schists, limestone and sandstone.	Probably not water bearing.	Not exposed.

have been identified in Hays County, in the Blanco River valley west of Wimberley, and in the Pedernales River valley in the northern part of the county. The Sycamore has been described as a conglomerate grading upward into a tan and red, cross-bedded sand. Its water-bearing capabilities in the area are not known. The Cow Creek limestone member, 60 to 80 feet thick, is a fossiliferous limestone, becoming more argillaceous and shaly in its lower half. The member reportedly yields small quantities of potable water. Cores obtained from the Hensell members of the Travis Peak formation in the upper limits of Canyon Reservoir on the Guadalupe River, show the material to be a light-colored, sandy, glauconitic dolomite with siliceous and calcareous geodes. In other localities it has been described as an argillaceous and calcareous, fine-grained sand with sandy, glauconitic limestone beds. The member yields water for stock and domestic purposes.

2. Glen Rose formation.- Rocks of the Glen Rose formation are the oldest exposed rocks in the western portion of the study area (Uvalde, Medina, and Bexar Counties). Outcrops of the formation occur in the Nueces and San Antonio River Basins where the streams have cut through the overlying Edwards and Comanche Peak limestones. In contrast to its relatively limited exposures in the western counties, the formation covers over half the surface area in the north and northeastern counties (Bandera, Kendall, Comal, and Hays). In Comal County where a complete section of Glen Rose is exposed, the Geological Survey 6/ has divided the formation into an upper and a lower member. The division was placed at the top of a well known and easily distinguishable fossiliferous zone containing abundant Salenia texana fossils. A thin, flaggy limestone bed, containing an abundance of the small clam, Corbula, immediately overlies the Salenia texana zone and is also used as a division marker. The division of the Glen Rose formation into upper and lower members has been widely accepted and was used during the course of this study.

a. The lower member of the Glen Rose is a massive, generally fossiliferous limestone with beds of dolomitic limestone, argillaceous or shaly limestone, and shale. On outcrop the rock is occasionally solutioned and honeycombed and, locally, is capable of yielding a considerable amount of water. In Hays County the Geological Survey 3/ noted a reef limestone at the base of the lower member which is believed to be the source of a spring, northwest of Wimberley, that contributes over 1000 gpm into the flow of Cypress Creek, as well as being the aquifer which supplies many wells in the vicinity of Wimberley.

b. As most of the dam sites investigated for this study are located in the upper member of the Glen Rose limestone, its geologic and hydrologic characteristics are well known. The rock has been cored and water pressure tested from the Nueces River valley in Uvalde County to the Blanco River valley in Hays

County. The results of this exploration have led to the conclusion that the rock is very difficult, if not impossible, to correlate lithologically between river basins. Typically the member is composed of alternating beds of limestone, argillaceous limestone or marl, dolomitic limestone, shale, clay, and occasionally sandstone or arenaceous limestone. One distinctive characteristic of the rock, not noted in the other formations, is the presence of abundant black specks (medium-grained). These specks appear to be either phosphatic nodules or fossil fragments that are scattered throughout the formation at various horizons. Although these "salt and pepper" zones are distinctive, they are not correlatable. In Uvalde County the Geological Survey 25/ reports two evaporite zones in the Glen Rose, one immediately overlying the *Corbula* bed and the other about 200 feet below the top of the formation, which can be correlated across the county. The evaporite zones were not found at the Cloptin Crossing Dam site on the Blanco River, but a thin gypsum bed was encountered at the Comfort Dam site on the Guadalupe River in Kerr County. Locally, shallow water features such as ripple marks are common. In outcrop the Glen Rose formation forms a distinctive "stairstep" type topography due to differential weathering of the alternating hard and soft beds which comprise the formation.

c. With the exception of the basal reef limestone sequence in the lower member of the Glen Rose limestone in Hays County, the formation is not known to yield large quantities of good water. Large seepage losses have been reported in the Glen Rose along Cibolo Creek, and minor losses have been encountered where other streams cross the outcrop in the area. Generally, hydraulic water pressure testing has shown the rock to be relatively impermeable, although locally, sufficient quantities of water are available for stock and domestic purposes.

(b) Fredericksburg group.- The Fredericksburg group consists of four formations which are, in ascending order, the Walnut, Comanche Peak, Edwards, and Kiamichi formations. The Comanche Peak, together with the Edwards and Georgetown limestones, is generally considered as one hydrological unit, often referred to as the Edwards and associated limestones. The water-bearing characteristics of these limestones are considered an integral part of the Edwards Underground Reservoir.

1. Walnut clay.- The Walnut clay, which conformably overlies the Glen Rose limestone, varies both in thickness and lithologic characteristics. The thickness of the formation varies from a few inches to a maximum of approximately 20 feet (Bexar County). The formation, along with the underlying Glen Rose limestone, serves as the lower confining bed for the water in the Edwards and associated limestones aquifer. During investigations at the Concan Dam site in Uvalde County, a 5-inch bed of clayey shale was encountered

overlying the Glen Rose limestone which may be the equivalent of the Walnut. At the Medina Lake reservoir, Medina County, the Walnut clay is represented by 9 to 14 feet of thin interbeds of calcareous silt and argillaceous and silty limestone. An abundance of Exogyra texana are encountered near the top and bottom of the unit. On the Blanco River in Hays County (Cloptin Crossing Dam site), the distinctive characteristics of the formation are its slope-forming nature and the abundance of Exogyra texana.

2. Comanche Peak limestone.- The Comanche Peak limestone conformably overlies the Walnut clay. The formation is generally described as a hard, gray, massive, nodular limestone, becoming marly at the base. In Uvalde County the most distinguishing characteristics of the formation are its nodular appearance and clay-filled boring tubes. To the east, in Comal and Hays Counties, calcite veinlets and nodules are used to distinguish the formation from the underlying Edwards limestone. The average thickness of the formation is approximately 40 feet but somewhat thicker sections may occur in Uvalde County.

3. Edwards limestone.- The Edwards limestone is a hard, dense, generally light-gray, crystalline limestone with some dolomite or dolomitic limestone interbeds. The rocks are generally massive although occasional thin-bedded marly zones are found. Perhaps the most distinguishing characteristic of the Edwards is the occurrence of chert or flint lenses and nodules scattered throughout the formation at various horizons. At Montell Dam site on the Nueces River oval-shaped chert lenses up to 3 feet in diameter were noted. The formation is similar lithologically to the conformably underlying Comanche Peak, but can be identified by a comparison of the fauna of the two formations. Except in Uvalde County, the Edwards limestone is the most important water-bearing formation in the Edwards Underground Reservoir. Because of its hard, competent beds, the stresses imparted by faulting have fractured and sometimes shattered the formation, providing ideal avenues for circulating ground water and accompanying solution activity. Many caves of considerable vertical and horizontal extent typify the Edwards limestone both in the outcrop area and in the artesian zone. Some of the largest springs in the southwestern part of the United States issue from the formation.

4. Kiamichi formation.- In western Uvalde County a series of thin-bedded to flaggy, gray, cherty, occasionally gypsiferous and petroliferous, limestone beds have been identified as belonging to the Kiamichi formation. The Geological Survey 25/ reports that the formation (155 to 210 feet thick), loses its identity to the east because the characteristic flaggy beds interfinger with thicker limestones and dolomites, and grade into a reeflike milliolitic limestone. Hydrological characteristics of the Kiamichi formation are not well known as the formation is a part of the Edwards and associated

limestones aquifer and wells that penetrate the Kiamichi also produce from the overlying Georgetown. However, the formation is not generally considered a prolific water producer.

(c) Washita group.- The Washita group consists of, in ascending order, the Georgetown, Buda, and Grayson formations.

1. Georgetown limestone.- The Georgetown limestone is the oldest formation of the Washita group and is commonly referred to as the uppermost unit of the Edwards and associated limestones aquifer. In Uvalde County the Georgetown has a maximum thickness of about 400 feet and consists of a hard, massive, flinty limestone unconformably overlying the flaggy Kiamichi limestone. Over 300 feet of Georgetown is exposed at Chalk Bluff on the Nueces River, 17 miles northwest of Uvalde. It is reportedly the principal water-bearing formation in the county. East of Uvalde County the Kiamichi is absent and the Georgetown, which thins to an average of 40 to 50 feet, directly overlies the Edwards. The small brachipod Kingena wacoensis (Roemer) is scattered throughout the formation and aids in distinguishing it from the Edwards. In Comal and Hays Counties, where deposition of the Georgetown was somewhat affected by a southeastward trending uplift known as the San Marcos arch, the formation is composed primarily of hard, massive limestone with interbeds of fossiliferous, argillaceous limestone and calcareous shale. The Georgetown thins considerably on the flanks of the structural high, probably to less than 10 feet in some places. The Georgetown formation in the study area, with the exception of Uvalde County, is not considered to be a water-bearing formation of any consequence. It serves as one of the upper confining beds in the artesian zone of the Edwards limestone in Comal County. 6/

2. Grayson shale (Del Rio clay).- The Grayson shale conformably overlies the Georgetown limestone and underlies the Buda limestone. The formation consists of 30 to 120 feet of blue-gray clay and clayey shale with varying amounts of gypsum and pyrite disseminated throughout. Where exposed in outcrops, the formation weathers yellow to yellow-brown and is characterized by an abundance of ram horn shaped oysters called Exogyra arientina (Roemer). These fossils are commonly cemented into beds of hard, well indurated shell-conglomerate that range from 6 to 12 inches in thickness. The Grayson shale is impermeable and does not yield water in the study area. In Uvalde County it is the confining bed over the artesian portion of the Georgetown limestone.

3. Buda limestone.- The Buda consists of 30 to 100 feet of hard, dense and brittle, fine-grained limestone, easily distinguishable because of its stratigraphic position between the shaly Grayson and Eagle Ford formations. Drillers identify the formation in the subsurface by the presence of black specks, believed to

be glauconite. In the western counties the rock is commonly disseminated with crystalline calcite veinlets and breaks into conchoidal fractures. The formation is not known to yield water except in small quantities in Bexar and Uvalde Counties.

(3) Gulf series.- The Gulf series has been divided into four units which are, in ascending order, the Eagle Ford shale, Austin chalk, Anacacho limestone-Taylor shale, and the Navarro group.

1. Eagle Ford shale.- The Eagle Ford is composed primarily of calcareous shale and thin argillaceous limestone flags which are more abundant in the upper half of the formation. The formation is readily distinguishable from the unconformably underlying Buda limestone, but the contact with the overlying Austin is less obvious because of the similar lithology. Black lignitic beds are reported in the subsurface but are not present in the outcrop. The Eagle Ford has an average thickness of 30 to 40 feet, but reportedly reaches a maximum thickness of 240 feet in western Uvalde County. The formation is not known to yield potable water in the study area.

2. Austin chalk.- The Austin chalk grades from a white, chalky, fossiliferous, argillaceous limestone and calcareous shale in the east to a massive, variable to thin-bedded, fossiliferous chalk and argillaceous limestone or marl in the west. Marcasite and pyrite crystals are commonly scattered throughout the formation, and it is believed that oxidation of these minerals has locally caused the water to be heavily charged with hydrogen sulfide. The formation averages about 200 feet in thickness to a maximum of about 580 feet in western Uvalde County. The contact with the underlying Eagle Ford shale is unconformable. Although caves and large solution caverns are common (i.e., Cibolo Creek and Robber Baron's Cave in Bexar County), the Austin chalk is not a large water producer. Where large quantities of water have been reported, it is generally believed that the rocks are hydraulically connected with the underlying Edwards and associated limestone through faults or fissures.

3. Anacacho limestone and Taylor marl.- Work by others has established that the Anacacho limestone west of San Antonio is the age equivalent of the Taylor marl in Comal and Hays Counties. The interfingering of the two formations is evident in eastern Medina and western Bexar Counties where the Taylor marl overlaps the eastward thinning Anacacho limestone. The Anacacho is composed of calcareous, sometimes pyroclastic clays, argillaceous limestone, chalk, and marl. Locally the rocks of the formation are asphalt impregnated and, in western Uvalde County, the formation is quarried for road surfacing. The formation does not yield potable water. The Taylor marl is primarily a calcareous clay and marl that locally yields small quantities of water at shallow depth.

(a) Navarro group.- The formations which comprise the Navarro group are, from oldest to youngest, the Corsicana marl, Escondido formation, and Kemp clay. In Uvalde County the group is represented only by the Escondido formation, a hard, fine-grained sandstone with clay and shale interbeds. In Medina County, the Escondido, primarily a sandstone and siltstone with sandy marl and shale interbeds (in part the equivalent to the Kemp clay to the east), is overlain by silty marl and shale which comprise the Corsicana marl. The formations of the group have not been differentiated in Bexar and Hays Counties, and in Comal County the Navarro is absent. Rocks of the Navarro group are not considered important water-bearing units although in Medina County some of the lower sand beds of the Escondido formation yield potable water suitable for domestic and stock use. When the water is encountered at shallow depths, the chemical quality is usually poor.

c. Tertiary system.- At the end of the Cretaceous period, the seas retreated from south central Texas but returned again in the early Tertiary time. Rocks of the Paleocene, Eocene, and Pliocene (?) series were deposited during the Tertiary period. They consist predominantly of clays, siltstones, sandstones, and fossiliferous limestones that were laid down unconformably on the strata of the Cretaceous Navarro group.

(1) Paleocene series.

(a) Midway group.- The Midway group is not present in Comal and Hays Counties, but in the western study area counties the group is represented by the Kincaid and Wills Point formations. The Kincaid is found only in Uvalde and Medina Counties and reportedly attains a maximum thickness of about 155 feet in southern Medina County. The formation is composed of clay, siltstone, sandstone, and limestone strata. According to the Geological Survey 1/ the Wills Point formation is probably the only formation of the Midway group in Bexar County although the Kincaid may be present in the subsurface. The formation consists primarily of sandy clay with sandy or limy concretions and reaches a maximum thickness of about 490 feet in the southern part of the county. The rocks of the Midway group are not known to yield water in the study area.

(2) Eocene series.- From oldest to youngest, formations of the Wilcox and Claiborne groups comprise the Eocene series in the study area.

(a) Wilcox group.

1. Indio formation.- The Wilcox group is represented in the study area by a series of sands, sandstones, clays, silts, carbonaceous shales, and thin lignite beds, all assigned to

The Indio formation. The formation, not present in Comal and Hays Counties, varies in thickness from about 200 feet in Uvalde County to approximately 1070 feet in Bexar County and unconformably overlies formations of the Midway group. Generally, the formation is not considered to be an important aquifer although locally a small to moderate amount of potable water may be obtained for domestic and stock use. Pumping yields of up to 400 to 500 gpm have been reported in Medina and Bexar Counties but the water is usually hard.

(b) Claiborne group.- The Claiborne group is present only in the western counties of the study area where it is represented by the Carrizo sand and the Mount Selman formation.

1. Carrizo sand.- The Carrizo, the older of the two formations, unconformably overlies the Indio formation of the Wilcox group and outcrops in the southern part of Uvalde, Medina, and Bexar Counties. It attains a maximum thickness of about 800 feet in Bexar County. The Carrizo is composed chiefly of a coarse-grained, locally crossbedded, quartzitic sand and sandstone with very thin interbeds of clay and clayey shale. Locally, ledges of ferruginous sandstone are common. The Carrizo sands yield a small to moderate amount of good quality water in the study area. However, to the south, in Zavala, Frio, and Atascosa Counties, the formation is a major aquifer, supplying water in sufficient quantities for both municipal and irrigation uses.

2. Mount Selman formation.- The Mount Selman formation overlies the Carrizo sand in Bexar and Medina Counties. The formation consists chiefly of sand, clay, and silty clay and is not know to yield water in the study area.

(3) Pliocene (?) series.

1. Uvalde gravel.- A high terrace deposit, designated as the Uvalde gravel and consisting of residual gravels composed primarily of chert, flint, and limestone derived from the Edwards formation, is found capping hills and forming stream divides throughout the study area. The residual, subrounded gravels are commonly embedded in a clay, silt, or caliche matrix and attain a maximum thickness of about 30 feet. The thin mantle of gravels does not produce any water.

d. Quaternary system.

(1) Pleistocene and Recent series.

1. Leona formation and Recent alluvium.- Shortly after the deposition of the Uvalde gravel in late Pliocene or early Pleistocene time the region witnessed a slight uplift that caused the streams to cut through the gravels into underlying bedrock, in which they have subsequently developed their present channels and flood plains. The terrace gravels deposited after this rejuvenation,

including the Recent streambed and flood plain gravels are considered as one unit both geologically and hydrologically. The Leona formation and Recent alluvium, composed primarily of silt, sand, clay, and gravel, is found mainly in the river valleys or in old, abandoned meander channels. The alluvium is thickest in the western counties, reaching a maximum of about 105 feet in Uvalde County. According to the U. S. Geological Survey 25/ the Leona gravels are an important water producer in the Leona Valley, located south of Uvalde, supplying sufficient water for irrigation. The gravels are evidently hydrologically connected with the Edwards and associated limestones in the Leona valley and, locally, appear to depend on overflow recharge from the limestone aquifer for production. Elsewhere, production from the alluvium depends on rainfall and stream runoff.

e. Igneous rocks.- Numerous igneous plugs, sills, and dikes, composed primarily of basalt and serpentine, are found throughout the Balcones fault zone in Uvalde County and a few occur in Medina County. These intrusives generally crop out in the Coastal Plain as low knobs or hills, disrupting the otherwise level topography. The age of the igneous rocks is conjectural but they are believed to have been intruded in late Cretaceous or early Tertiary time. Igneous intrusives have been encountered at two dam sites in Uvalde County. Tom Nunn Hill Dam site, located about 8 miles southwest of Uvalde on the Nueces River, was explored in 1938. Core borings into the igneous intrusive encountered a "sedimentary fossiliferous serpentine" containing small fragments of unaltered limestone and fossils believed to be from the Austin chalk formation. The material appears to be a composite of debris from the igneous intrusive and the surrounding sedimentary rock, and would tend to date its occurrence at Tom Nunn Hill as early Austin chalk equivalent. The Geological Survey 25/ has noted the presence of bentonitic clay in the Eagle Ford formation which may be the earliest recorded volcanic activity in the area. A second igneous intrusive was encountered in the Sabinal River valley during the exploration for the Sabinal Dam site and, contrary to the general rule, there was no surface expression of the plug. A discussion of the lithologic characteristics of the intrusive is included in the report on Sabinal Dam site No. 2.

(1) It is not known what effect these igneous intrusives may have on the movement of ground water in the Balcones fault zone, but it is doubtful that they significantly affect the overall regional movement. Locally, the formations into which the igneous rocks are intruded are highly broken and fractured and considerably more permeable than the rocks away from the intrusive. This condition may have some very localized effect on the water table or ground-water movement.

7. STRUCTURAL GEOLOGY.

a. Balcones fault zone.- The Balcones fault zone is a variable width zone of moderate to intense faulting, extending from McLennan County in central Texas to Kinney County in southwest Texas. U. S. Highway 81 from Austin to San Antonio generally parallels the prominent escarpment that reflects movement along one or more of these faults. West of San Antonio in Medina and Uvalde Counties the escarpment occurs north of U. S. Highway 91. In the western part of Uvalde County the fault zone becomes one of folding and fracturing rather than large scale faulting.

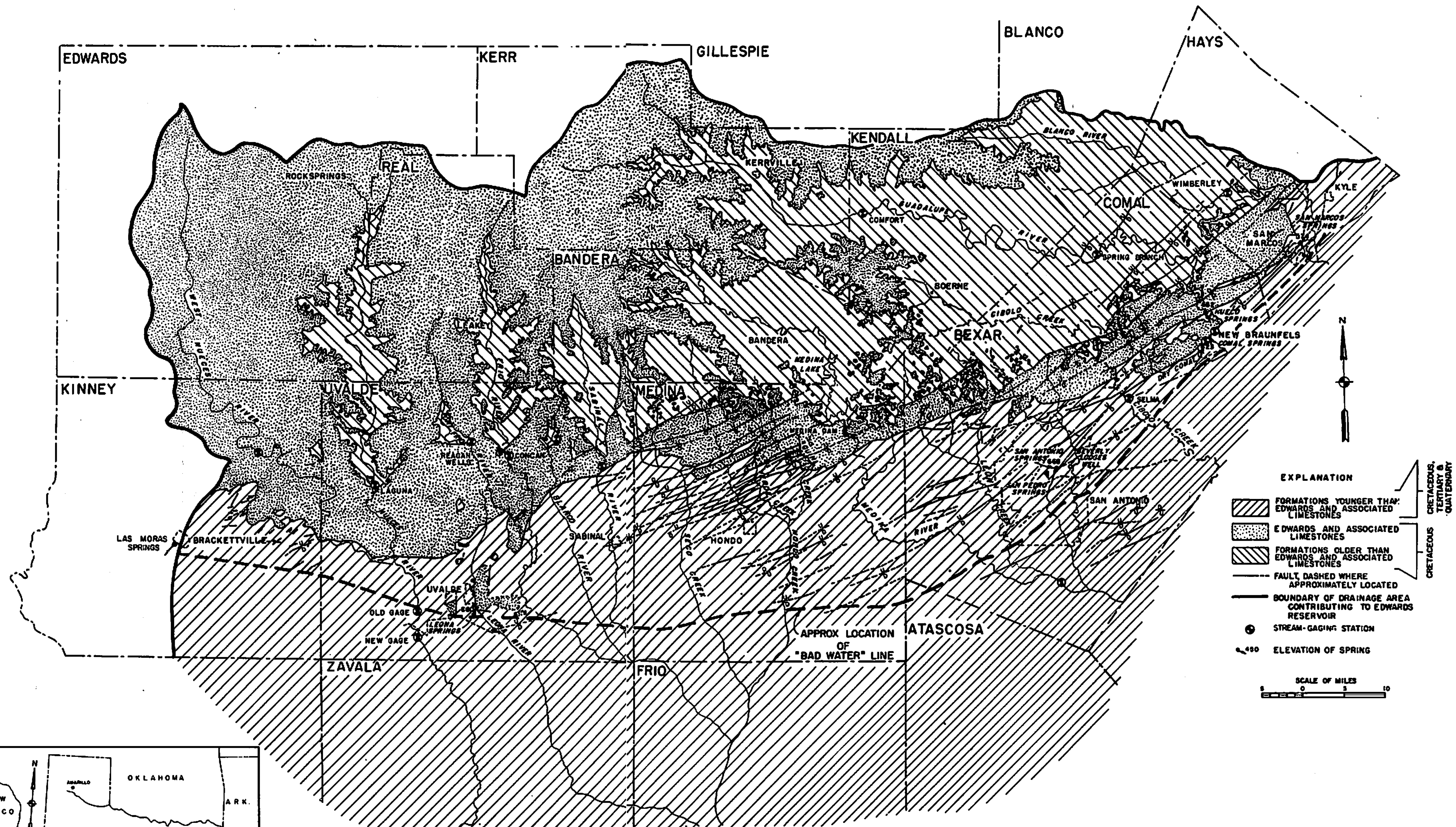
(1) Faults comprising the Balcones zone are generally normal or gravity faults with downthrow to the south or southeast. The straight or near straight fault traces in rugged topography indicate that the fault planes are dipping at a steep angle. Displacements vary greatly, tending to be at a maximum near the center and diminishing toward the ends of individual faults. Single faults within the system exhibit displacement up to 700 feet and can be traced for approximately 50 miles throughout the area. Total displacement across the zone varies from a maximum of approximately 1500 feet in Comal County to about 700 feet in northeastern Uvalde County. The cause of the faulting has generally been attributed to the tensions set up as the Gulf Coastal Plain settled under its continual depositional load. Once the tensional forces overcame the elasticity of the rocks, faulting or rupturing was inevitable and the prominent escarpment between the Edwards Plateau and the Gulf Coastal Plain was developed. The age of the faulting is conjectural, but is believed to have taken place between early Cretaceous and Pleistocene time.

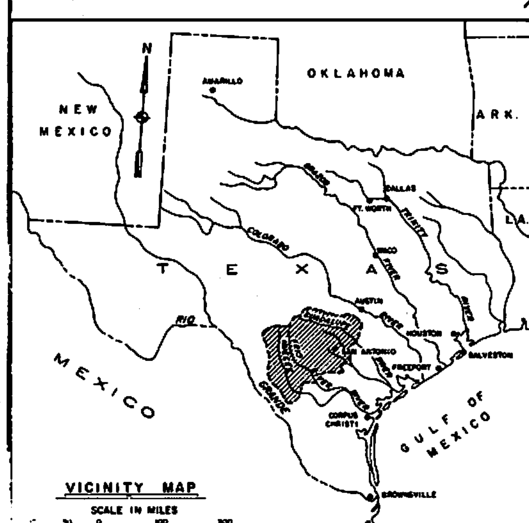
b. Other structural features.- The Uvalde salient, a structural high composed of closely connected crustal uplifts, is evident between Uvalde and Knippa in Uvalde County. Edwards and associated limestones have been uplifted to the surface and the relatively resistant limestone beds form easily recognizable rolling hills. Basaltic intrusives and large-scale faulting are associated with the high.

(1) A broad, southwestward plunging anticline, the Culebra anticline, extends from north central Bexar County into eastern Medina County.19/ The fold, 7 to 9 miles wide, consists of a core of Austin chalk overlapped by beds of Taylor and Navarro age on the flanks. Faults border and terminate the flanks of the anticline. The Medina River flows around the westward plunging nose of the anticline in eastern Medina County.

(2) The third major structure in the area is the San Marcos arch, an ancient, broad uplift, extending in a southeastward direction from the Llano uplift through San Marcos to Gonzales County. The San Marcos River generally follows its crest. Surface expression of the high is absent, but its presence is identified in the subsurface by the thinning of upper Cretaceous sediments across the arch.

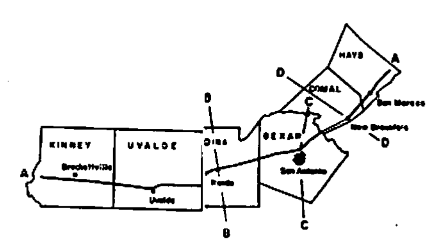
c. Regional dips.- In the Edwards Plateau the Cretaceous strata dip south and southeasterly toward the gulf of Mexico at a rate of about 10 to 20 feet per mile, conforming very closely to the slope of the land surface. South of the Edwards Plateau in the Coastal Plain the average dip of the rocks steepens to about 100 to 150 feet per mile. Since this average dip is steeper than the slope of the land surface, successively younger beds crop out downdip to the south and southeast. Occasionally, within the Balcones fault zone, the regional southerly dip of the rocks becomes abnormally steep and variable. This condition is especially apparent adjacent to faults.





VICINITY MAP

SCALE IN MILES



LOCATION MAP FOR SECTIONS SEE PLATE 2

NOTES

1. Compiled from U. S. Geological Survey maps
2. Not all faults are shown due to the scale of this plate. It is intended to show only the major faults associated with the Balcones fault zone. The relative movement is not always shown, but the downthrown side is usually to the south.

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

REGIONAL GEOLOGY

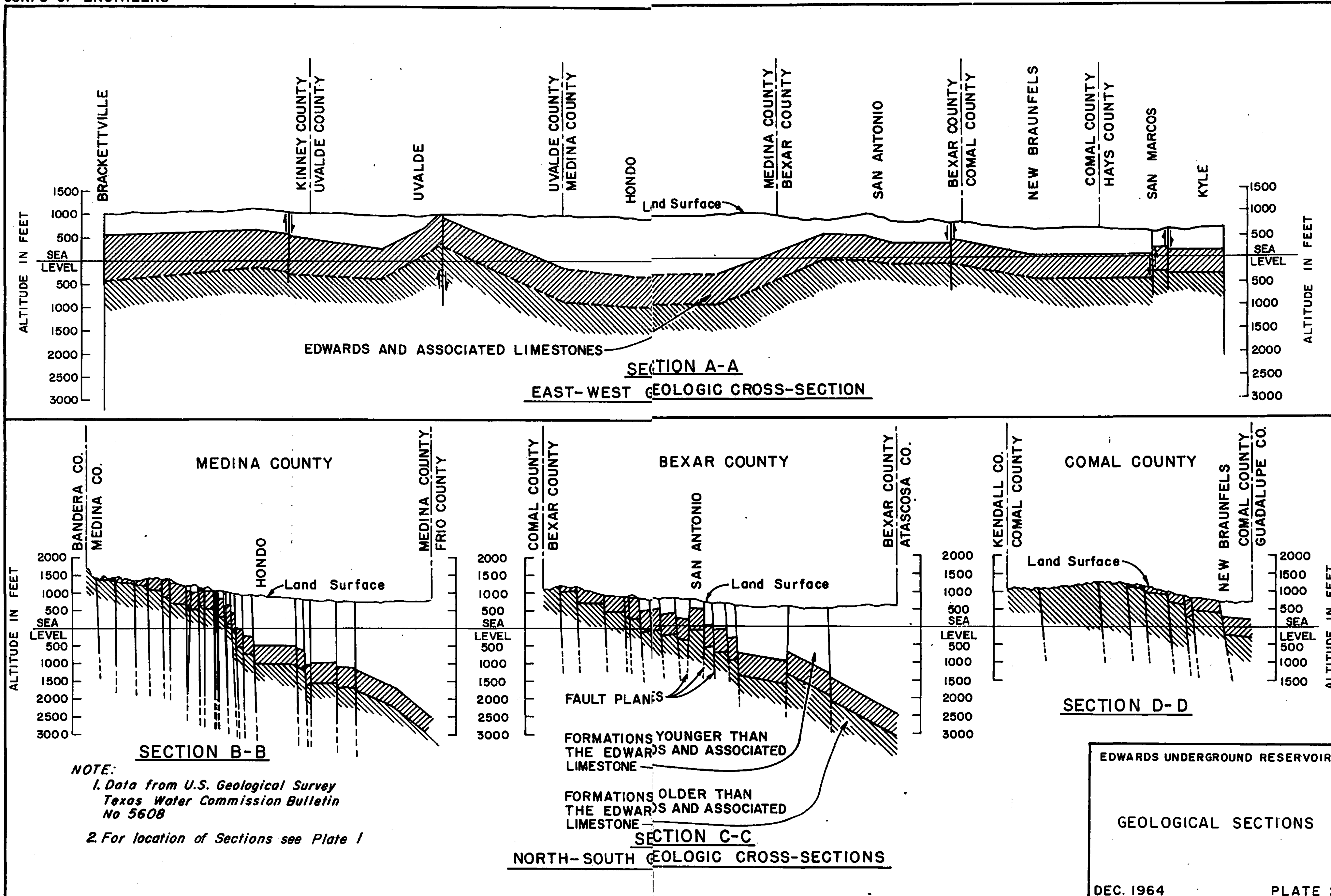
SCALES AS SHOWN

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

SUBMITTED: W. E. Wood, ENGINEER | APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION | APPROVED: COL. CORPS OF ENGINEERS, DISTRICT ENGINEER

PREPARED: ENGINEER

DRAWN BY: | CHECKED BY: | TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR | FILE: GUAD 707-2


BRACKETTVILLE
KINNEY COUNTY
UVALDE COUNTY
UVALDE
UVALDE COUNTY
MEDINA COUNTY
HONDO
Land Surface
MEDINA COUNTY
BEXAR COUNTY
SAN ANTONIO
BEXAR COUNTY
COMAL COUNTY
NEW BRAUNFELS
COMAL COUNTY
HAYS COUNTY
SAN MARCOS
KYLE
ALTITUDE IN FEET
1500
1000
500
SEA LEVEL
500
1000
1500
2000
2500
3000
EDWARDS AND ASSOCIATED LIMESTONES
SECTION A-A
EAST-WEST GEOLOGIC CROSS-SECTION
BANDERA CO.
MEDINA CO.
MEDINA COUNTY
HONDO
Land Surface
MEDINA COUNTY
FRIO COUNTY
SECTION B-B
COMAL COUNTY
BEXAR COUNTY
BEXAR COUNTY
SAN ANTONIO
BEXAR COUNTY
ATASCOSA CO.
FAULT PLANES
FORMATIONS YOUNGER THAN THE EDWARDS AND ASSOCIATED LIMESTONE
FORMATIONS OLDER THAN THE EDWARDS AND ASSOCIATED LIMESTONE
SECTION C-C
NORTH-SOUTH GEOLOGIC CROSS-SECTIONS
KENDALL CO.
COMAL COUNTY
COMAL COUNTY
NEW BRAUNFELS
COMAL COUNTY
GUADALUPE CO.
SECTION D-D
NOTE:
1. Data from U.S. Geological Survey Texas Water Commission Bulletin No 5608
2. For location of Sections see Plate 1
EDWARDS UNDERGROUND RESERVOIR
GEOLOGICAL SECTIONS
DEC. 1964
PLATE 2

GROUND WATER

8. EDWARDS AND ASSOCIATED LIMESTONES AQUIFER.- Two distinct ground-water reservoirs have been formed in the Edwards and associated limestones aquifer, an unconfined reservoir in the Edwards Plateau and an artesian reservoir in the Balcones fault zone. In the Edwards Plateau the rocks slope gently to the south and southeast about 20 feet to the mile, which is equal or slightly more than the natural slope of the land surface. The Edwards limestone covers most of this area and, being relatively permeable, absorbs a substantial amount of rainfall. The rainfall 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 and flows laterally through the limestone. Much of this water reappears as springflow at or near the base of the Edwards and associated limestones located in the valleys that have been cut through the formation. These springs are the source of perennial streams that drain the Edwards Plateau. As these streams flow south, they cross honeycombed and cavernous stretches of Edwards limestone which has been downfaulted into the streambeds. Along this stretch the streams lose virtually all of their perennial flow and much of their flood flow.

9. In the Balcones fault zone, where the Edwards limestone has been extensively faulted downward and is overlain by 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 a combination of major faults and decreased permeability, causing the water 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 varying sizes. Some of the solution channels are large caverns, the largest of which generally follow the lines of major faulting.

10. The northern and southern limits of the artesian reservoir generally coincide with those of the major faulting in the Balcones fault zone. This faulting is marked by a prominent escarpment that readily identifies the northern boundary. However, the southern boundary cannot be identified by surface expression of faulting and is better defined by an imaginary 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. South of the Balcones fault zone, the Edwards limestone has a progressively increasing dip of approximately 100 feet per mile, and ultimately reaches depths of more than 5,000 feet below sea level.

11. NATURAL RECHARGE.- Recharge to the Edwards Underground Reservoir occurs by a cyclic method. The rainfall on the Edwards Plateau filters down through the Edwards and associated limestones and later reappears as springflow at the top of the underlying Glen Rose limestone. The cycled water then forms the base flow of streams that drain the area. Because the Glen Rose limestone controls the flow and is relatively impervious, the flow does not enter the Edwards Underground Reservoir until it crosses the Balcones fault zone located some distance downstream. At these locations the water partially or completely disappears underground into the Edwards Reservoir. Streams that flow through the study area are in the drainage systems of three major river basins - the Nueces, San Antonio, and Guadalupe.

a. Nueces River Basin.- The principal streams in the Nueces River Basin that make a significant contribution to recharge of the Edwards limestone aquifer are the Nueces, West Nueces, Frio, Dry Frio, and Sabinal Rivers and Verde, Hondo, and Seco Creeks which are tributaries of the Frio River. These streams drain 3,112 square miles of the Edwards Plateau and contributed an average of 231,500 acre-feet per year of recharge water to the Edwards Reservoir for the period 1935-1956. 4 /

(1) The streams in the Nueces River Basin have cut deep canyons through the Edwards and associated limestones, and, for the most part, flow over the underlying, relatively impervious Glen Rose limestone. The canyons occasionally widen into narrow valleys, particularly where intercepted by tributary streams. Below the Blacones escarpment the narrow valleys and canyons change into a wide valley section and the stream channels decrease in size and capacity. Two of the larger streams in the plateau, the Frio and Nueces Rivers, have minimum bankfull capacities of 5,000 to 30,000 cubic feet per second. An example of the potential recharge from the streams that cross the outcrop of the Edwards limestone is shown in the Geological Survey data compiled during the March 1958 flood on the Frio and Dry Frio Rivers. Outcrops of the Edwards limestone occur along approximately 11 miles of the Frio River and along approximately 14 miles of the Dry Frio River.25/ Gage records for the 1958 flood indicate that water entered the aquifer at a rate as great as 939 cubic feet per second where the combined streams crossed the outcrop.4 / Similar conditions occur along a 13-mile stretch of the Nueces River west of Uvalde and along a 3-mile stretch of the Sabinal River.25/

(2) The West Nueces River does not follow the general characteristics described above. The stream is usually dry and seldom has a flow at its confluence with the Nueces River, except in periods of heavy rainfall. For the most part, the bed of the stream is underlaid by gravel and the recharge moves eastward as underflow.

b. San Antonio River Basin.- Streams that flow through the Edwards Reservoir area in the San Antonio River Basin and contribute to the Edwards Underground Reservoir are the Cibolo, Salado, and Leon

Creeks and Medina River. These streams have deeply entrenched channels with large carrying capacities, and overbank flooding is infrequent. The San Antonio River and its tributaries, Olmos, San Pedro, Alazan, Apache, and Martinez Creeks are not considered major contributors to the recharge of the Edwards Underground Reservoir.

(1) Losses to the Edwards Reservoir from streams in the San Antonio River Basin total approximately 145,800 acre-feet per year (1935-1956). The U. S. Geological Survey has estimated that 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. Along the wide meanders of Cibolo Creek there are many caves, caverns, sinkholes, crevices, and honeycombed limestones which permit the flow to escape into the underground solution channels leading to the Edwards aquifer. One of the largest caverns in the state, the Natural Bridge Cave, is located in this area about 18 miles north-northeast of San Antonio. The cave has an entrance in the Edwards limestone, but most of the openings lie within the upper member of the Glen Rose limestone. The maximum depth is approximately 250 feet, and the caverns extend some 5,300 feet in a northerly direction to within about 750 feet of Cibolo Creek.

c. Guadalupe River Basin.- The principal streams in the Guadalupe River Basin that cross the Edwards limestone aquifer are the Guadalupe River and two of its 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, forming vertical cliffs 200 to 300 feet high. The Edwards limestone is left only to cap the hills. The flood plains are generally narrow and contain isolated,thin strips of flat bottom land. The streambeds lie principally in limestone and are void of sediments except for large boulders. Rapids are sometimes found where the streams cross major faults. The Guadalupe River is a perennial stream and, except for periods of below normal rainfall, has a substantial flow maintained by springs issuing from the Edwards limestone.

(1) Streamflow losses through the Balcones fault zone into the Edwards aquifer are generally limited to the Blanco River and Dry Comal Creek. The Guadalupe River contributes very little recharge to the underground reservoir. Its base flow between the cities of Comfort and New Braunfels is almost constant. The U. S. Geological Survey contributes this condition to two principal causes: 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 table in the area stands at approximately the same elevation as the streambed.14/

(2) Total recharge to the Edwards Underground Reservoir is about 45,900 acre-feet per year (1935-1956) from the Guadalupe River Basin.

12. ARTIFICIAL RECHARGE.- The injection system of artificial recharge, whereby waters are introduced into an aquifer by means of wells, caves, crevices, and other openings has been used in Uvalde County since the early 1950's. One of the first advocates of artificial recharge for this area was Mr. F. M. Getzendaner, a geologist well acquainted with the local geology. It was largely through his efforts that the first such project, a grating over a cave in the Leona River bed two miles north of Uvalde, was constructed by the city of Uvalde in 1940.23/

13. Since the establishment of a Uvalde County Flood Control Advisory Committee in 1951 several structures have been constructed in the county to divert floodwaters and runoff into natural openings or drilled wells in dry streambeds. These structures generally consist of low concrete dams located a short distance downstream from protected openings into the bedrock. Recharge structures of this type have been constructed on Indian Creek, Leona River, Dry Frio River, and the Sabinal River north and northeast of Uvalde. Sink holes west and southeast of Uvalde have been developed for recharge by inserting perforated concrete pipes 20 to 25 feet into the sinks and covering the openings with trash racks. Most of these structures are still in existence and provide some recharge to the Edwards Underground Reservoir.

14. Attempts have been made to evaluate the benefits derived from these small uncontrolled recharge projects in Uvalde County, but because of the lack of stream-gaging stations and strategically located recorder wells in the Edwards and associated limestones, the benefits are still conjectural. It is true that some floodwaters that would otherwise escape are diverted into the underground reservoir, but just how much or whether the expenditures are justifiable is not known. Runoff or floodwater is captured only after heavy rains and it is during these periods of abundant rainfall that the artificial recharge is generally not so critical. Although large controlled recharge projects on major streams in the Edwards Plateau will capture and contain most of the runoff there are areas where the small retention type structures possibly would be effective. One such area is Seco Creek where a suitable dam and reservoir site for controlled recharge could not be justified. Small dams and injection wells along this creek might prove economically feasible and desirable but care should be exercised in locating recharge sites where it is certain the water will find its way into the Edwards Underground Reservoir.

15. DISCHARGE.- The discharge from the Edwards and associated limestones aquifer is through springs and wells situated in the area. A general description of the principal springs and a brief history of the wells in the Edwards Reservoir area are presented in the following paragraphs.

a. Springs.- The Edwards Plateau, together with the Balcones fault zone area, is one of the most prolific 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 along the southern edge of the Balcones escarpment where water is forced to the surface by artesian pressure through fissures leading from the subsurface aquifer. Two of 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.

PRINCIPAL SPRINGS OF THE EDWARDS RESERVOIR AREA

Name	Location	Springflow - 1000 acre-feet per year 4/			
		Maximum	Minimum	1935-36 Average	June 2/ 1964
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	139.8
Hueco	New Braunfels	69.5	0	19.6	-
San Marcos	San Marcos	211.5	33.3	93.0	81.1
TOTAL				352.4	

(1) The Leona Springs issue from the gravels in the Leona River at a location where the stream has cut through an impervious clay bed into underlying gravels. The gravels in the Leona formation are evidently hydraulically connected to the Edwards limestone in some places, and the flow of the springs depends primarily on recharge from the Edwards and associated limestones. Evidence pointing to this conclusion is based on the fact that water levels in the Leona gravels fluctuate similarly with those in the Edwards and associated limestones.

(2) The San Antonio and San Pedro Springs, located within the city limits of San Antonio, are the largest springs in Bexar County. They have as their source the Edwards and associated limestones and issue to the ground surface along faults and fissures that extend into that aquifer. The discharge from the springs has been intermittent in recent years because of heavy pumping and lowered water levels in the aquifer in the San Antonio area. The springs had essentially no flow from 1949 to 1956.

(3) Except for a 5-month period (June 13 to November 3, 1956) occurring toward the end of a 7-year drought period, Comal Springs has maintained a spectacular flow. The water issues from many openings along the base of the Comal Springs fault escarpment,6/ contributing almost all of the flow to Comal River. The water is clear and maintains an almost constant temperature of 74° F. The high rate of discharge, lack of turbidity and near constant temperature have led to the conclusion that the source of the water is regional rather than local and that the favored flow paths are not large caverns, but, instead, a system of relatively small joints, fractures, and solutioning channels, all interconnected.

(4) Hueco Springs, located about 3 miles north of Comal Springs, issues from the Edwards limestone near the intersection of the Hueco Springs fault with the Guadalupe River. Because of the turbid appearance of the water from Hueco Springs after heavy rains and the fluctuations in the water temperature, it is believed that the Edwards Reservoir is not the principal source for these springs. However, during high reservoir stages in the underground aquifer there may be some contribution from the Edwards Reservoir to the flow of the springs. It would appear that the main recharge area for the springs is Dry Comal Creek in the Guadalupe River drainage basin.

(5) San Marcos Springs is a perennial spring discharging from several fissures in the Edwards limestone where the Edwards is locally faulted against the Taylor marl. 3/ Like Comal Springs at New Braunfels, it is believed that the San Marcos Springs have their principal flow from the Edwards Underground Reservoir. The quantity of flow appears to be controlled by the Edwards Reservoir level, which in turn is controlled by the pumpage from Edwards wells located southwest of the spring area.

b. Wells.- The first well was drilled into the Edwards and associated limestones aquifer in about 1884 by George W. Brackenridge for 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. 10/ By the year 1953 there were more than 2,000 wells in Bexar County tapping the Edwards aquifer. There are today about 4,000 wells drawing water from the reservoir in the five-county area which includes Uvalde, Medina, Bexar, Comal, and Hays Counties.

(1) 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) were pumped in Bexar County. 17/ Prior to 1954 most of the discharge from the aquifer had been from springs. However, by 1954, in the middle of the 1947 to 1957 drought period, the discharge from wells exceeded that from springs.

(2) There are many large wells that draw water from the Edwards aquifer. The two wells that are generally considered to be the most productive are located in Bexar County. One of the wells is reported to have had a natural flow of 16,800 gallons per minute in 1942. The other, a well located in the San Antonio City Water Board's Market Street Plant, yielded 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.14/

16. CONTROL OF DISCHARGE FROM THE EDWARDS UNDERGROUND RESERVOIR.- Although the Edwards Underground Reservoir is a vast complex of relatively pervious strata receiving recharge from several drainage basins, its high rate of discharge through springflows precludes it from being classified as an ideal ground-water reservoir. For example, during the period from 1935 to 1956 the average annual recharge was approximately 423,200 acre-feet of water; whereas the average annual discharge from springs was 352,400 acre-feet. Pumping during the same period averaged only 171,300 acre-feet (increased to 268,200 acre-feet in 1962). Assuming that this unbalanced condition could be improved by controlling the springflows and considering that most of the discharge is from Comal Springs in New Braunfels and San Marcos Springs in San Marcos, there appear to be four approaches to the problem:

a. Control the recharge. The springflow is approximately proportional to the water level in the reservoir; therefore, by controlling the recharge and keeping the reservoir at an optimum level, the flow from the springs can be regulated. This plan would require dams constructed upstream from the high seepage loss areas of the streams, storing the water and releasing it as needed to keep the water in the underground reservoir at a certain level. This plan of operation was considered inadequate during the critical drought period because of the very high evaporation losses that would occur while storing the water in surface reservoirs.

b. Intercept the water before it emits from the springs. Large pumping stations located up-reservoir or southwest of Comal Springs could intercept some water which would ordinarily escape from the springs. This pump-up storage would require some sort of surface reservoir unless the water not used directly is reintroduced into the underground reservoir west of the heavy use area through existing stream and river beds or through recharge wells. However, evaporation would undoubtedly prohibit the use of surface storage reservoirs in the area.

c. Construct ring dikes around the springs to equalize the hydrostatic head in the underground reservoir. The problems involved in an undertaking of this sort are tremendous. Comal Springs, for example, is made up of many flows issuing from openings in the Edwards limestone along the base of the Comal Springs fault. The springs extend for about 500 yards along the escarpment 6/ in a highly developed area. The biggest problem, however, would not be in constructing the ring dike but would be in preventing the springs from breaking out to the surface at some other point along the fault. It is the considered opinion of many that, because of the probable breakouts, ring dikes are not feasible for Comal and San Marcos Springs.

d. Construct a grout curtain southwest of Comal Springs across the Edwards Underground Reservoir. A few miles southwest of New Braunfels the Edwards Underground Reservoir is confined in a strip about five miles wide. A positive cutoff constructed across this relatively narrow strip could conceivably reduce the flow from the springs; however, based on present technical knowledge, it is very doubtful that a program of this sort is feasible. Information developed in a deep exploration boring (see Edwards Core Boring, page III-31) in the general area showed the Edwards limestone to be highly broken and cavernous except for the bottom 50 feet. The core recovery and drilling action showed several cavities to be over two feet high and of probably even greater lateral extent. Considering the cavernous condition, the greater depth (430 to 700 feet), and the relatively high hydrostatic head, it is believed that the minimum design for an Edwards grout curtain would require a triple line of grout holes on 2- to 5-foot centers. Even then there could be no assurance that the increased hydrostatic head would not cause the ground water to circumvent the curtain or develop new leakage paths through previously backfilled caverns.

e. In consideration of above-mentioned problems it is believed that storage of water in surface reservoirs would be questionable because of high losses from evaporation; ring dikes would not be effective in confining flows because of the highly solutioned and cavernous subsurface; and the cost of a grout curtain of the magnitude required to effect an adequate cutoff would be prohibitive. In summation it does not appear practical or economically feasible to attempt to control the springflow from the Edwards Underground Reservoir.

17. CHEMICAL QUALITY OF WATER.- The ground water in the greater portion of the Edwards limestone is of good quality, but concentrations of calcium bicarbonate (20 to 200 ppm) impart a moderate degree of hardness. This water hardness is typical of limestone reservoirs inasmuch as limestone is composed principally of calcium carbonate which becomes readily soluble when acted upon by the carbon dioxide (carbonic acid) in the water. Dissolution by this process has accounted for most of the honeycombed channels and caverns in the Edwards formation. An exception to this good quality occurs in the deeper portions of the reservoir toward the south and southeast. Because of this condition an imaginary line, referred to as the "bad water" line, has been arbitrarily selected and is used to

establish the southern and southeastern boundaries of the reservoir. The separation is based on water having more than 1,000 ppm dissolved solids as opposed to water having less than 1,000 ppm dissolved solids. In the zone of poor quality along the southern extremity of the artesian aquifer the water is charged with hydrogen sulfide, a chemical that has an offensive odor and is highly corrosive to metal. This condition is believed to have resulted from restrictions (faulting and reduced permeabilities) in the formation which have prevented the free circulation of the ground water. However, the water is generally acceptable for irrigation, and the hydrogen sulfide can be removed by prolonged aeration and filtration through charcoal. Further south along the downdip of the Edwards limestone the water becomes highly mineralized with the concentration of dissolved solids as great as 5,000 ppm. Chloride concentration in this area is as great as 2,000 ppm.

a. "Bad-Water" Line.- The U. S. Geological Survey has made a ground-water study of the transition zone between the good and bad water that correlates changes in the water quality with changes in the aquifer head. 5/ This study was based on several selected wells along the "bad-water" line. During the study period between 1955 to 1962 the aquifer head fluctuated from a record low (end of the drought) to a near record high. Three zones of different quality water were sampled. Zone 1 was in an area of good quality water (about 300 ppm); zone 2 was near the "bad-water" line and tested close to 1,000 ppm; and zone 3 represented an area of highly mineralized water (3,000 to 4,000 ppm). The water from zone 1 showed no significant quality change during the study period. In zone 2 the quality of the water decreased during the pumping seasons from May through October, but improved (decreased in dissolved solids) as the pumping diminished between November through April. It was also found that there was a relation between the amount of withdrawal and the amount of chemical quality change; that is, the higher the withdrawal by pumping, the higher the change in dissolved solid content of the water. These changes have been attributed to a disruption of the hydraulic equilibrium of the water in this zone caused by extreme pumpage and recharge. Overall, the quality of the water in zone 2 changed almost 13 percent from the median; the maximum improvement was about 8 percent from the median; and the increase in dissolved solids was about 5 percent.

(1) The quality of the water in zone 3, the area containing 3,000 to 4,000 ppm dissolved solids, exhibited exactly opposite results from those achieved in zone 2. In this case, the water quality improved with increased pumping and became poorer when pumpage was lightest. The change lagged approximately six months behind the change in zone 3 and is believed to correspond to a regional lag in the lateral movement of the ground water. The total checmical quality change in zone 3 during the study period was less than 5 percent.

(2) The water quality study has pointed out that changes in the mineral content of the water near the "bad-water" line occur as the reservoir stage fluctuates. However, to date, at the record low, these changes have been nominal. Just what effect the lowering of the reservoir below this historic low would have on the stability of the "bad-water" line is conjectural.

SPECIAL INVESTIGATIONS

18. INTRODUCTION.- Special investigations were made of specific problems that developed as a part of the overall Edwards Underground Reservoir study. These investigations included: drilling a deep boring in Bexar County near Cibolo Creek, which penetrated the entire Edwards and associated limestones section; electric logging of investigational borings and existing water wells; investigation of an existing dam on the Medina River; radioactive tracer studies to develop hydrologic aspects of the Edwards Underground Reservoir; a siltation study to ascertain effect of siltation as related to recharge areas; and investigation of dam sites on principal streams in the underground area for location of conservation storage and recharge reservoirs. The results of all these studies are discussed in detail in the following paragraphs.

19. EDWARDS CORE BORING.- Throughout the history of the Edwards Underground Reservoir studies a stratigraphic core hole had never been drilled that penetrated the entire thickness of the Edwards and associated limestones. Although numerous surface studies in the form of measured sections, etc., have been completed, very little information is available concerning the in-place geological and hydrological conditions pertinent to formation solutioning and flow paths. In efforts to develop this information a 777.5-foot deep core boring, designed to penetrate the entire section of Edwards and associated limestones, was drilled in northeastern Bexar County at the intersection of Evans and Nacogdoches roads on the right bank of the Cibolo Creek. This location, selected in cooperation with the U. S. Geological Survey, was chosen after an inventory of surrounding wells revealed relatively high ground-water yields. In this particular area the underground reservoir or aquifer narrows to a zone approximately 5 miles wide. By necessity, large quantities of water must pass through this restricted zone in order to supply Comal and San Marcos Springs, making this particular zone one of very high permeability.

20. In 1963 a 10-inch diameter hole was drilled to the top of the Georgetown limestone. This initial drilling phase was completed to a depth of 238.8 feet. After an electric log of the open hole was made, the well was cased with 8-inch diameter line pipe, and the annular space between the casing and the open hole was cemented. The hole was drilled from this point with a 6-inch diameter core bored to a depth of 321.5 feet where the boring was reduced to NX size (3-inch) to its final depth.

21. A detailed geologic log of the boring is shown on plate 3. A summary of the log is as follows:

Depth	Material
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
229.0 to 243.8	Georgetown limestone
243.8 to 711.5	Edwards limestone (as determined with the assistance of representatives of Shell Oil Company)
711.5 to 777.5	Glen Rose limestone

The Walnut clay and Comanche Peak limestone formations were not identified in the cores. However, it is believed the bottom 60 feet of the Edwards formation is a time equivalent of the Walnut and Comanche Peak. The bottom 51 feet of Edwards limestone from 660.6 to 711.5 exhibits characteristics very similar to those of the Glen Rose limestone. Lithologically it has essentially the same characteristics as the Glen Rose, consisting of a moderately hard, occasionally dolomitic, and generally argillaceous limestone. Thin shale partings and a typical "speckled" appearance (phosphatic nodules?) also resemble the Glen Rose. However, correlation with other electric logs in the area where the top of the Glen Rose is known or has been generally accepted shows the contact at about 711.5 feet. Assuming the 711.5 depth is the correct contact between the Edwards and the Glen Rose and discounting any faulting in the section, the total thickness of the Edwards and associated limestones appears to be about 482 feet. Regardless of which depth represents the Edwards/Glen Rose contact, the referenced 50-foot interval, for all practical purposes, is hydraulically a non-contributing zone to the Edwards Underground Reservoir.

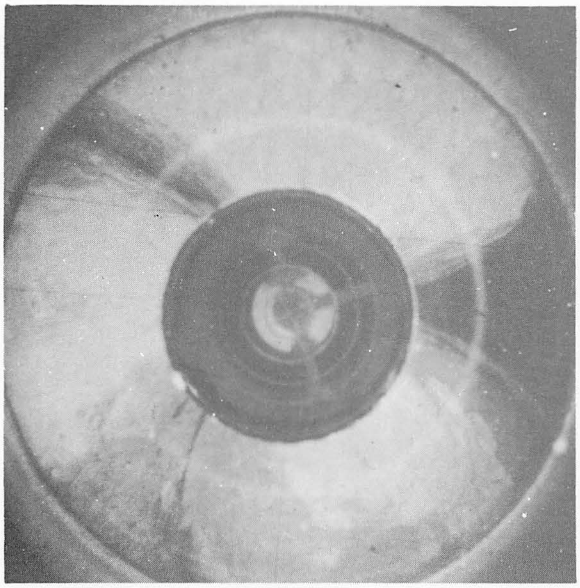
22. The Edwards limestone, as revealed by the cores, is a hard, dense, lithographic to subcrystalline limestone, generally highly broken and solutioned. Several reef zones, as well as chert lenses and nodules, were noted and the rock did not appear to be uniformly permeable. Favored flow paths, developed by continuous solutioning action, are found throughout the section. The most highly solutioned and broken zone occurs from approximately 486 to 598 feet. In this interval the core recovery was very poor and the driller logged cavities up to 2 feet in diameter. The total core recovery was approximately 65 percent of the total depth of the hole. As this is relatively poor recovery for this type of rock, it is believed that the loss further attests to a highly solutioned and open jointed condition. Photographs of the core are shown on figures 2 through 7.

23. A bore hole camera was used in the Edwards exploration boring from 238.0 to 480.0 feet to supplement the information obtained from the cores and to show the condition of the rock in place. Only the structure of the rock (i.e., joints, fractures, solution cavities, etc.) has been logged from the photographs. (See plate 4). This was done in an attempt to define the principal joint pattern of the rock. However, the determination of the individual joint sets was not possible because the rock was too highly broken and fractured. It was also intended to photograph the entire depth of the boring, but obstructions in the bore prevented the camera from penetrating beyond a depth of 480 feet. Although the interval from 486 feet to 598 feet, where the core loss was greatest, could not be photographed, it is believed enough of the hole was photographed to give a preview of the rock conditions to be expected in this interval. Figure 1 shows four bore photographs of typical Edwards limestone.

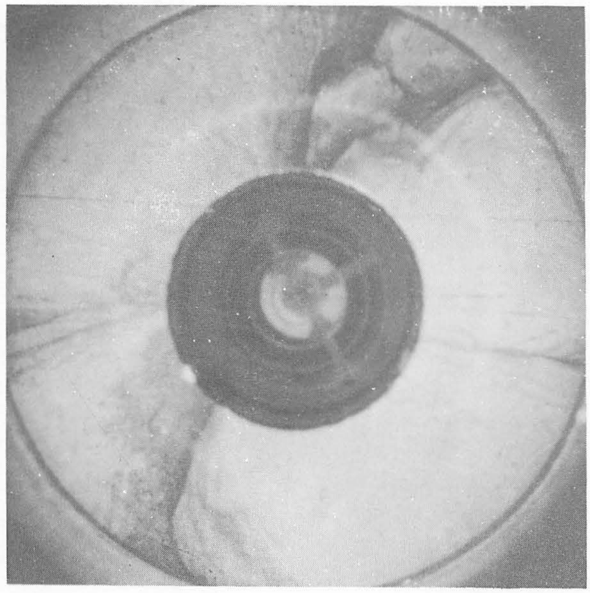
24. Present plans now call for a recorder to be installed in the well for use by the U. S. Geological Survey and the Edwards Underground Water District in their continuing study of the aquifer. An E-log of the hole is shown on plate 5.

25. ELECTRIC LOGGING.- Electric logs were made in exploration borings at all of the investigated dam sites. Through the cooperative assistance of the Geological Survey and a number of private companies, electric logs were also obtained of a number of new and old wells throughout the area. The E-logs have been very valuable in the correlation of the rocks and in the defining of formational contacts. To permit a continuing accumulation of ground-water data, local well drilling companies have been supplied with cards addressed to the Fort Worth District requesting pertinent data on new wells drilled in the area.

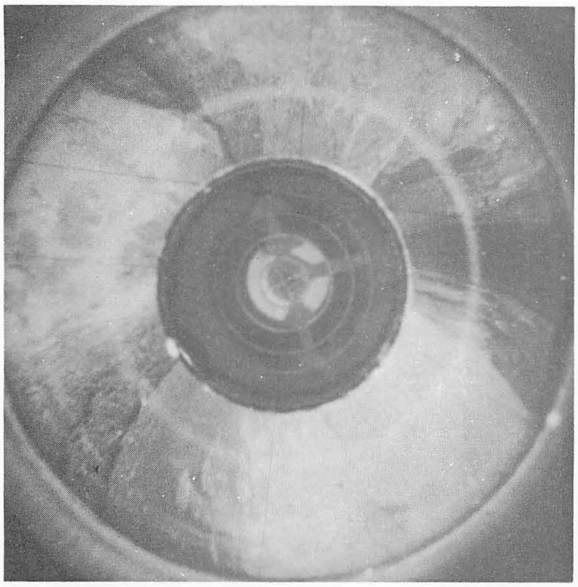
The Bore Hole Camera is an 8-mm moving picture camera included in a stainless steel tube 2-3/4 inches in diameter and 34 inches long. A cable is attached to one end by which it is lowered into the bore hole with a special lowering device. The lower end of the tube contains a transparent quartz window which encircles the cylinder. Inside the quartz window a conical mirror directs an image of the bore hole as viewed through the window upward into the camera lens. A hole through the axis of the conical mirror enables the camera to include in the center of each circular picture an image of a compass and drift indicator located below the mirror. A 360° one-inch image of the bore hole is photographed at 3/4-inch intervals as the camera is raised in the hole. 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 plane as a "doughnut". The photos that appear in figure 1 are approximately true scale exposing about a 1-inch segment of the bore hole. They should be viewed as if one were in the bottom of the hole looking out, the outside portion of the "doughnut" being the lowermost portion of the 1-inch segment.



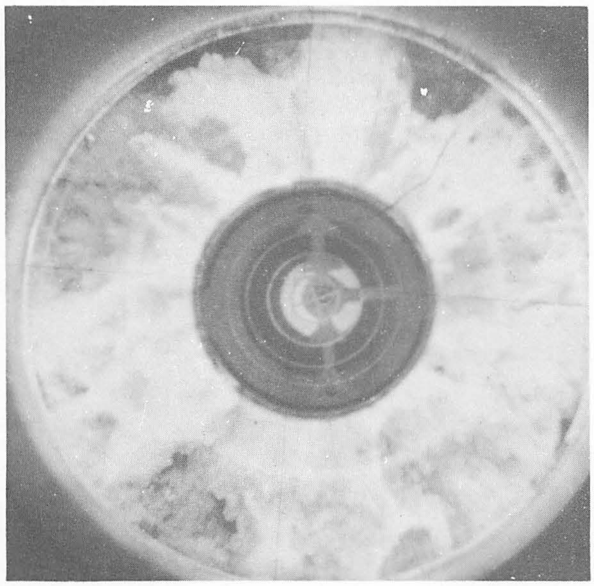
DEPTH 328.0. ARROW IN CENTER OF PHOTO POINTS TO THE NORTH (MAGNETIC). LIMB TO RIGHT OF ARROW DENOTES EAST SIDE. NOTE THE LARGE OPEN FRACTURE ALONG EAST SIDE OF HOLE.



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.

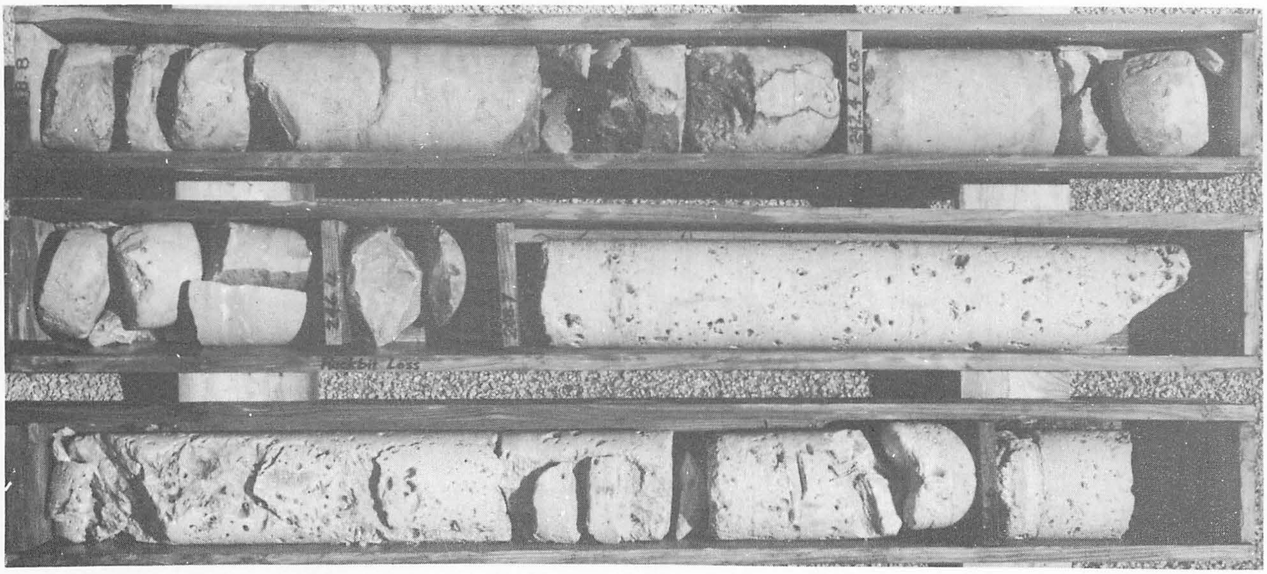


DEPTH 460.3. ROCK IS HIGHLY SOLUTIONED; NOTE OXIDE STAINS AND SOLUTION CAVITIES.

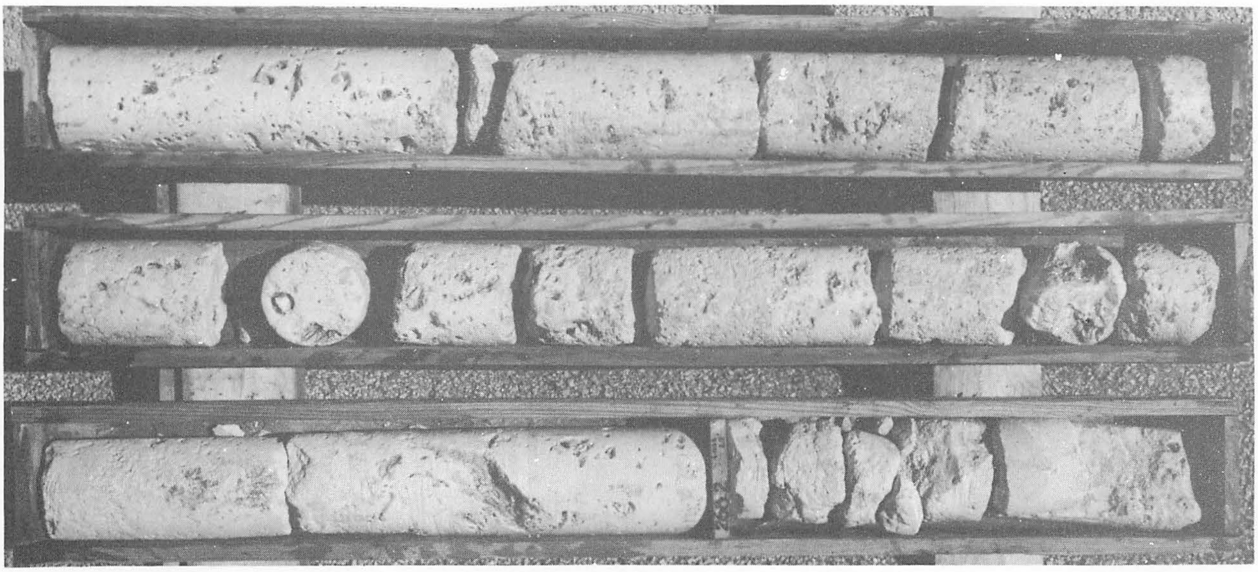
FIGURE I

BORE HOLE PHOTOS
EDWARDS EXPLORATION BORING

EDWARDS UNDERGROUND RESERVOIR



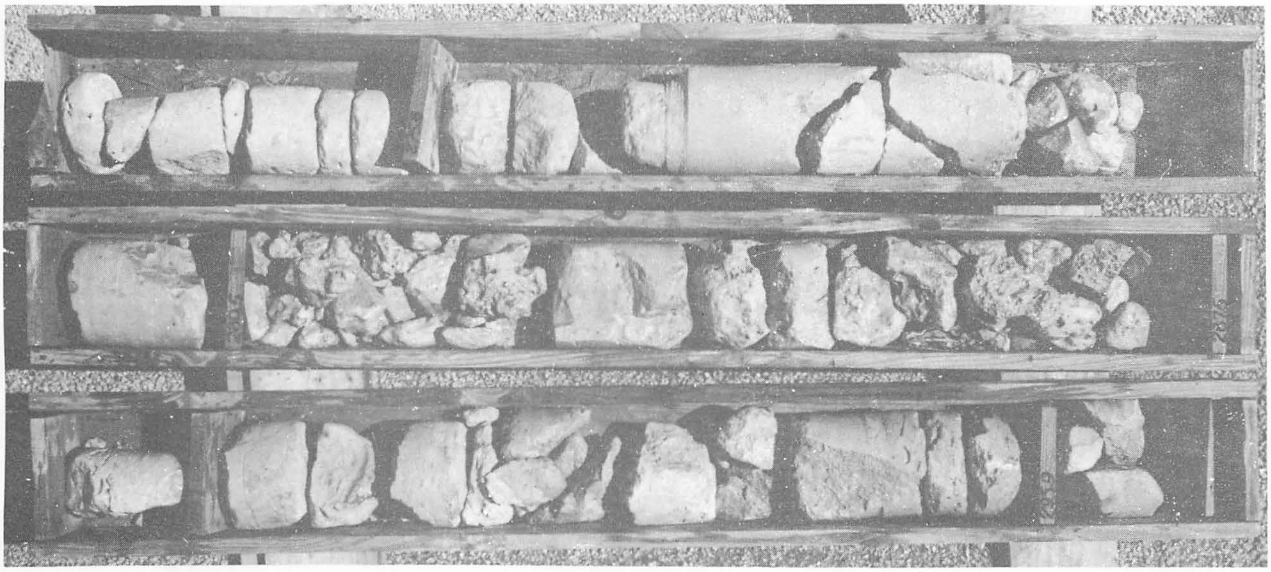
Box I through 3; 238.8 to 255.0. Georgetown - Edwards contact is at 243.8, near top of second box. Note reef limestone from 248.7. Depth increases from upper left to lower right.



Box 4 through 6; 255.0 to 270.2. Reef limestone continues to about 268.2

FIGURE 2

CORE FROM EDWARDS CORE BORING

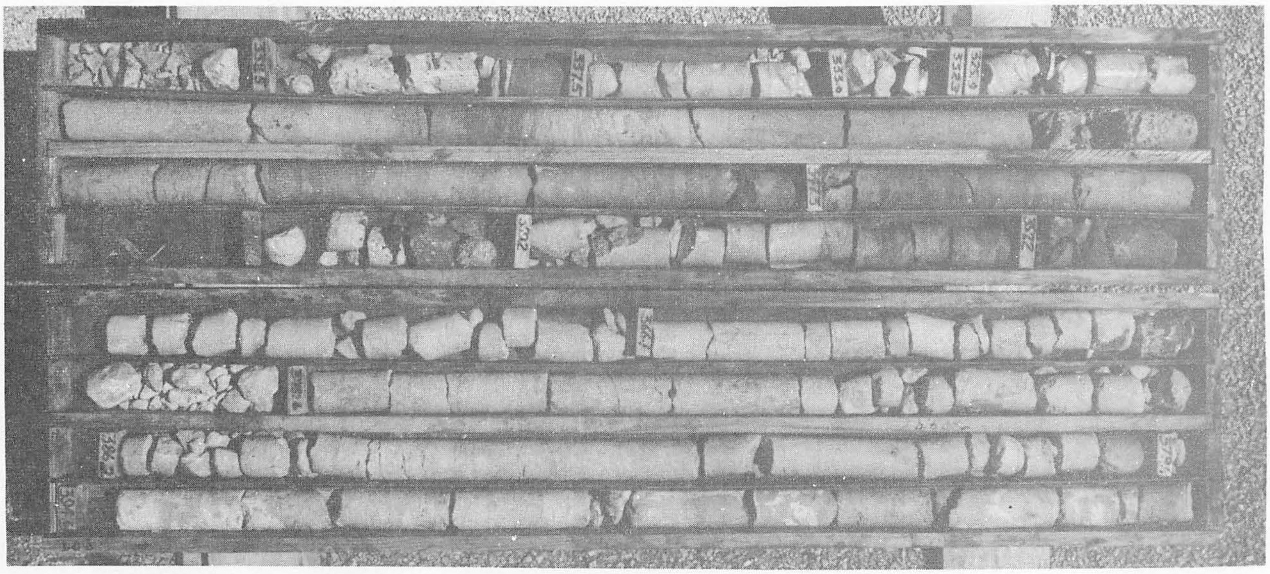


Box 7 through 9 ; 270.2 to 296.3. Considerable core loss in this interval. Rock highly broken and solutioned.

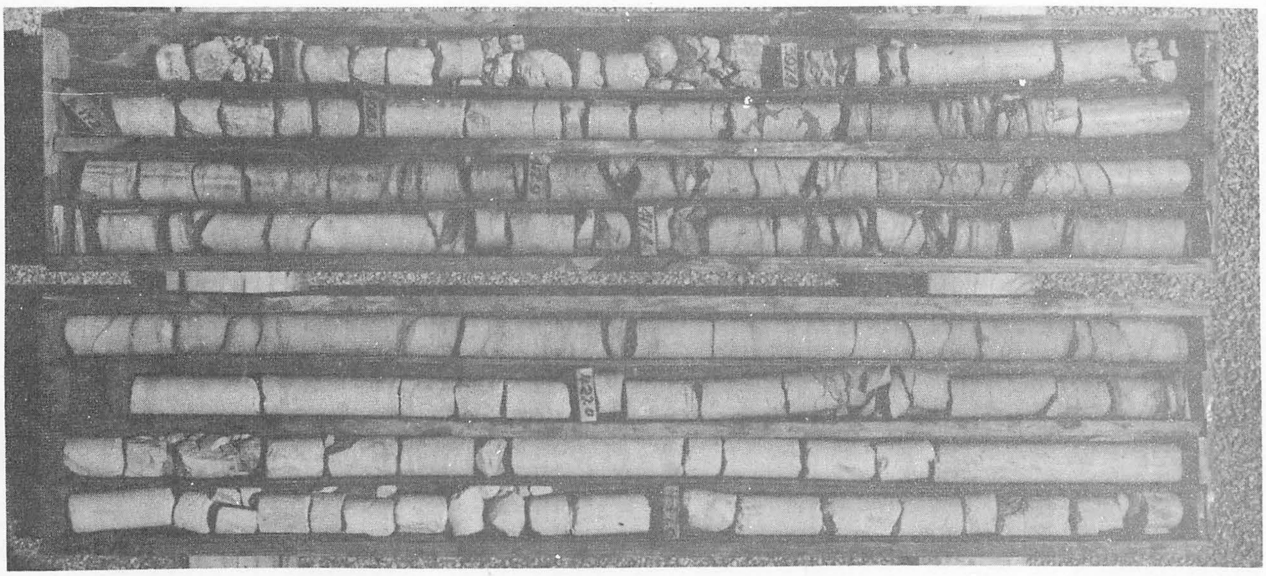
Box 10 through 13; 298.9 to 317.9. Rock bit used from about 296.3 to 298.9. Rock is very hard and generally highly fractured and solutioned in last three boxes.

FIGURE 3

CORE FROM EDWARDS CORE BORING



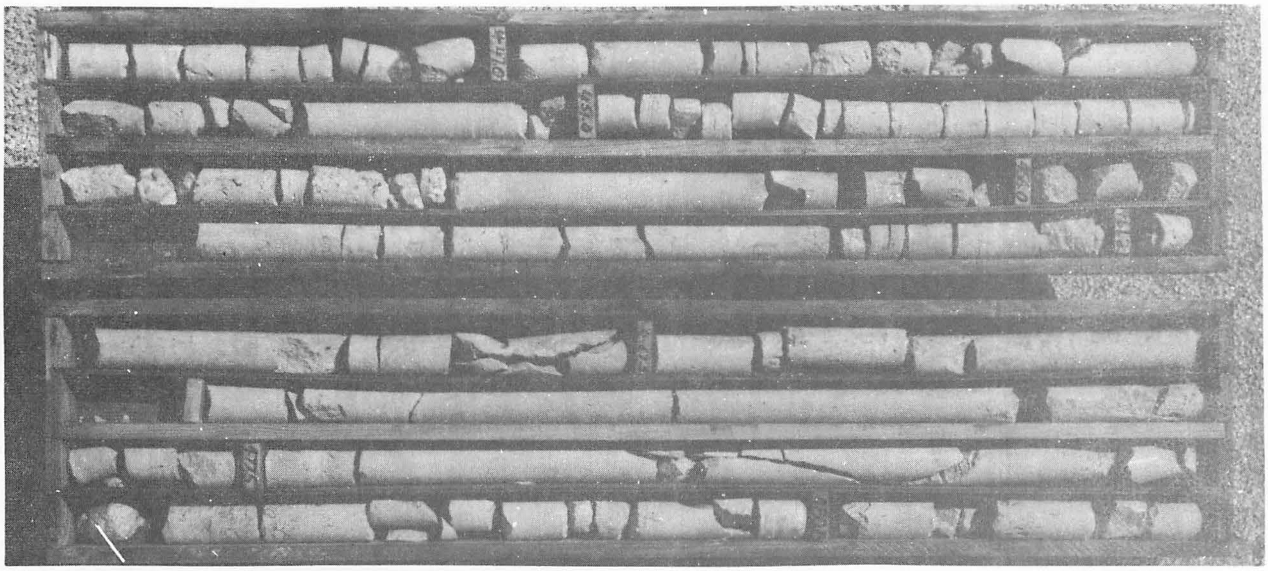
Box 14 and 15; 321.5 to 394.6. Core reduced from 6" to 2". Depth increases from upper right to lower left. Used rock bit from 317.9 to 321.5 and from 325.9 to 332.3. Generally very poor core recovery. Note scattered chert from 359.2 to 360.3.



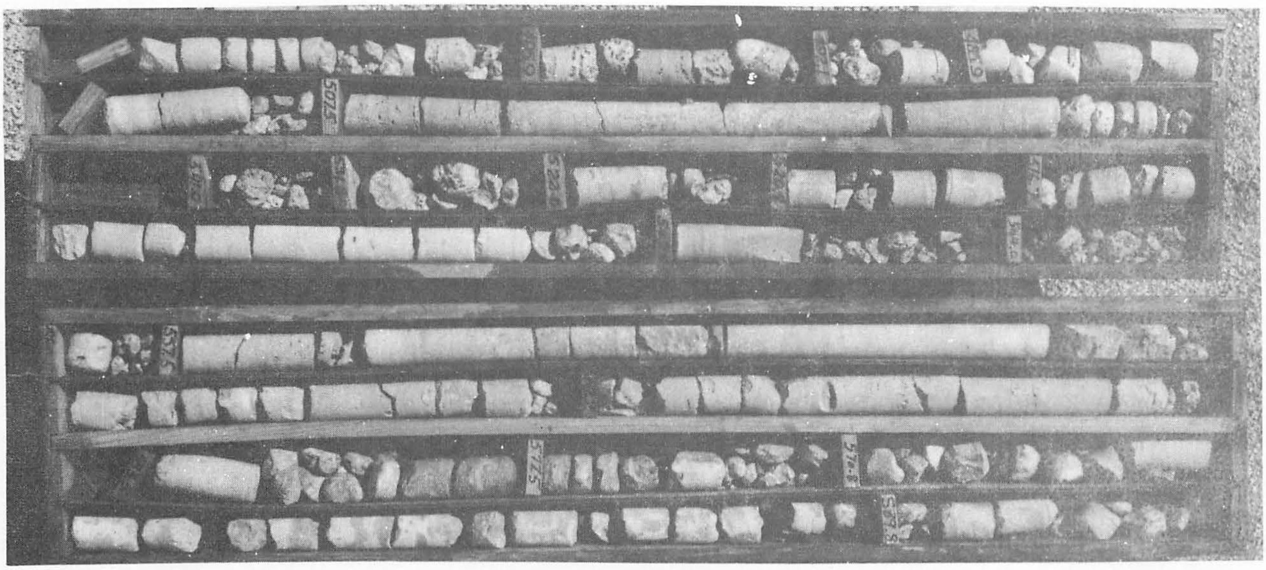
Box 16 and 17; 394.6 to 439.6. Core from 405.0 to 426.2 identified as "Dr. Burton's Ammonite Bed" by Shell Oil Co.

FIGURE 4

CORE FROM EDWARDS CORE BORING



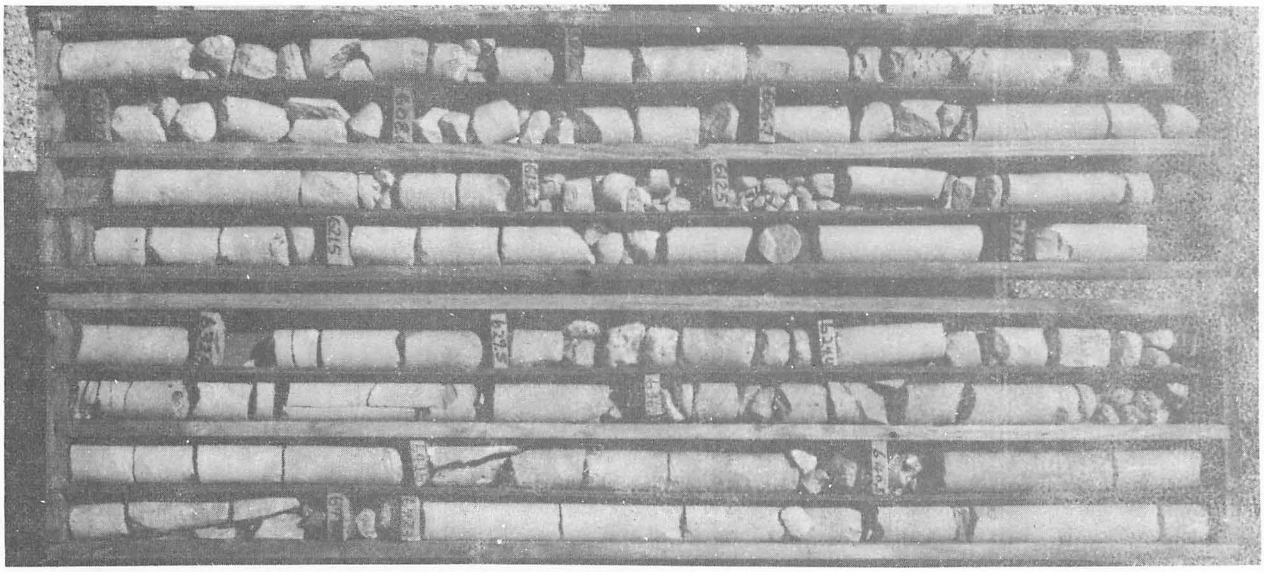
Box 18 and 19; 439.6 to 484.2. Chert nodule at 447.3. Cavity reported from 483.0 to 484.4. Note vertical and near vertical fractures.



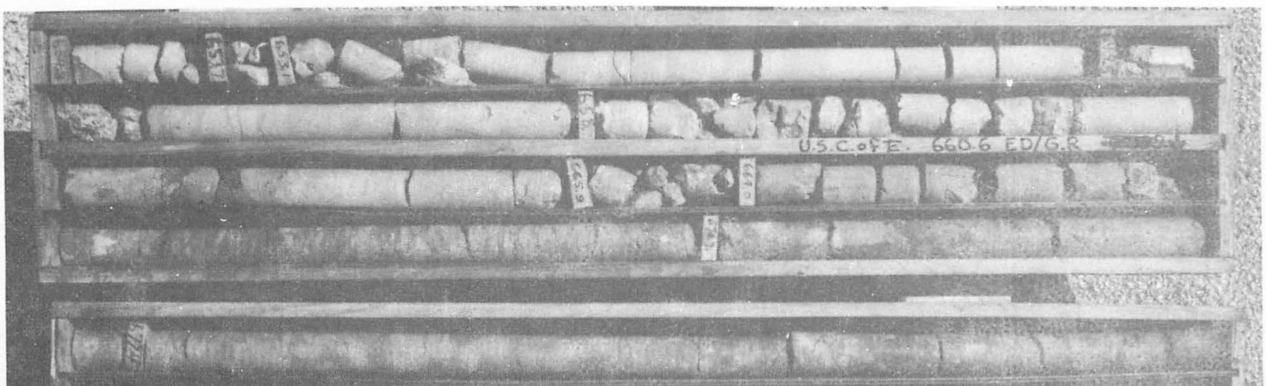
Box 20 and 21; 484.2 to 593.3. Very heavy core loss in this interval. Core in box 20 represents all that was recovered in 66.7 feet of hole. Highly solutioned with cavities up to 2'.

FIGURE 5

CORE FROM EDWARDS CORE BORING



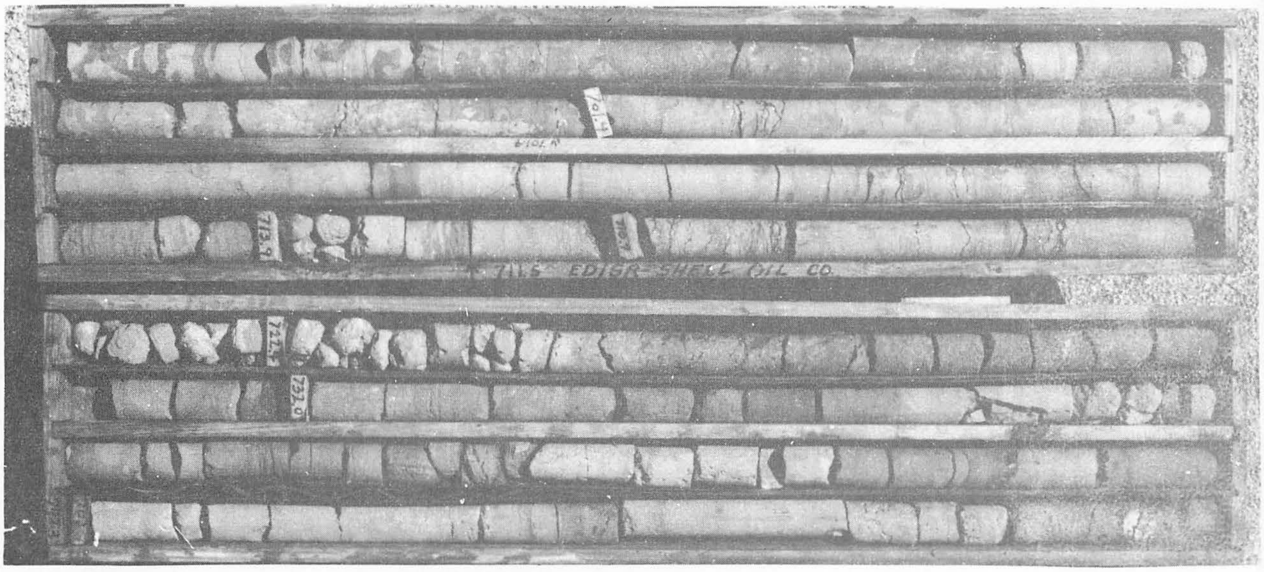
Box 22 and 23; 593.3 to 649.0. Physical characteristics of rock improves considerably at 640.0.



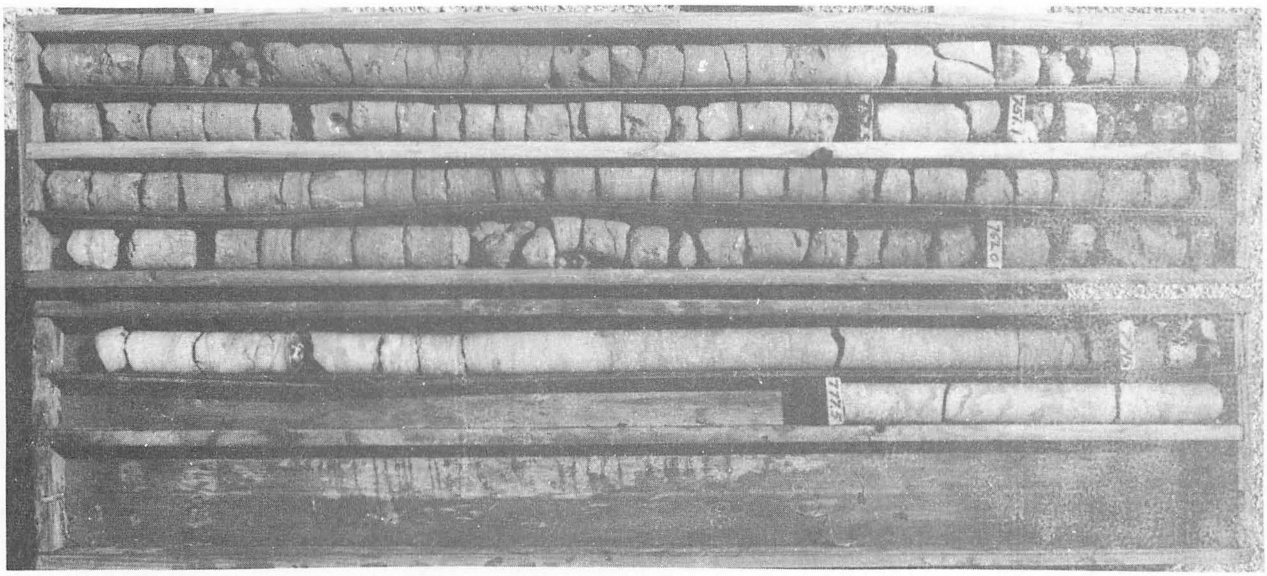
Box 24 and 25; 649.0 to 691.9. Rock below 660.6 is lithologically and hydrologically similar to the Glen Rose. Contact was originally chosen at that depth.

FIGURE 6

CORE FROM EDWARDS CORE BORING



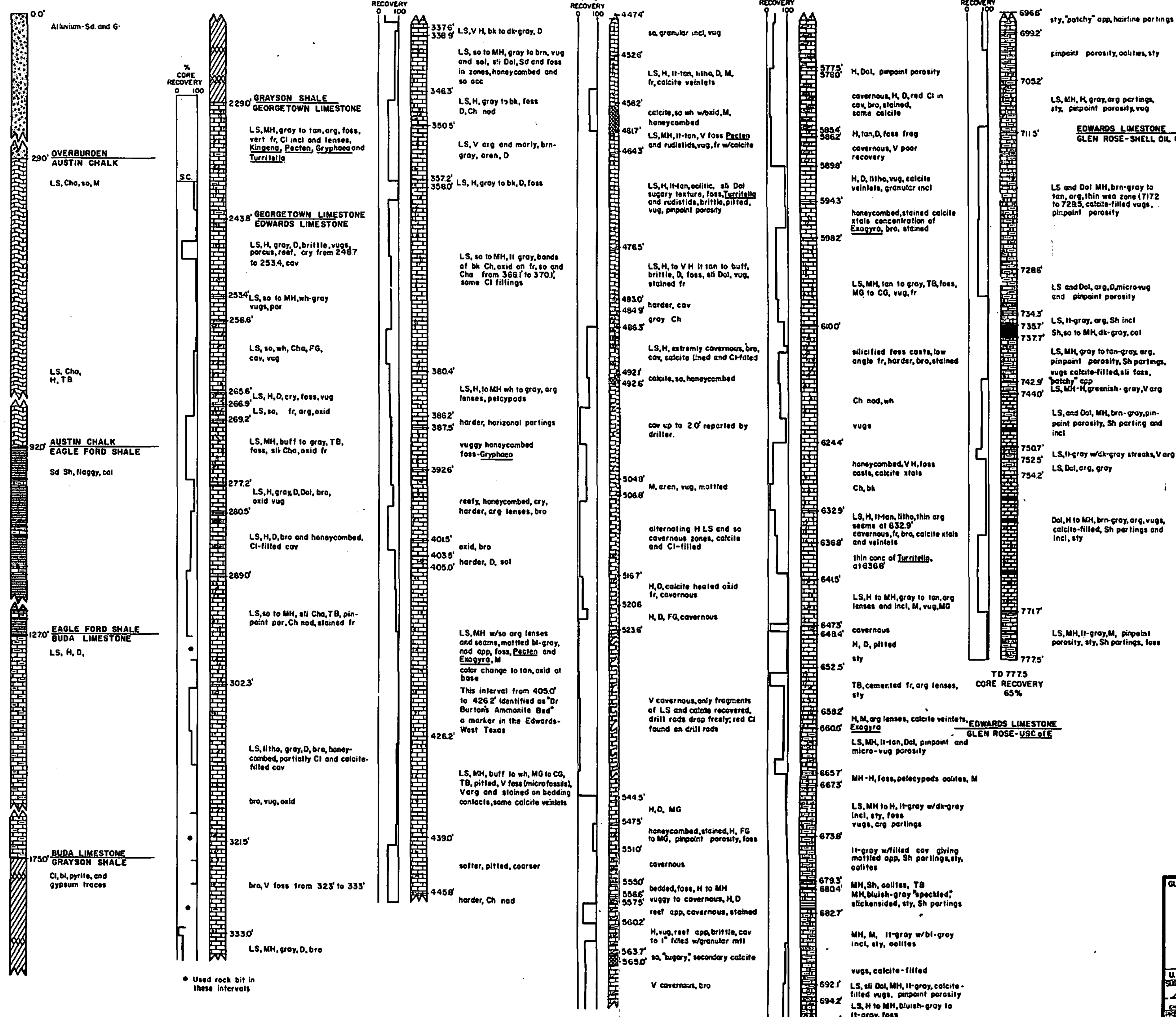
Box 26 and 27; 691.9 to 742.3. Edwards - Glen Rose contact, as selected by representatives of Shell Oil Co., is at 711.5. Interbedded limestone and dolomite below 711.5.



Box 28 and 29; 742.3 to 777.5. Glen Rose limestone. Bottom of hole 777.5.

FIGURE 7

CORE FROM EDWARDS CORE BORING



LEGEND

Gr	Sd
Cl	Cha
Sh or V arg seam	LS
Dol	calcite
foss	sol cav
Ch	wea
fr	

LS	Limestone	litho	Lithographic
dol	Dolomite or Dolomitic	arg	Argillaceous
Sd	Sand or Sandy	cav	Cavity
Gr	Gravel or Gravelly	sol	Solution or Solutioned
Cl	Clay or Clayey	cry	Crystaline
Cha	Chalk or Chalky	fr	Fractures or Fractured
Ch	Chert or Cherty	oxid	Oxidized or oxidation stain
Sh	Shale or Shaly	foss	Fossiliferous
H	Hard	bro	Broken
MH	Moderately Hard	vug	Vugs or Vuggy
so	Soft	D	Dense
V	Very	incl	Inclusions
lt	Light	nod	Nodules
dk	Dark	occ	Occasional
brn	Brown	app	Appearance
bk	Black	xtals	Crystals
wh	White	mtl	Material
bl	Blue	frag	Fragments
TB	Thin-Bedded	sty	Stylolitic
M	Massive	wea	Weathered
FG	Fine-Grained	cal	Calcareous
MG	Medium-Grained	por	Porous
CG	Coarse-Grained	sli	Slightly
SC	Started Coring	conc	Concentration

NOTE:

Core loss column to left of the graphic log does not take into account the areas of extensive solution cavities and voids where no material exists; therefore, although a recovery of only 30% is shown, possibly as much as 80% of the available rock was recovered.
Boring is located in Bexar County on the right bank of Cibolo Creek at the intersection of Evans and Nacogdoches roads.
For a detail of structure (i.e. joints, fractures, etc.) for interval of boring from 238.0 to 480.0, see Plate 4 Photo Log of Edwards Core Boring.

VERTICAL SCALE OF FEET 5 0 5 10

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

LOG OF EDWARDS CORE BORING

SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, CHIEF, PROJECT PLANNING BRANCH	CHIEF, ENGINEERING DIVISION	DISTRICT ENGINEER
PREPARED: CHIEF, FOUNDATION & MATERIALS BRANCH	DRAWN BY: J.L. CHECKED BY: M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE: GUAD. 707-2

CORPS OF ENGINEERS

U.S. ARMY

BORE HOLE PHOTO LOG

Boring No.	Edwards Core Boring
Site	Edwards Underground Reservoir
Location	Selma, Texas
Date photographed	15 October 1963
Hole setting	5-1/2" φ 8.0
Condition of boring	Fair to Poor
Depth photographed	238.0 - 480.0
Hole depth	Above 238.0
Camera condition	Good
Feet casing	0 / 0 / 242.0

Depth	Description
238.0	Start photography
239.0-240.0	Fracture, hairline, tight, strike N30°W, dip 30°SW. Rock appears stained.
240.2-241.2	Multiple fracture zone, rock is stained, hairline, tight to 1/32-inch
	partially open, strike trends N30°W and N60°E, dips 30°SW and 60°NW.
241.5-243.2	Multiple fracture zone hairline, tight to partially open, rock appears
	disturbed, strike trends N40°E to E-W, N45°W, dip 50°-60°SW and vertical.
244.7-245.2	Fracture, hairline, tight, slightly vuggy, some rock is chipped away from
	the fracture plane at 245.1 and 245.2, strike E-W, dip approximately
	vertical.
246.2-247.0	Disturbed zone, rock is broken and weathered, some rock missing due to
	drilling, no orientation.
247.4-248.2	Rock is weathered with vugs up to one inch long.
248.4-249.1	Fracture, hairline, tight, weathered strike N70°E, dip 80°SE.
249.4-264.5	Vuggy zone, rock is slightly to highly weathered.
252.1-254.1	Fracture, hairline, tight, weathered, strike N40°W, dip vertical.
266.5-267.7	Highly vuggy zone.
268.0-272.2	Fracture zone, multiple, weathered, vuggy, hairline, tight to partially
	open. 270.4-270.6 rock is broken and weathered, some rock missing, strike
	trends N30°E, N45°E and N50°E, dip trends 80°SE and vertical.
274.3-274.7	Rock broken, some rock missing.
275.2-275.3	Vuggy zone.
275.2-279.4	Disturbed zone, the rock is weathered, vuggy, broken, fractured, and
	chipped out from wall of the hole.
280.1-289.0	Disturbed zone, rock appears highly weathered and vuggy. 280.1-281.9
	appears to be cavernous with the rock broken back from the walls of the hole.
289.1-290.2	Fracture, hairline, tight, rock is weathered, strike N45°E, dip 60°SW.
290.7-291.9	Zone of rock is chipped out of the wall.
292.7-294.9	Fracture and broken zone, the rock is broken, vuggy, and weathered with
	some rock missing at 293.8 - 294.1. Major strike trend N45°E, dip vertical.
295.6-298.2	Highly weathered and vuggy zone, some rock missing.
298.3-298.9	Fracture, hairline, tight, strike E-W, dip 85°N.
299.2-300.3	Fracture, hairline, tight to partially open, strike N15°E, dip 55°SE.
302.6-304.8	Fracture appears open, approximately 1/16-inch, strike E-W, dip 30°N.
304.3-304.9	Rock missing, some of the rock appears to be broken away from the wall.
305.0-306.7	Disturbed zone, rock is moderately to highly weathered, fractured, broken
	and vuggy, some rock missing, strike trends N5°E, N30°E, and N45°W, dip
	45°W, 60°NW, and 80°NE.
309.7-311.1	Highly weathered, vuggy zone.
311.5-312.5	Vuggy zone.
311.6-312.2	Fracture hairline, tight, strike N-S, dip 80°E, complex and discontinuous.
313.2-313.9	Multiple hairline, tight fractures disappearing into a vuggy, leached zone.
313.9-314.5	Highly weathered and vuggy zone with sandy material within the vugs.
314.5-315.9	Complex fracture zone, hairline, tight to partially open, strike trends
	N60°W, N50°E, dip trends 45°SW and vertical. Sandy material noted in some
	of the vugs and fractures, probably drill cutting.
316.6-326.7	Fracture and broken zone, rock is weathered, vuggy and broken some rock
	missing to 317.3, hairline, tight fractures continue to 318.6 where rock
	becomes badly broken and disturbed, some rock missing. Most of the rock is
	broken back from the original wall of the hole due to the casing being
	pulled from the zone. 325.0-326.0 the rock is not wholly broken back and
	fractured but is partially in place. Grout noted from 317.2-322.8.
326.7-327.4	Rock is vuggy and iron stained.
327.4-328.5	Badly broken zone, no orientation.
329.0-329.7	Badly broken zone, no orientation.
330.2-331.3	Badly broken zone, no orientation.
331.8-332.4	Fracture zone, fracture appears to be associated with an open iron stained
	joint striking N60°E, dipping about 45°SE.
333.1-333.-	Joint, hairline, tight to partially open, some iron staining noted, some
	rock broken away from the joint plane and accompanied by hairline fractures.
	Strike NE, dip 60°E.

Depth		Description
333.7-335.3	Badl	broken zone, no orientation.
335.3-335.8	High	weathered, vuggy, iron stained rock.
335.6-330.0	Brok	and fractured zone, some rock missing, no orientation.
338.0-340.0	Weat	ed, iron stained, vuggy limestone.
356.0-356.3	Join	surrounding rock broken, iron stained, no orientation.
358.9-359.4	Brok	zone, rock is broken away from the walls of the hole, heavily iron
	stai	d.
360.7-360.8	Join	hairline, appears open, heavily iron stained. Strike N75°E, dip
	45°S	Rock has a spotted appearance due to iron stains.
361.6-361.8	Hori	tal joint open 1/16-inch, the rock is badly stained and broken.
362.1-362.-	Rock	broken away from the walls with some fractures noted, heavily
	iron	ained.
364.8-365.0	Join	1/32-inch open, heavily iron stained, some rock broken, strike
	N50°	dip 60°NW.
366.0-366.3	Join	1/1 -inch zone, heavily iron stained, strike N45°E, dip 55°SE.
366.6-367.0	Join	/16-inch open, heavily, iron stained, some rock broken strike N40°E,
	dip	SE.
367.9-368.1	Join	/32-inch open, heavily iron stained, strike approximately EW, dip
	45°W	
368.2-368.3	Join	appears open, rock broken, heavily iron stained, no orientation.
368.6-368.8	Join	appears open, some rock broken, strike N30°W, dip about 45°SW.
369.0-370.9	Brok	zone, heavily iron stained, rock broken away from the walls, no
373.5-373.8	Distu	ed zone, heavily iron stained, no orientation.
374.3-374.8	Joint	open, up to 1/16-inch, the rock is broken around the joint plane and
	is he	ily iron stained. Strike N70°E, dip 45°SE.
375.4-376.4	Broke	and fractured zone, some rock broken back from the walls of the hole.
	One f	cture is hairline, open, some staining noted, strike N50°E,
	dip v	tical.
379.2	Horiz	tal, open, iron stained joint.
380.0-380.5	Broke	zone, heavily iron stained, no orientation.
380.7	Joint	horizontal, appears open, heavily stained.
381.5-381.6	Low a	le irregular, iron stained joint, open.
383.2-383.7	Broke	zone, some rock missing, highly iron stained, no orientation.
384.0-384.5	As ab	e.
385.7-385.9	Horiz	tal joint, open, about 1/4-inch highly iron stained, some rock
	broke	
386.1	As ab	e (open about 1/16-inch).
386.2-386.4	Joint	open, highly iron stained, the rock is broken around the joint plane,
	strik	N45°E, dip 30°NW.
386.5-386.7	Joint	open about 1/16-inch, highly iron stained, strike N50°W, unable to
	deter	ne dip.
387.3	Horiz	tal, open, iron stained joint.
387.6-387.1	Joint	open, 1/32-inch, iron stained, strike N60°E, dip 45°SE.
388.1	Horiz	tal, open, 1/16-inch, iron stained joint.
388.3-393.4	Hairl	e, iron stained joint leading to a 4.5 foot cavity. An occasional
	porti	of rock would show up out of focus back in the cavity.
394.0-394.5	Joint	as 1/16-inch, highly iron stained, strike N30°E, dip 60°SE.
394.9-395.7	Broke	zone, the rock is highly iron stained and broken, no orientation.
396.7-398.6	Verti	l joint, rock broken away from walls at 396.7-397.4 and 398.2 -
	398.6	strike EW, dip vertical, highly iron stained.
399.3-399.6	Broke	zone, no orientation.
400.7-401.0	Broke	zone, no orientation.
401.5-402.1	Broke	zone, no orientation.
402.9-404.0	Broke	zone, no orientation.
404.7-405.8	Broke	zone, no orientation.
406.6	Horiz	al joint, open, iron stained.
406.8	Horiz	al joint, open, iron stained.
407.6	Horiz	al joint, open, iron stained.
408.0-408.4	Joint	were open and iron stained.
408.6	Horiz	al joint, open, iron stained.
408.7-408.8	Joint	low angle, appears open and iron stained.
410.5-410.8	Distu	d zone, iron staining noted.
412.0-412.1	Broke	zone, iron stained.
416.2-416.3	As ab	

Depth	Description
426.2-426.3	Joint, tight, strike EW, unable to determine dip.
426.6	Horizontal joint, iron stained, some rock broken.
426.6	As above.
427.1-427.2	Broken zone, highly iron stained, no orientation, appears open.
429.2	Joint, open, iron stained, horizontal, description of the rock from 409.0
	-431 may appear vague, but it is due to the mirror in the camera being
	fogged over causing the pictures to be hazy.
430.8	Horizontal, iron stained, joint.
431.7	Horizontal, open, iron stained, joint.
432.8-432.9	Joint, irregular, hairline, tight, iron stained.
433.1-436.7	Hairline, tight, fracture zone.
435.4	Joint, horizontal, open, iron stained.
439.4	Joint, horizontal, open, iron stained.
441.7-443.1	Joint, complex, tight to partially open, highly iron stained, some rock
	broken, strike N05°E, dip vertical.
443.3-445.5	Joint, tight to partially open, highly iron stained.
447.4-447.5	Rock is chipped away from the wall.
448.7-448.8	Joint, hairline to partially open, rock broken, some rock missing, highly
	iron stained, strike N50°E, dip 45°SE.
451.5	Joint, horizontal, appears open, and highly iron stained.
453.1-454.6	Multiple joints, hairline, tight to 1/32-inch open, highly iron stained,
	strike trends N15°E, S15°E, and N60°E, dip trends 60°SE, 70°SE, and 60°SE.
455.0-455.1	Fractured and broken zone, appears open, heavily iron stained, no orientation
455.6	Joint, horizontal, hairline and iron stained.
455.8-456.2	Joint, hairline, discontinuous, iron stained, strike N45°E, dip vertical.
456.7-457.1	Fracture, hairline, tight, strike N50°E, dip 75°NW.
457.4-461.2	Rock changes to a highly vuggy, leached iron stained material.
457.6	Joint, horizontal, open, highly iron stained.
460.8-461.5	Joint, 1/32-inch open, highly iron stained, strike N45°E, dip about vertical
462.1	Joint, open, horizontal, highly iron stained.
462.3-462.5	Broken zone, appears open, highly iron stained, no orientation.
465.6-466.1	Joint, hairline, tight, strike N60°E, dip 70°NW.
466.2	Joint, horizontal, appears open, highly iron stained.
466.3-467.0	Vuggy, iron stained zone, containing a partially open joint from 466.7 -
	466.9, strike N75°E, dip approximately vertical.
467.6-470.7	Multiple complex joints, hairline to 1/32-inch open, some filled with drill
	cuttings, strike trends N60°E and NW that changes to N60°E then to N70°E,
	dip vertical.
472.5-475.3	Multiple, complex, joint zone becoming a broken zone at 477.1 - 477.8. The
	joints range from hairline tight to 1/32-inch open, highly iron stained
	with some of the surrounding rock being broken. (Cont'd)
472.5-475.3	Strike trends N45°E to N70°E to NW, dip trends about vertical. No orienta-
(Cont'd)	tion within the broken zone or the 0.5 foot section below 477.1 - 478.1.
478.5-480.0	Broken zone, appears open, highly iron stained, no orientation.
	Bottom @ 480.00

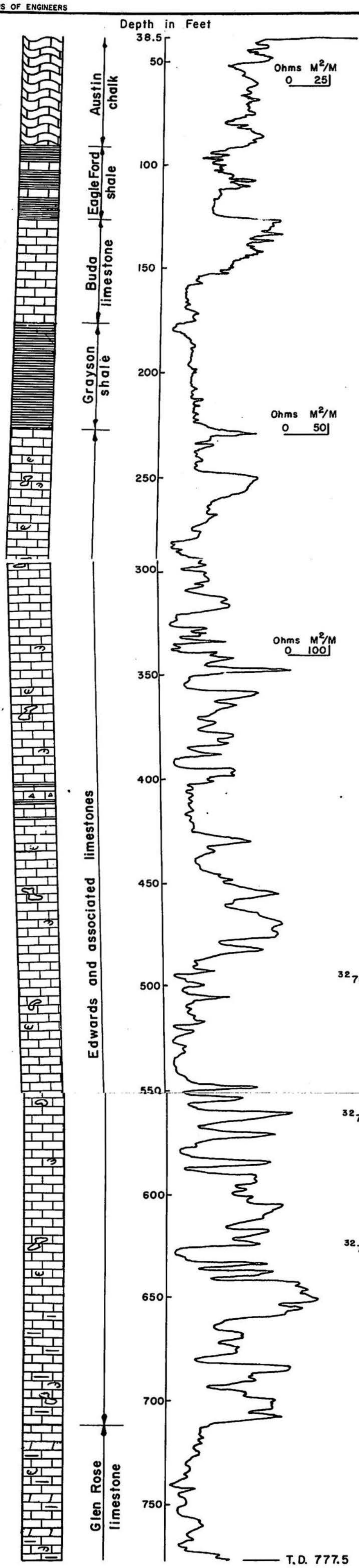
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

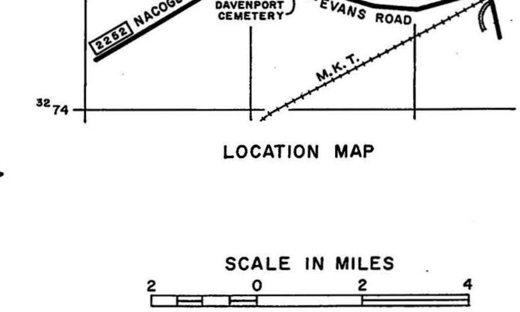
EDWARDS UNDERGROUND RESERVOIR

PHOTO LOG OF EDWARDS CORE BORING

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
Chief, Project Planning Branch	Chief, Engineering Division	District Engineer
PREPARED: Chief, Foundation & Materials Br.	DRAWN BY T.L.M.B. / CHECKED BY M.O.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2





LOCATION MAP

EDWARDS UNDERGROUND RESERVOIR

ELECTRIC LOG OF
EDWARDS CORE BORING

DEC. 1964 PLATE 5

26. MEDINA DAM.

a. Introduction.- Medina Dam is a concrete gravity structure located on the Medina River about 14 miles north of Castroville, Texas. The spillway, 1200 feet long, is located over a saddle on the right abutment and spills into an adjoining ravine. Construction on the dam was commenced in late 1911 and completed in late 1912 to a height of 164 feet. The dam has a crest width of 25 feet, a base width of 128 feet, and a length of 1580 feet. The structure contains almost 300,000 cubic yards of concrete. Plans show a core trench with 1-1/4-inch holes on 6-foot centers "grouted with neat cement under pressure"; however, no data are available on the quantities of grout used or the number of holes required. The Diversion Dam, located about 4 miles downstream, is an overflow weir with ogee crest and rollway. The structure is 50 feet high, 44 feet wide at the base, 440 feet long, and is arched slightly upstream.

(1) Both structures are infamous because of the leakage from the reservoirs contained by the dams. It has been estimated that an average of 42,700 acre-feet of water were lost annually by leakage from the Medina Lake and Diversion Dam Lake for the period from 1935 to 1956. 4/

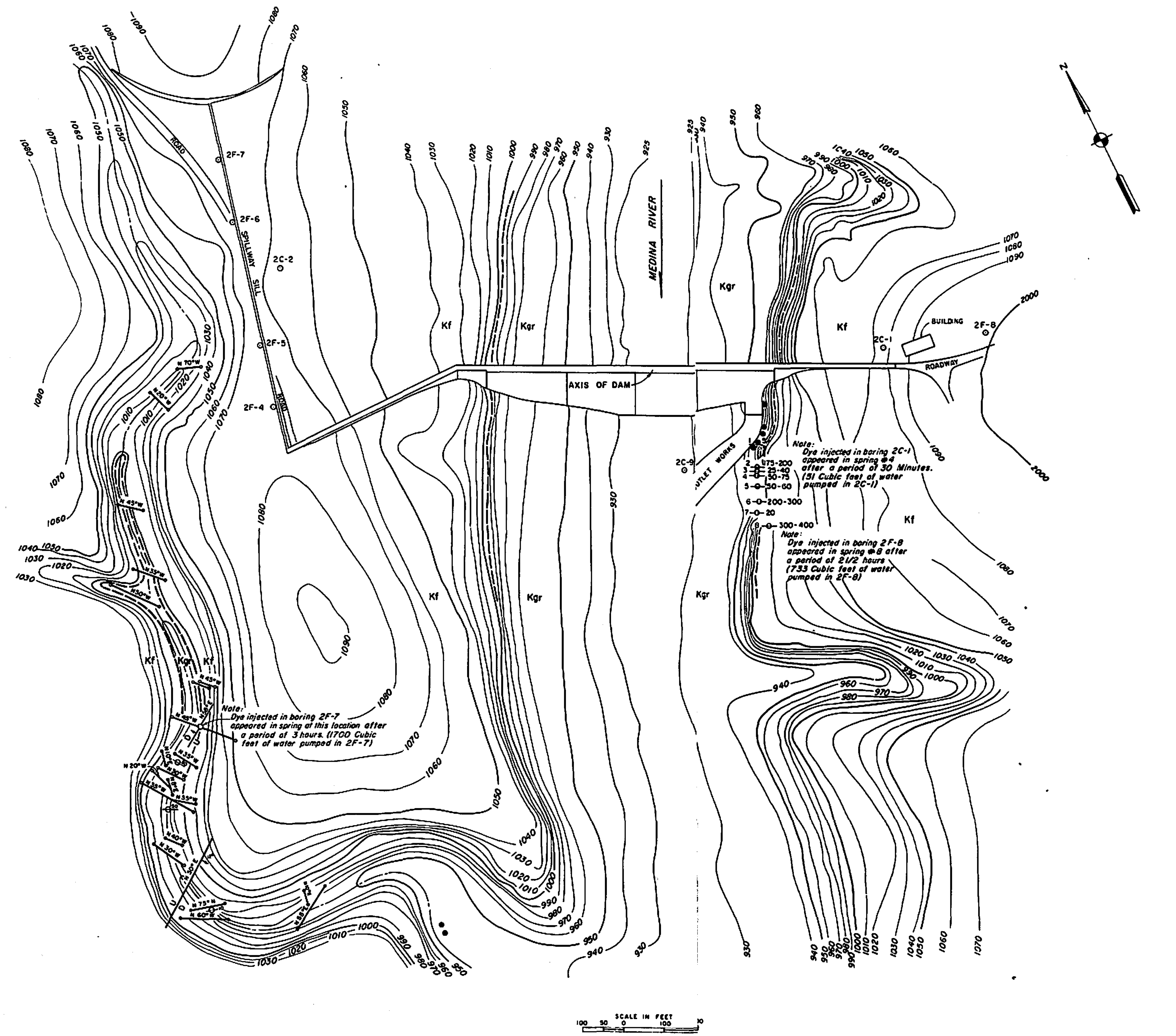
b. General Geology.- Medina Dam is founded on the Glen Rose limestone, Walnut clay, Comanche Peak limestone, and Edwards limestone. The Glen Rose, an argillaceous, thin- to medium-bedded limestone with thin interbeds of clay and shale, crops out in the river valley and in the canyon walls to about elevation 1000 (see plate 6). The Walnut clay, a tan to gray, soft to moderately hard, argillaceous limestone bed, approximately 12 to 14 feet thick, overlies the Glen Rose. The rock is distinguished by an abundance of *Exogyra* scattered throughout. The Comanche Peak limestone, about 37 feet thick at the dam, is composed of a soft to moderately hard, fossiliferous limestone. Lithologically the rock is very similar to the overlying Edwards except the Edwards is generally more crystalline and massive, and contains chert nodules and lenses.

(1) All of the rock in the vicinity of Medina Dam, from the Glen Rose limestone through the Edwards limestone, has been rather extensively jointed and fractured due to their proximity to the Balcones fault zone. Solutioning is well developed along these features as witnessed by rather spectacular springflows in the spillway discharge channel and along the river bluff in the left abutment downstream from the dam. From observations over the past year it has been noted that the volume of springflow appears to be directly proportional to the storage in the reservoir. Two sets of joints have been identified in the area: (1) a primary or predominant set trends about N35°W to N50°W, and (2) a near normal set trending about N50° E to N58° E,

roughly parallel the faulting in the Balcones fault zone (see plate 6). Two minor faults with 6 to 8 feet of displacement were mapped in the discharge channel.

c. Investigations.- The feasibility of reducing leakage from Medina Reservoir has been explored by (1) geologic mapping, (2) core and "fishtail" borings, (3) electric logs, (4) water pressure tests, and (5) dye injection tests. The geology and structure were mapped in the vicinity of the dam and in the spillway discharge channel to develop the principal joint and fracture pattern and to define the formational contacts; three 2-inch diameter core holes, one on each abutment and one in the river channel below the dam, were cored to depths variable from 100 to 163 feet to study the physical characteristics of the bedrock and to locate formational contacts; five holes were "fishtailed" to a depth of 175 feet and water pressure tested in 10-foot increments to define the zones of high permeability; E-logs were made in all eight borings for correlation purposes; and dye tests, using a fluorescein dye, were conducted in one spillway hole, 2F-7, and two left abutment holes, 2C-1 and 2F-8, to determine if communication could be established with springs below the dam. The results of these investigations are shown on plate 6, Geology, plate 7, Plan and Geologic Profiles, and plate 8, Logs of Borings, and discussed in the following paragraphs.

d. Results of investigations.- As previously noted, the limestones at Medina Dam are generally highly jointed and fractured, and leakage is associated primarily with an interconnected system of joints, fractures, and bedding planes which act as conduits between the reservoir and springflow. Water pressure tests conducted in all of the borings showed the rock to be generally tight except where joints and fractures were encountered. Additional evidence of the interconnection of the joint system was evidenced from the results of the dye tests. After introducing dye and pumping about 1700 cubic feet of water over a three-hour period in boring 2F-7 in the spillway saddle, dye appeared in a spring in the spillway channel some 1350 feet south of the hole. The water was pumped in the hole between the depths of 108.8 feet and 120.0 feet. Similar results were obtained with dye tests in two borings on the left abutment. Dye was introduced in boring 2C-1 below a depth of 80 feet and, after pumping 30 minutes at a rate of about 1.7 cubic feet per minute, dye emitted from spring No. 4, located approximately 430 feet southwest of 2C-1. Dye introduced in 2F-8 appeared in spring No. 8, about 700 feet south of the hole after pumping about 733 cubic feet of water in the boring below a depth of 55 feet over a 2-1/2-hour period. These tests show that the springs contiguous to and downstream from the abutments have direct communication with the reservoir through interconnected joints and fractures. Assuming that this condition also exists in the foundation rock, it appears that very large volumes of water can be lost through open jointing, especially under full or high reservoir head.



LEGEND

LOWER CRETACEOUS

FREDERICKSBURG GROUP — Kf — FREDERICKSBURG GROUP UNDIFFERENTIATED. INCLUDES WALNUT CLAY, COMANCHE PEAK & EDWARDS LIMESTONES

TRINITY GROUP — Kgr — GLEN ROSE LIMESTONE

CRETACEOUS

GEOLOGIC CONTACT

KNOWN FAULTS SHOWING UP AND DOWN SIDE, DIP AS INDICATED

VERTICAL FRACTURE JOINTS WITH STRIKE INDICATED

SPRING WITH LESS THAN 1 GPM LEAKAGE

SPRINGS INDICATING LEAKAGE IN GPM

CORE, PRESSURE TEST & ELECTRIC LOG BORING

NOTES:

1 Elevations and contours shown are those determined by owner at time of construction.

2 All elevations should be reduced by 7.5 feet to conform to mean sea level datum.

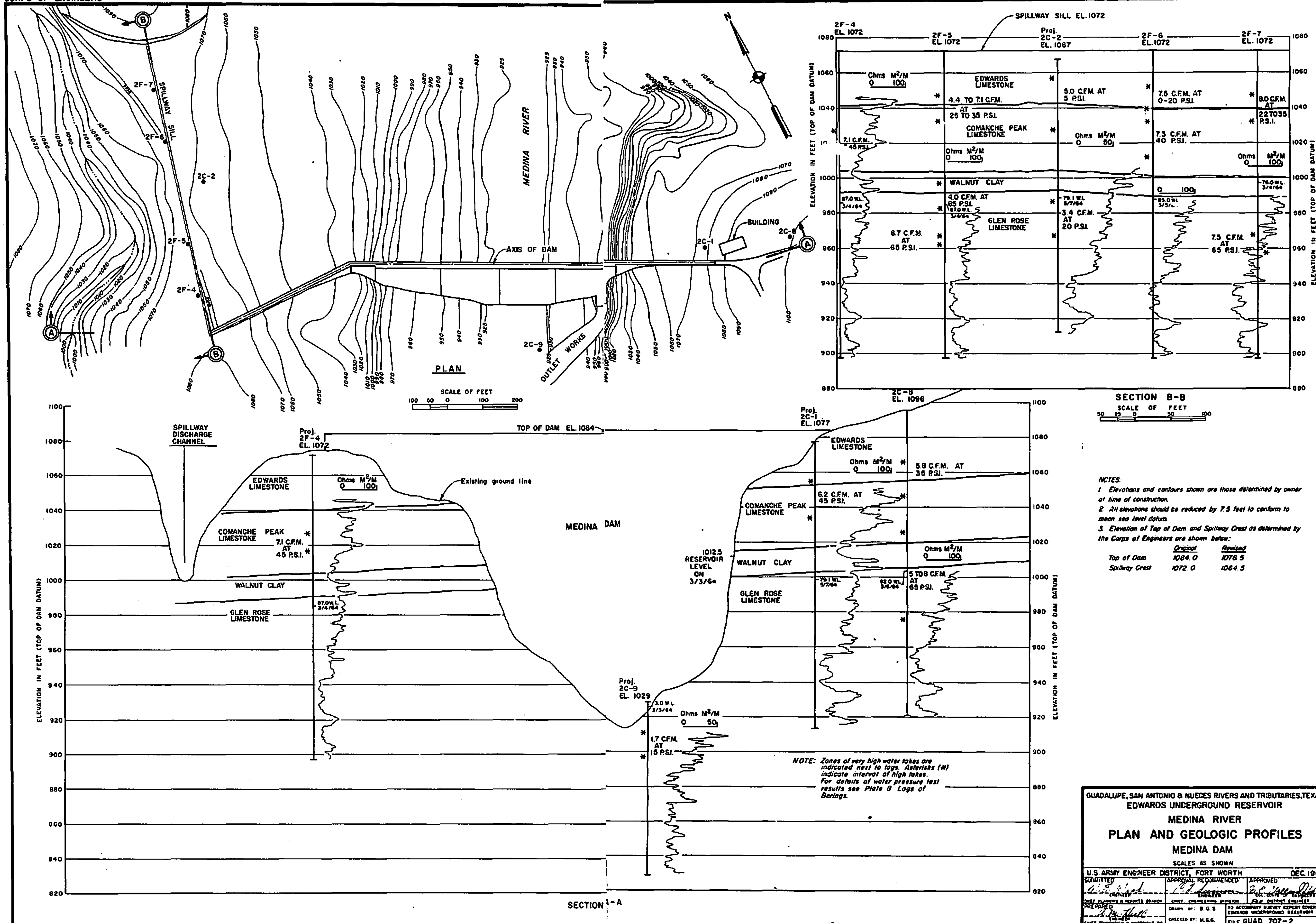
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

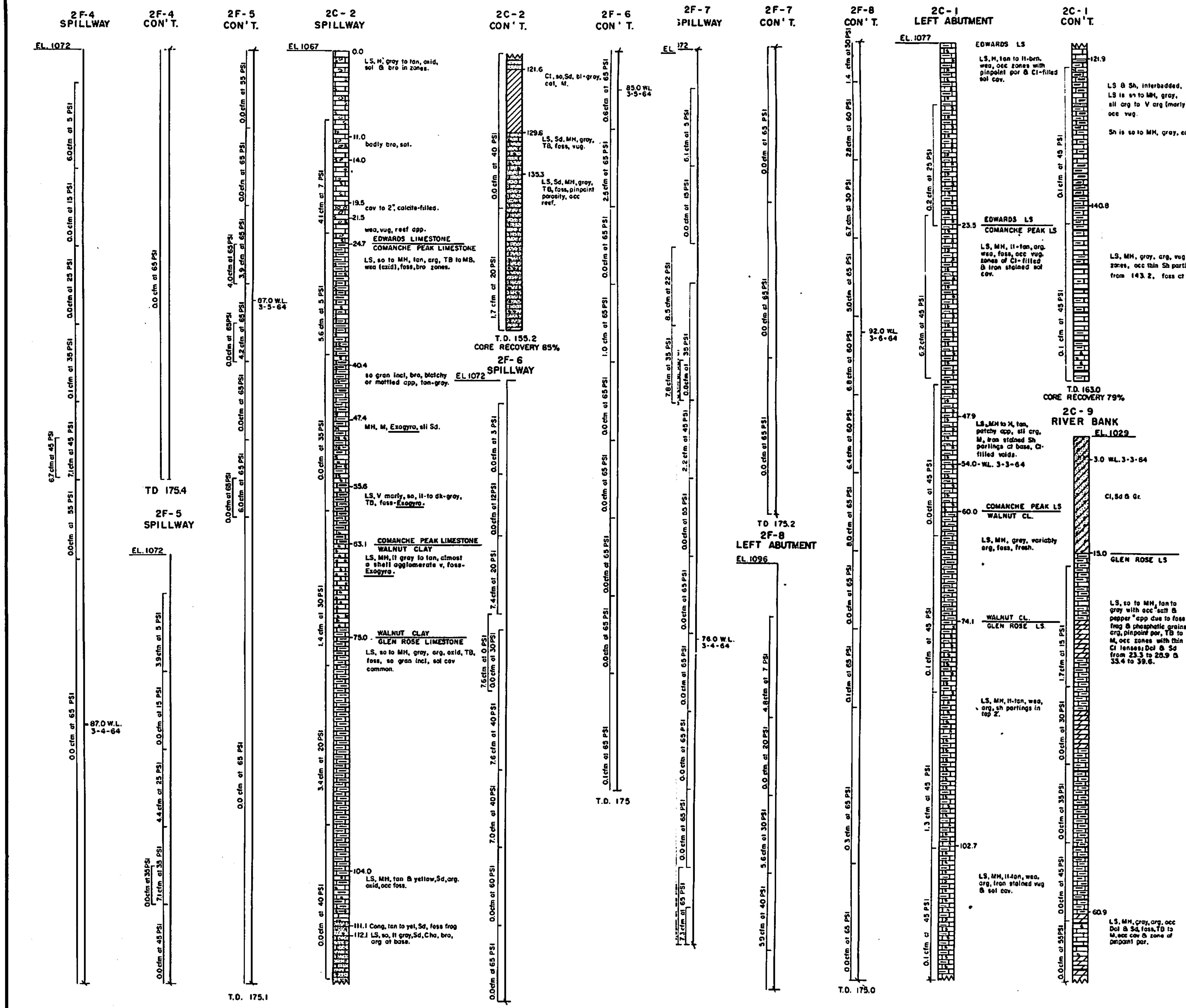
EDWARDS UNDERGROUND RESERVOIR

MEDINA RIVER
GEOLOGY
MEDINA DAM

SCALES AS SHOWN

U.S. ARMY ENGINEER DISTRICT, FORT WORTH		DEC. 1964
SUBMITTED: ENGINEER, CHIEF, PLANNING & REPORTS BRANCH	APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION	APPROVED: LT. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF, FOUNDATION & MATERIALS BR.	DRAWN BY A.M.F. CHECKED BY M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR FILE GUAD 707-2


PLAN
SCALE OF FEET
SPILLWAY SILL
AXIS OF DAM
MEDINA RIVER
OUTLET WORKS
BUILDING
SECTION B-B
SPILLWAY SILL EL. 1072
2F-4 EL. 1072
2F-5 EL. 1072
Proj. 2C-2 EL. 1067
2F-6 EL. 1072
2F-7 EL. 1072
EDWARDS LIMESTONE
COMANCHE PEAK LIMESTONE
WALNUT CLAY
GLEN ROSE LIMESTONE
ELEVATION IN FEET (TOP OF DAM DATUM)
SECTION A-A
TOP OF DAM EL. 1084
SPILLWAY DISCHARGE CHANNEL
Existing ground line
MEDINA DAM
1012.5 RESERVOIR LEVEL ON 3/3/64
Proj. 2C-9 EL. 1029
Proj. 2C-1 EL. 1077
2C-8 EL. 1096
NOTE: Zones of very high water takes are indicated next to logs. Asterisks (*) indicate interval of high takes. For details of water pressure test results see Plate 8 Logs of Borings.
NOTES:
1 Elevations and contours shown are those determined by owner at time of construction.
2 All elevations should be reduced by 7.5 feet to conform to mean sea level datum.
3 Elevation of Top of Dam and Spillway Crest as determined by the Corps of Engineers are shown below:
Original Revised
Top of Dam 1084.0 1076.5
Spillway Crest 1072.0 1064.5
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
MEDINA RIVER
PLAN AND GEOLOGIC PROFILES
MEDINA DAM
SCALES AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
DRAWN BY: B. G. S.
CHECKED BY: M.G.G.
FILE GUAD. 707-2



LEGEND

Abbr.	Meaning
Cl	Clay or Clayey
Sd	Sand or Sandy
Gr	Gravel or Gravelly
LS	Limestone
Cha	Chalk or Chalky
Cong	Conglomerate
Dol	Dolomite or Dolomitic
Sh	Shale or Shaly
so	Soft
MH	Moderately Hard
H	Hard
V	Very
bl	Blue
yel	Yellow
brn	Brown
lt	Light
TB	Thin-bedded
MB	Medium-bedded
M	Massive
arg	Argillaceous
wea	Weathered
foss	Fossiliferous
vug	Vug or Vuggy
sol	Solution or Solutioned
cav	Cavity
sli	Slightly
app	Appearance
por	Porosity
gran	Granular
incl	Inclusions
occ	Occasionally
oxid	Oxidation or Oxidized
bro	Broken
cal	Calcareous
T.D.	Total Depth
W.L.	Water Level

OVERBURDEN

Cl, Sd, Gr

PRIMARY MATERIAL

LS
Arg LS
CL
Sh
Dol
Cong
Wea
Foss

PRESSURE TESTS RESULTS & DATA

1.4 cfm at 30 PSI — 1.4 Cubic feet per minute leakage at 30 pounds per square inch gauge pressure. Brackets indicate interval of boring tested.

2C = 2" Core boring
2F = 2" Fishtail boring

NOTES:
1. See plate 6 for location of borings
2. All elevations should be reduced by 7.5 feet to conform to mean sea level datum

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX

EDWARDS UNDERGROUND RESERVOIR

MEDINA RIVER

LOGS OF BORINGS

MEDINA DAM

SCALES AS SHOWN

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

SUBMITTED: Chief, Project Planning Branch
APPROVAL RECOMMENDED: Chief, Engineering Division
APPROVED: District Engineer
PREPARED: Chief, Foundation & Materials Br.
DRAWN BY A.M.F.
CHECKED BY M.G.G.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2

e. Conclusions and recommendations.- Based on the subsurface exploration and surface observations made at Medina Dam to date, it would appear that a comprehensive grouting program could reduce leakage from Medina Lake. However, to determine the effectiveness and cost of such a program, a detailed and comprehensive investigation would be needed. For example, additional ground-water studies would be necessary to determine the relationship of possible adjoining ground-water divides; subsurface and structural investigations would be necessary to delimit possible faulting and its relation to the presently recognized jointing; and detailed geologic mapping of the reservoir would be required to develop the pertinent surface characteristics.

27. RADIOACTIVE TRACER STUDY.- An investigation of laboratory and other scientific methods for obtaining information regarding movement of underground waters revealed that satisfactory results could be obtained 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 isotpoe of hydrogen. This natural isotope of hydrogen, which is present in the atmosphere and in water at all times, is produced by interaction of the atmosphere with cosmic rays from the sun. Its concentration, however, has been increased in the past few years by the nuclear bomb testing programs. This radioactive tritium appears in the water and atmosphere in only minute quantities and is not hazardous to human or animal life. Tritium 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. The use of natural properties of water molecules in underground reservoir tracer studies is recognized as being superior to the introduction of artificial dyes or other chemicals.

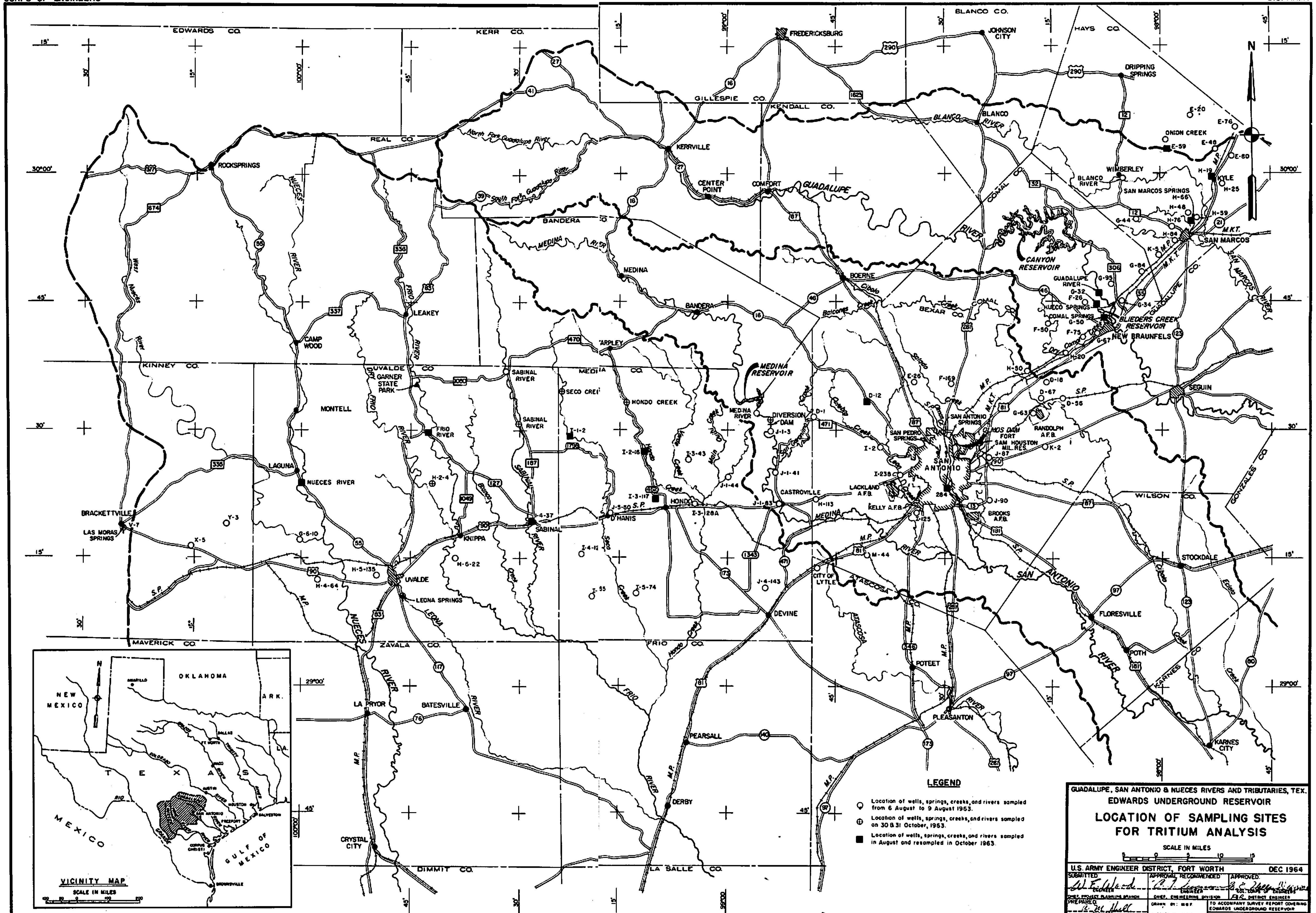
28. To learn how effective tritium can be in studying the movement of water in the Edwards Underground Reservoir, the Fort Worth District entered into a contract with Isotopes, Inc., of Westwood, New Jersey, in early 1963 to perform a localized pilot test program using natural tritium measurements. The procedures to be employed called for three initial samples, one each from the Nueces and Medina Rivers and Comal Springs, to be analyzed to determine the natural basic tritium count over the area. After it was determined the tritium count in the area could be measured, a program of sampling was planned by the Fort Worth District, in cooperation with the U. S. Geological Survey, calling for approximately 100 samples from wells, springs, and rivers. The samples were collected in two stages; the first set prior to a rainy season and

the second set after the rains. Unfortunately, the anticipated heavy rains did not come although there was some minor precipitation in the area in late October and early November 1963. A total of 94 samples was collected in August and November of 1963 and forwarded to Isotopes, Inc., for analysis. The location of the sampling sites is shown on plate 9.

29. Only 13 of the 75 wells sampled had a measurable quantity of tritium without enriching the samples by an electrolytical process. Therefore, in order for a detailed study to be conducted, the laboratory equipment would have to be refined so that lower counts of tritium could be measured (communications with Isotopes, Inc., inform that equipment is presently being modified to measure as little as 15 tritium units) or the samples would have to be enriched. Because of the lack of traceable tritium in many of the samples, the results of the investigation are not conclusive. It is generally felt, however, that the measurement of natural tritium in the water can resolve many recharge/discharge problems. Velocities and flow paths can be determined by means of an artificial injection program whereby known quantities of tritium can be injected into the reservoir and traced throughout their course. The method suggested would be to start artificial injection around an area of large discharge such as Comal Springs, then work in increments setting up measuring stations for injection along the gradient of the reservoir. It is not known how long such a program would require.

30. Based on the initial work by Isotopes, Inc., it is believed that radioactive tracer studies can be successfully utilized to resolve problems not as yet fully understood about the hydrology of the Edwards Underground Reservoir. The report by Isotopes, Inc., entitled, "Technical Report Tritium Analyses on Surface, Spring, and Well Water from the San Antonio Area, Texas," is included as an attachment to this appendix.

31. SILTATION.- A review of available information concerning the effect of siltation as related to recharge areas (solution channels, joints, fractures, and faults) does not suggest that reservoir siltation will seriously impair existing recharge capabilities. It is recognized that the streams in the Edwards Plateau carry a considerable volume of suspended solids during flood stages and that at least a portion of this material is deposited into openings through which recharge water infiltrates. This is very much evident in Uvalde County where small recharge projects were successful only after the large rock openings were protected with steel grates to keep out trash (vegetation) and rock material carried by the runoff water. However, this condition is not typical as the streams carry very little material during normal flow and only in isolated cases will large openings be available. More typical are the many small, sometimes minute, joints, fractures, and solution channels in the rock. Although silting could conceivably

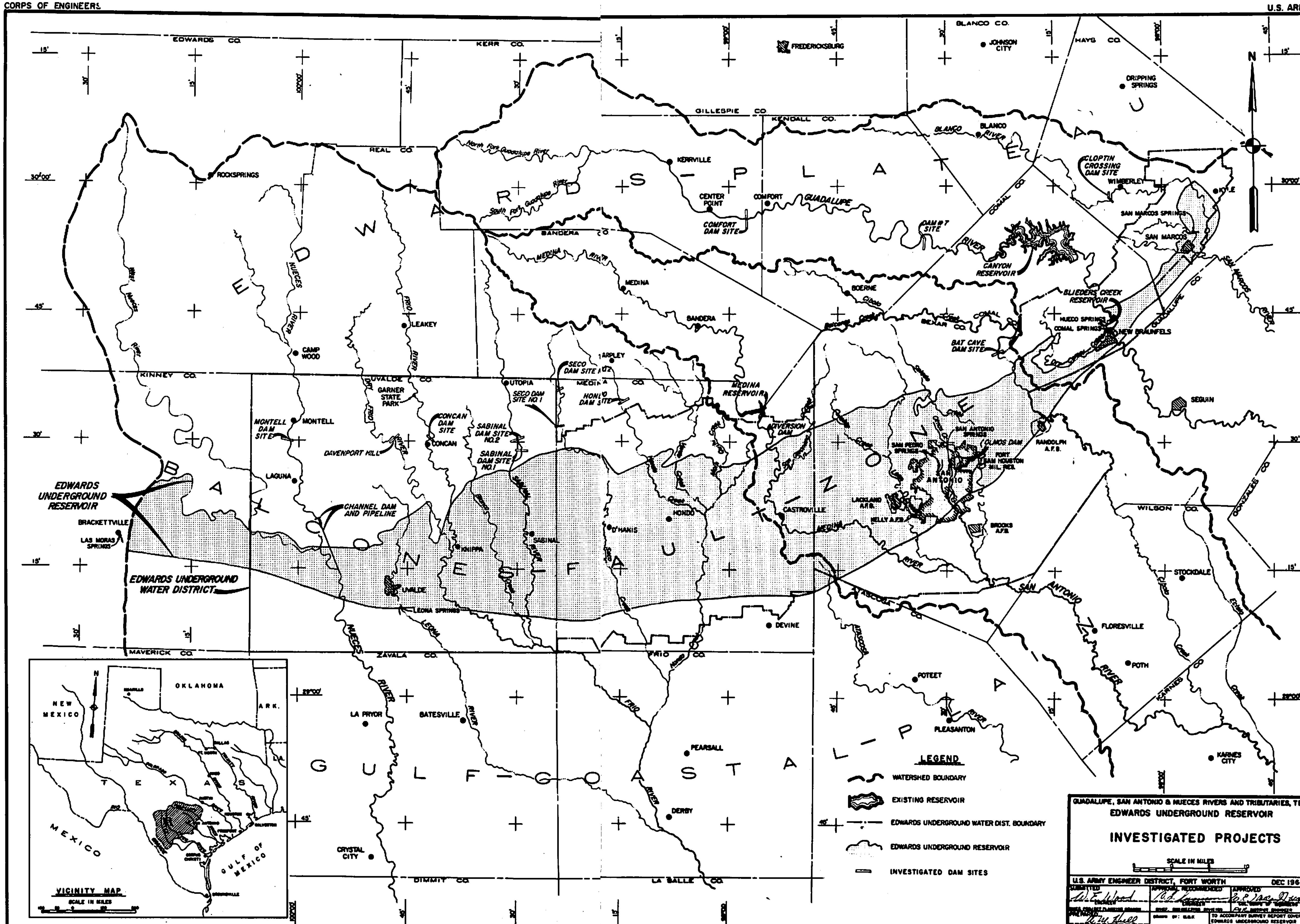

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
LOCATION OF SAMPLING SITES FOR TRITIUM ANALYSIS
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
DRAWN BY: MEF
CHECKED BY: MAR
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 707-2
LEGEND
Location of wells, springs, creeks, and rivers sampled from 6 August to 9 August 1963.
Location of wells, springs, creeks, and rivers sampled on 30 & 31 October, 1963.
Location of wells, springs, creeks, and rivers sampled in August and resampled in October 1963.
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
EDWARDS CO.
KERR CO.
BLANCO CO.
HAYS CO.
GILLESPIE CO.
KENDALL CO.
REAL CO.
BANDERA CO.
KINNEY CO.
UVALDE CO.
MEDINA CO.
BEXAR CO.
COMAL CO.
GUADALUPE CO.
WILSON CO.
GONZALES CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
ATASCOSA CO.
KARNES CO.
DIMMIT CO.
LA SALLE CO.
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
KERRVILLE
CENTER POINT
COMFORT
ROCKSPRINGS
BLANCO
WIMBERLEY
KYLE
SAN MARCOS
SAN MARCOS SPRINGS
CANYON RESERVOIR
BOERNE
BANDERA
MEDINA
LEAKEY
CAMP WOOD
GARNER STATE PARK
MONTELL
LAGUNA
BRACKETTVILLE
LAS MORAS SPRINGS
UVALDE
LEONA SPRINGS
KNIPPA
SABINAL
D'HANIS
HONDO
CASTROVILLE
MEDINA RESERVOIR
DIVERSION DAM
SAN ANTONIO
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
OLMOS DAM
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
NEW BRAUNFELS
COMAL SPRINGS
HUECO SPRINGS
BLIEDERS CREEK RESERVOIR
SEGUIN
STOCKDALE
FLORESVILLE
POTH
KARNES CITY
POTEET
PLEASANTON
CITY OF LYTLE
DEVINE
PEARSALL
DERBY
LA PRYOR
BATESVILLE
CRYSTAL CITY
NUECES RIVER
FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN ANTONIO RIVER
LEONA RIVER
ATASCOSA RIVER
HONDO CREEK
SECO CREEK
ONION CREEK

cause a minor plugging effect in some of these small openings, it is anticipated that more of the openings will be enlarged by water erosion and dissolving action than will be filled with silt. It is conceivable that reservoirs constructed in the loss areas will experience some siltation on the reservoir floor, but such deposits would not necessarily preclude leakage and would have no effect on the leakage which takes place through the interconnecting cracks and channels in the reservoir rim. A good example of continued leakage over a long period of time is evidenced at Medina Dam and Diversion Dam on the Medina River. This project has been in operation for 50 years, and the leakage at present is as great as at any time in the past.

32. DAM SITE INVESTIGATIONS.- Dam sites were located on all of the major rivers and creeks flowing from the Edwards Plateau south and southeastward to the Gulf. Investigations were conducted along some of the streams in the recharge area (west of San Antonio) to locate dam sites designed for structures with two different plans of operation. First, sites for conservation reservoirs were located above the heavy seepage loss areas in zones where the streams have cut through the Edwards and Comanche Peak limestones into the underlying Glen Rose limestone. Generally, these sites were located as far downstream as geologic conditions permitted so that maximum resources could be developed. Second, sites designed for "dry-pool reservoirs" were located downstream in the Balcones fault zone on the Edwards outcrop. These sites would be designed to capture the floodwaters and release them at the infiltration rate of the streams in the Edwards outcrop area. At these sites leakage from the reservoir is acceptable so long as it does not occur as direct underseepage which could affect the structure foundation. The location of the sites is shown on plate 10 and listed in the following tabulation:

SITE	STREAM	APPROXIMATE LOCATION
Montell	Nueces River	2 Miles S of Montell
Davenport Hill	Dry Frio River	5 Miles SE of Reagan Wells
Concan	Frio River	1.5 Miles N of Concan
Sabinal No. 1	Sabinal River	11 Miles N of Sabinal
Sabinal No. 2	Sabinal River	12 Miles N of Sabinal
Seco No. 1	Seco Creek	16 Miles NW of D'Hanis
Seco No. 2	Seco Creek	21 Miles NW of D'Hanis
Hondo	Hondo Creek	17 Miles NW of Hondo
Bat Cave	Cibolo Creek	6 Miles NW of Bracken
Comfort	Guadalupe River	3 Miles W of Comfort
Cloptin Crossing	Blanco River	2 Miles SW of Wimberley
Dam No. 7	Guadalupe River	11 Miles NE of Boerne

33. All of the dam sites were not investigated by core borings. Generally, it was felt that detailed exploration was more important on the dam sites considered for conservation pools. Furthermore, foundation problems are not expected to be as prevalent in the "dry-pool" locations (Edwards and Comanche Peak limestones) as in the sites for the conservation pools (Glen Rose limestone). At the sites selected for subsurface investigations the core borings were generally located on the abutments and in the river valleys to determine the suitability of the rock as a foundation for the proposed structure. Water pressure tests were conducted in each individual boring, where possible, to determine the rock permeability and to assist in estimating seepage losses. Also, electric logs were made to aid the correlation between abutments. In addition to the core borings at each site, a geology map of the proposed dam and reservoir area was prepared for Montell, Concan, Cloptin Crossing, and Bat Cave Dam sites. This permitted a study designed to evaluate potential leakage conditions in the reservoirs. A controlled mosaic was flown for the Montell site, and topography on the left abutment and spillway saddle was prepared using a Kelsh plotter.


EDWARDS CO.
KERR CO.
BLANCO CO.
HAYS CO.
GILLESPIE CO.
KENDALL CO.
REAL CO.
BANDERA CO.
KINNEY CO.
UVALDE CO.
MEDINA CO.
BEXAR CO.
COMAL CO.
GUADALUPE CO.
WILSON CO.
GONZALES CO.
KARNES CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
ATASCOSA CO.
DIMMIT CO.
LA SALLE CO.
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF COASTAL PLAIN
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
KERRVILLE
CENTER POINT
COMFORT
ROCKSPRINGS
WIMBERLEY
KYLE
SAN MARCOS SPRINGS
SAN MARCOS
CLOPTIN CROSSING DAM SITE
COMFORT DAM SITE
DAM #7 SITE
CANYON RESERVOIR
BLIEDERS CREEK RESERVOIR
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
BOERNE
MEDINA
BANDERA
LEAKEY
CAMP WOOD
BAT CAVE DAM SITE
SECO DAM SITE NO. 2
SECO DAM SITE NO. 1
HONDO DAM SITE
UTOPIA
MEDINA RESERVOIR
DIVERSION DAM
SEGUIN
GARNER STATE PARK
CONCAN DAM SITE
CONCAN
SABINAL DAM SITE NO. 2
SABINAL DAM SITE NO. 1
MONTELL DAM SITE
MONTELL
DAVENPORT HILL
LAGUNA
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
OLMOS DAM
FORT SAM HOUSTON MIL. RES.
SAN ANTONIO
RANDOLPH A.F.B.
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
CASTROVILLE
EDWARDS UNDERGROUND RESERVOIR
BRACKETTVILLE
LAS MORAS SPRINGS
CHANNEL DAM AND PIPELINE
KNIPPA
SABINAL
D'HANIS
HONDO
UVALDE
LEONA SPRINGS
EDWARDS UNDERGROUND WATER DISTRICT
DEVINE
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
PEARSALL
DERBY
CRYSTAL CITY
North Fork Guadalupe River
South Fork Guadalupe River
GUADALUPE RIVER
BLANCO RIVER
MEDINA RIVER
NUECES RIVER
FRIO RIVER
SAN ANTONIO RIVER
LEONA RIVER
ATASCOSA RIVER
SAN MARCOS RIVER
West Nueces River
N
30°00'
45'
30'
15'
29°00'
LEGEND
WATERSHED BOUNDARY
EXISTING RESERVOIR
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
INVESTIGATED DAM SITES
NEW MEXICO
OKLAHOMA
ARK.
TEXAS
MEXICO
GULF OF MEXICO
VICINITY MAP
SCALE IN MILES
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
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34. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Montell Dam site is located on the Nueces River approximately two miles south of Montell, Texas, in Uvalde County. The site is included in the Edwards Plateau section of the Great Plains physiographic province north of the Balcones fault zone. Topography within the area features the moderate to strong relief of a dissected, gelogically young plateau. A short distance south of the dam site and beyond the Balcones fault zone the land form changes to the flat, featureless topography of the Coastal Plains physiographic province.

35. At the proposed dam site the Nueces River has cut its channel through the Edwards and Comanche Peak formations, Fredericksburg group, into the underlying Glen Rose formation, Trinity group, and now meanders in a broad valley between fairly steep canyon walls. The Glen Rose formation crops out along the valley walls and supports the alluvial deposits in the valley section. Where investigated, the formation consists of an argillaceous, light colored limestone with thin interbedded calcareous shale seams. Stairstep topography, typical of the Glen Rose, is not prominent in the proposed reservoir area. The overlying Comanche Peak formation is lithologically similar to the upper member of the Glen Rose formation. A distinguishing feature is its product of weathering, which is generally characterized by irregular, angular nodules with indistinct bedding planes. In areas where the two formations are not exposed, the Glen Rose can often be distinguished by its greater abundance of vegetal cover. Total thickness of the Comanche Peak at the dam site is approximately 50 feet. The Edwards formation, which immediately overlies the Comanche Peak, caps the hills and ridges in the area. The formation consists of a gray, hard, massive, dense, and sublithographic variable to medium-grained limestone. Chert nodules up to 2-1/2 feet in diameter are found throughout the formation. Although the Edwards is reportedly only 50 to 100 feet thick in the area, approximately 182 feet of Edwards-like limestone was measured near the right abutment. This section did not reveal a well-defined contact with the overlying Kiamichi formation. The only distinction in the section was the thin bedding exhibited in the upper 64 feet in contrast with massive bedding in the lower 118 feet.

36. The Edwards and associated limestones, which include the Comanche Peak, Edwards, Kiamichi, and Georgetown formations, have been mapped as one unit (see plate 11). The Walnut clay has not been identified at the dam site to date and reportedly does not exist in Uvalde County.

37. STRUCTURAL GEOLOGY.- Although the major zone of faulting in the Balcones fault system is located south of the dam site, a few small related faults have been found in the proposed reservoir. Field mapping and exploration did not reveal faulting between the

abutments, but, west of the right abutment (west abutment), two vertical fracture zones trending N80°E and N86°E cut the Edwards, Comanche Peak, and the Glen Rose limestone formations. Surface expression of these zones is marked by limonitic ironstone debris and vegetation, best seen on the Edwards limestone exposures. The northernmost fracture zone is 8 to 10 feet wide with no apparent displacement, and the southern fracture zone is 12 to 15 feet wide with minor displacements to the south. These zones of fracturing extend at least 3.5 miles southwestward in an en echelon pattern. Southwest of the dam site a few minor fracture zones are noticeable and a small graben, involving at least two and possibly three vertical faults, is located approximately 1.2 miles west of Montell in the Dry Creek area (see plate 11, Dam Site and Reservoir Geology). The aggregate apparent displacement of the two southernmost faults appears to range from 80 to 110 feet with downthrow to the north. Displacement on the third vertical fault could not be determined. The two southernmost faults apparently intersect southwest of Dry Creek and continue to the west as a single zone, faulting out the Comanche Peak limestone and the lower part of the Edwards limestone. Best available evidence indicates that this single zone has a minimum stratigraphic displacement of 108 feet and a probable maximum of 140 feet. The general strike for the referenced faulting is approximately N80°E. Other faults or fracture zones are located approximately 5.5 miles northwest of the town of Montell. These fractures have disrupted bedrock and at one point have caused Montell Creek to abandon an old meander. No displacements are apparent although the zone of fracturing is 250 to 300 feet wide in the bluff east of Montell Creek. The principal zone of this fracturing is approximately 1.4 miles long and trends N72°W. A smaller but associated zone trends about N67°E. The fracture dips are generally near vertical.

38. The bedding in the dam site area strikes eastward and suggests a slight dip southward. Dips up to 9° have been noted near faults. The most prominent geologic structures generally trend parallel to the regional strike.

39. RESERVOIR LEAKAGE.- Texas Water Commission Bulletin 5807D, Channel Gain and Loss Investigations, Texas Streams, 1918-1958, reports that no sizeable water losses occurred in the 25 miles of river channel investigated from Barksdale in Edwards County to Laguna in Uvalde County. Low-flow investigations were made in December 1954, February and September 1955, and July 1957. Underflow in the porous gravels covering the Glen Rose limestone makes the determination of losses and gains very difficult, but apparently the Glen Rose limestone is not accepting appreciable amounts of water in the immediate reaches above the proposed dam. Geologic mapping of the area revealed several small faults in the proposed reservoir; however, it is not believed that these faults will cause excessive leakage as secondary limestone and banded calcite deposits have sealed many of the exposed joints and fractures. A possible leakage area

may develop in a 25-foot vertical sink located in the Glen Rose limestone approximately 8,200 feet west-southwest of the right abutment. The sink is included in the previously described fracture zone. Another possible source of leakage may be a 4.5' by 4.5' cave located in close proximity to the sink and extending approximately 15 feet horizontally along a fracture zone into the steep bluff of Comanche Peak limestone. Obvious solutioning has taken place along this zone and additional investigations will be required to evaluate the condition. No vegetation is associated with the previously mentioned graben fault structure west of Montell, but both areas of the large scale fracture zones are marked by narrow bands of dense vegetation and some open fractures.

40. INVESTIGATIONS.- Exploration began on Montell Dam site in 1938 with the drilling of 19 shallow earth auger holes and the excavation of two shallow test pits. However, these borings did not reach the top of rock along the proposed axis and only penetrated a portion of the valley alluvium. In late February and early March 1962, two NX-size core borings were drilled to explore foundation conditions on the right abutment and to determine the bedrock configuration beneath the valley floor. In March of 1963, two NX-size core borings were drilled on an alternate, contiguous, upstream axis and one NX-size core boring was drilled at the lower site. The lower site boring was drilled in the area southwest of the right abutment for investigations of a possible spillway site. Subsequent design studies, however, indicated economic advantages in locating the spillway on the left abutment. Materials studies consisted of one 8-inch diameter auger boring in the valley alluvium. The location of recent exploration borings are shown on plate 11, Dam Site and Reservoir Geology.

41. Geologic mapping in the vicinity of the dam site was completed in July 1963 by U. S. Geological Survey personnel. The primary purpose was to locate possible leakage sources due to geologic structures or rock characteristics. A controlled mosaic was flown for the reservoir. Topography on the left abutment and spillway saddle was prepared using a Kelsh plotter.

42. An upper site, approximately 1.5 miles above Montell, Texas, was considered, and a topographic profile was prepared. In 1938 the site was initially explored with several shallow core borings and auger holes. After reservoir storage considerations, it was decided the lower site was the more desirable.

43. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The Glen Rose formation of the Trinity group will confine the reservoir and provide the foundation for the dam and appurtenant structures. Geologic mapping at the dam site located the top of the Glen Rose at approximately elevation 1500. The formational sequence overlying the Glen Rose, in order of decreasing age, includes the

Comanche Peak, Edwards, and Kiamichi formations (Fredericksburg group), and the Georgetown formation (Washita group). With the exception of the Glen Rose, the referenced formations are all located above the proposed maximum pool level. The Edwards, Kiamichi, and Georgetown formations are undifferentiated and generally cap the hills and ridges with resistant limestones.

b. Lithology.- The Glen Rose limestone is an argillaceous, light-tan to medium-gray, sometimes dolomitic limestone with occasional thin shale and clay seams. The rock is aphantitic to fine-grained, moderately hard, and highly fractured in zones. Some of the beds contain small vugs, solution channels,and fractures that are occasionally clay filled. Fossiliferous beds are found throughout the formation. The overlying Comanche Peak formation is similar to the Glen Rose formation in the vicinity of the dam site. The rock is chiefly a moderately hard, light-gray limestone that weathers into irregular, angular nodules. The fossil Exogyra texana is scattered throughout the formation but is more common toward the base. The Edwards limestone, undifferentiated from the overlying Kiamichi and Georgetown formations, crops out as resistant limestone bluffs,capping the hills. The rock is a hard, brittle, very resistant, light-gray, lithographic variable to medium-grained, massive limestone. Scattered chert nodules are found throughout the entire thickness of the formation.

c. Weathering.- Chemical weathering in the form of solutioning, oxidation, and hydration is very apparent in the cores obtained during the exploration drilling, as well as from the outcrops in the vicinity of the dam site. The weathered surfaces of the limestone are generally pitted and contain some solution cavities and fractures which are commonly iron stained. Boring 2C-1, located on the right abutment at station 3+13, exhibited minor weathering effects in the form of oxide staining and clay fillings in and on the fracture surfaces over the total depth of boring (49.7 feet). Boring 2C-4, located at station 0+00 on the right abutment also showed minor staining and solutioning to its total depth (80.0 feet). However, intense weathering (alteration of entire rock mass) appears to be surficial, generally less than 10 feet below top of rock. Beneath the valley alluvium, the Glen Rose limestone is generally fresh or only slightly weathered to depths of 5 or 6 feet. Mechanical weathering (rock separation and pulverizing by the action of tree and shrub roots) is evident on the Glen Rose outcrops, but is very minor as compared to the effects of chemical weathering.

d. Faulting.- Core boring data and geologic mapping did not reveal faulting at the proposed dam site. The top of the Glen Rose is found at approximately elevation 1500 on both abutments and apparently is not offset. Faulting and intense fracturing, as determined by geologic mapping, have been described earlier in this report.

e. Overburden.- Alluvium up to 45.5 feet in depth has been deposited in the broad valley formed by the meandering Nueces River. Boring 2C-2 and 8A2C-3 encountered 44.7 and 45.5 feet, respectively, of silty sandy clays, sandy gravels, and gravels. Generally, 10± feet of sandy clay is found overlying 11 to 13 feet clayey sand and gravel which, in turn, is underlain by 20 to 25 feet of gravel composed of limestone and chert. Additional gravel deposits have been noted as bar deposits along the tributary streams in the dam site area. However, these deposits are often caliche cemented. The abutments support a relatively thin mantle of residual soil and talus composed primarily of clays with some silt and gravel. The spillway saddle, located north of the left abutment, probably supports some overburden but the depth is not believed to exceed 5 to 10 feet. Plate 12, Geologic Profile, shows the inferred depth and extent of overburden along the proposed dam axis.

f. Leakage.- Hydraulic pressure testing was conducted in the core borings at the Montell Dam site. Borings 2C-1 and 2C-4, located on the right abutment, showed the Glen Rose limestone to be slightly to moderately permeable over the total depth tested. Generally, high water takes were experienced in the upper portion of the borings where weathering is the most extensive. Boring 2C-4, for example, took an average of 4.8 cfm from depths of 19.6 feet to 42.4 feet. From 42.4 to 53.8 feet, the boring took only 0.3 cfm at 40 psi. The remainder of the boring took approximately 1.5 cfm at 50 psi. Boring 2C-5, located southwest of the right abutment, took an average of 5.5 cfm over the first 43 feet tested and was essentially impermeable over the remainder of the boring. The total drill water losses in the upper limits of boring 2C-5 also indicate some leakage. Both valley holes 2C-2 and 8A2C-3 were tight with no takes encountered at 50 psi. The pressure test results are shown on plate 13, Logs of Borings.

g. Water table.- The abutment borings at the dam site did not encounter a water table. Core hole 8A2C-3, located in the valley, recorded a water level at a depth of 25 feet four days after the boring was completed. Based on available information, it is believed that the local ground-water level is tributary to the proposed reservoir area. Also, inasmuch as several springs emit from the basal Edwards, located high on the valley wall, it is believed that some isolated,perched levels occur within the reservoir rim. Detailed subsurface information concerning the regional aspect of the ground-water levels is not available and the possible existence of ground-water depression or divides effecting reservoir losses will require investigation during subsequent planning.

44. CONSTRUCTION MATERIALS.- Investigational borings at the dam site indicate that the Nueces valley includes relatively large deposits of river alluvium. Where investigated, the deposits appear to consist of approximately 10 feet of sandy clay mantle,underlain by approximately 30 feet of sand and gravel. The clay mantle may include varying

proportions of gravel. Additional investigations will be necessary to determine the suitability of these deposits for embankment materials. Limestone for use as random rockfill will be available from the required spillway excavations in the Glen Rose limestone and can also be obtained from other adjacent areas. Use of this material, however, may require some processing or selective quarrying to remove the clayey portions. A better quality rock is available from the Edwards limestone formation located at higher elevations at and contiguous to the dam site. Local sand and gravel deposits have not been tested for use as concrete aggregate. Approved sources are located in the general area of San Antonio, Texas.

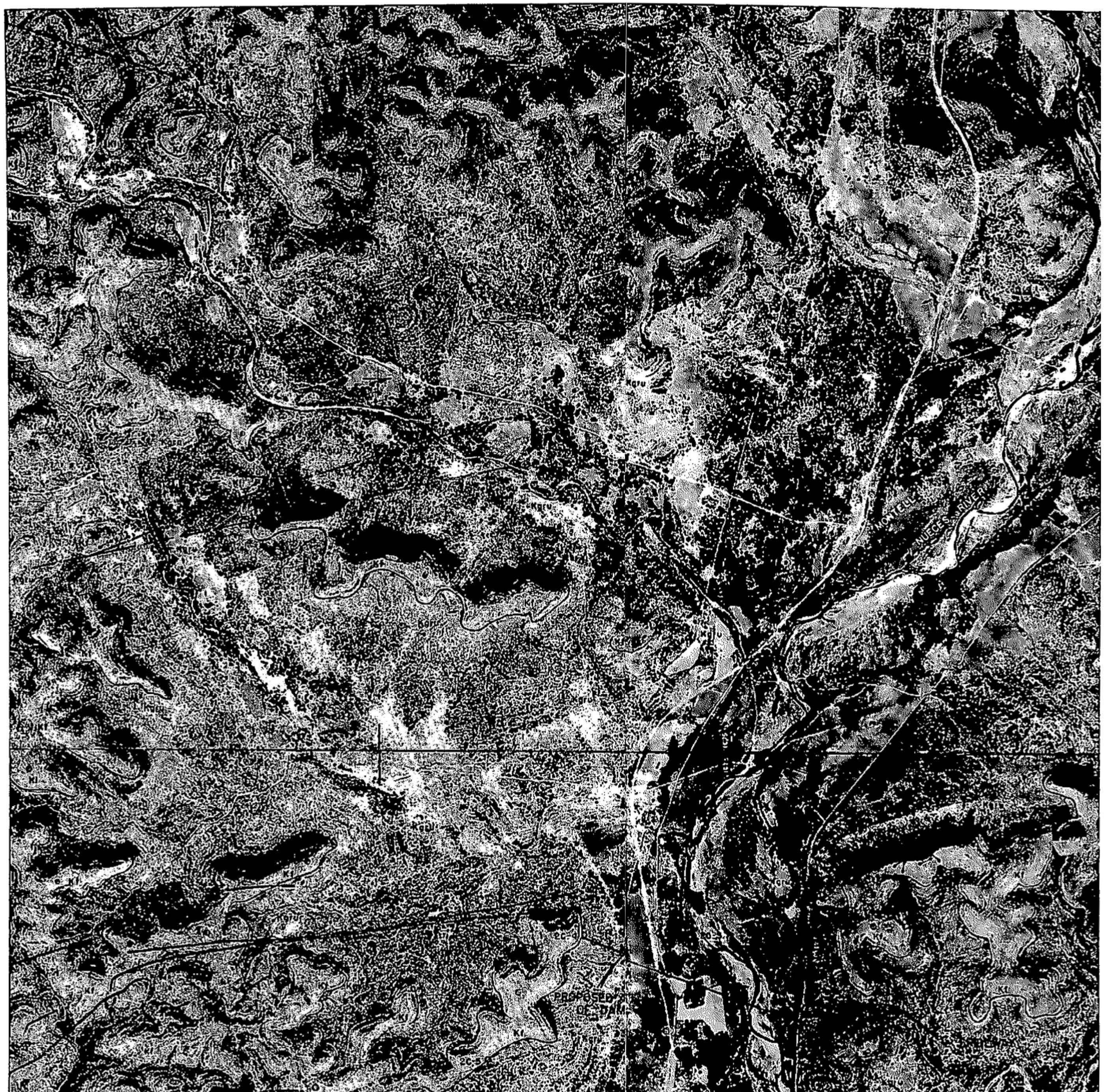
45. CONCLUSIONS AND RECOMMENDATIONS.- The following conclusions and recommendations are based on investigations conducted to date:

a. The Upper Glen Rose limestone will provide a satisfactory foundation for the dam and its appurtenant structures. The spillway located north of the left abutment has not been explored by core borings, but information from geologic mapping does not indicate any structural problems. It is believed, however, that weathering has extended for a considerable depth into the rock in the spillway saddle. Overburden, consisting of permeable sands, gravels, silts, and clays, is at least 45 feet thick throughout the valley, and a cutoff trench to bedrock will be required. Foundation treatment will be required.

b. There are no known faults cutting the dam axis. A fracture zone, located north of the right abutment, is traceable for a considerable distance, but will not affect the dam foundation.

c. The Glen Rose limestone will form the reservoir for the proposed Montell Dam site. Generally, experience has shown the Glen Rose to be relatively impermeable and capable of containing a reservoir. Hydraulic pressure tests in the valley borings have shown the rock to be tight, while minor takes were recorded in the abutment borings. The fracture zone, located north of the right abutment, shows evidence of solutioning, as indicated by caves and sinks, and may require further exploration to define the in-place, subsurface conditions. Outside of the referenced fractured zone, geologic mapping and core boring exploration did not reveal any unusual leakage conditions.

d. Relatively large quantities of alluvium are included in the valley of the Nueces River but from present investigations appear to be predominantly sand and gravel. Adequate quantities of material suitable for an impervious core are believed available from the mantle of clay, silt, and clayey sand overlying the gravels in the valley flood plain. Limestone suitable for use as random rockfill material is available locally.



LEGEND

CRETACEOUS

- Kf — Fredericksburg Group undifferentiated. Includes Kiamichi, Edwards & Comancho Peak formations.
- Kgru — Glen Rose limestone, upper member.
- 9° — Strike and dip of bedding.
- ⊕ — Horizontal beds or dip of less than 1/2 Degree.
- Strike of vertical joint planes.
- 45° — Strike and dip of joint planes.
- D / U — Known fault showing up and down sides, fault dashed where inferred or concealed.
- Wide fracture zone or fault.
- T — Thrust fault; dashed where inferred or concealed.
- Kf — Geologic contact; dashed where inferred or concealed.
- SK — Sink.

NOTES:

Base prepared from sheets 7 and 9 of a controlled mosaic prepared by the Corps of Engineers, U.S. Army, Fort Worth, Texas.

Geology by U.S. Geological Survey for U.S. Army Corps of Engineers, Fort Worth District, June 1963.

SCALE OF FEET

2000 0 2000 4000

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

NUECES RIVER

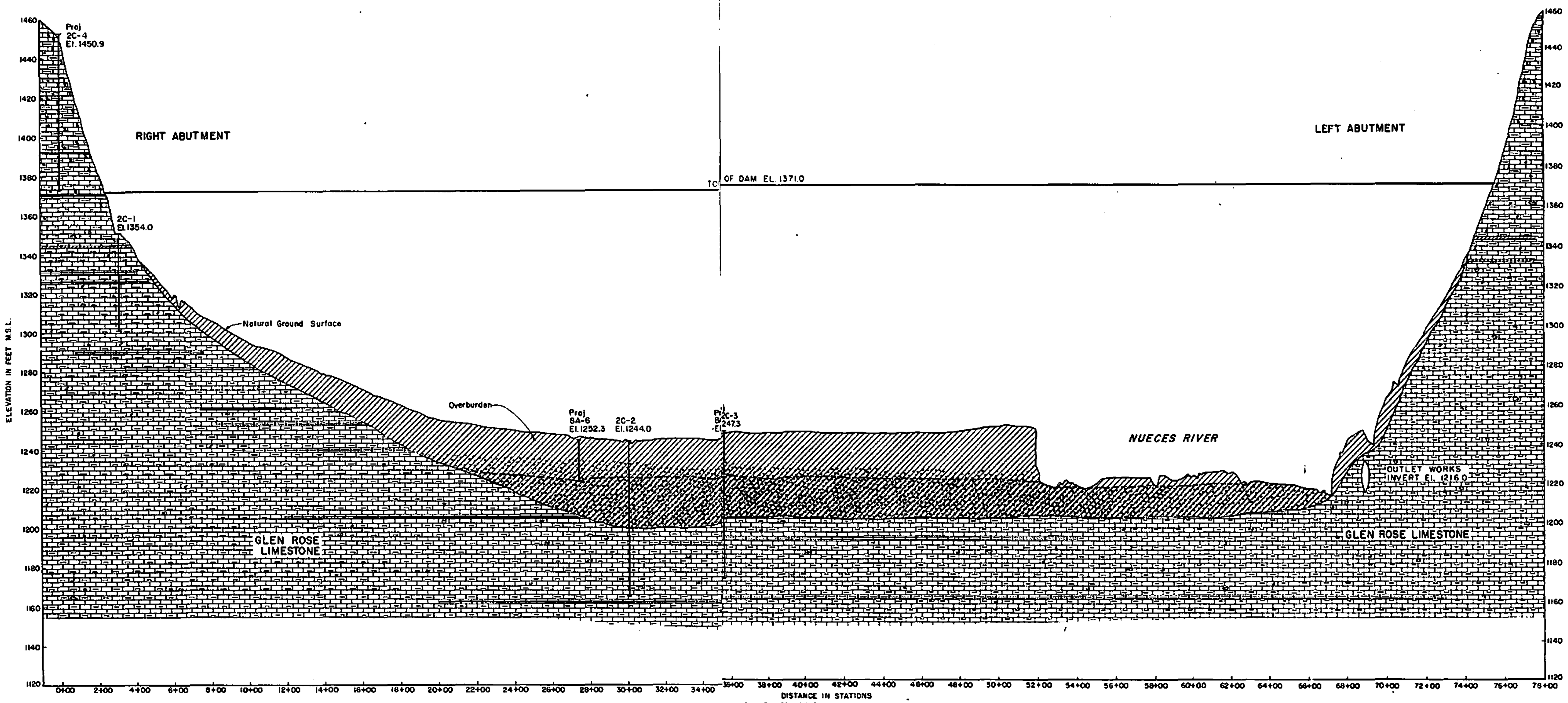
DAM SITE & RESERVOIR GEOLOGY

MONTELL DAM SITE

SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
ENGINEER / CHIEF, PROJECT PLANNING BRANCH	ENGINEER / CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS / DISTRICT ENGINEER
PREPARED — ENGINEER / CHIEF, FOUNDATION & MATERIALS BRANCH	DRAWN BY A.M.F. / CHECKED BY M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD: 707-2



SECTION ALONG AXIS OF DAM

LEGEND

OVERBURDEN

- Clay, Silty, sandy, brown.
- Sand, clayey, silty, tan, scattered gravels.
- Gravel, Sand and Clay.

PRIMARY MATERIAL

- Limestone, Light-gray to dark-gray, medium hard to hard, argillaceous, thin to massive-bedded, occasional shale and clay seam and solution cavity, variably fossiliferous.
- Shale seam
- Clay seam
- Weathering
- Cavities
- Fossiliferous
- 8A 8" Auger boring
- 2C 2" Core boring

NOTES:

See Plate NO. 13 for pressure test results and data.

Horizontal extent of clay and shale seams shown on Geologic Profile is unknown. Because of small scale not all clay seams are shown but appear on Plate NO. 13, Logs of Borings.

Absence of ground water levels opposite boring logs does not mean that water will not be encountered at the locations or within the vertical reaches of the borings.

For location of borings, see plate 11.

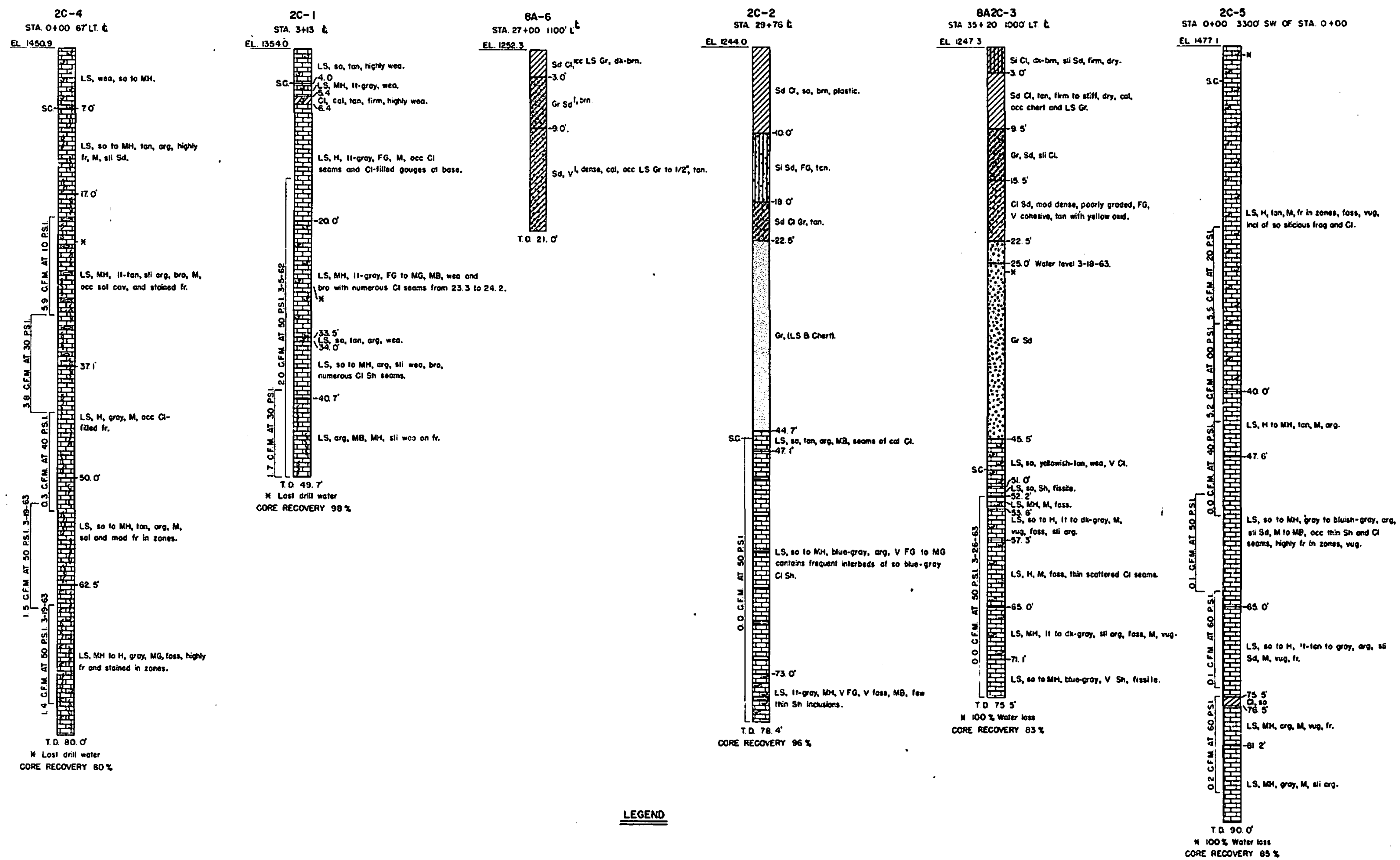
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
NUECES RIVER

GEOLOGIC PROFILE
MONTELL DAM SITE

SCALES AS SHOWN

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

SUBMITTED: W. E. Wood, Engineer, Chief, Project Planning Branch
APPROVAL RECOMMENDED: Engineer, Chief, Engineering Division
APPROVED: Col. Corps of Engineers, District Engineer
PREPARED: Engineer, Chief, Foundation & Materials Br.
DRAWN BY: V. J. M.
CHECKED BY: M. G. C.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2



LEGEND

T.D. • Total Depth

Pressure Test Results and Data

1.4 C.F.M. AT 10 P.S.I. 6-6-63 — 1.4 Cubic feet per minute leakage at 10 pounds per square inch guage pressure in June 6, 1963.

LS	Limest
Sd	Sand — Sandy
Si	Silt or — Silty
Cl	Clay o — Clayey
Sh	Shale — Shaly
Gr	Gravel — Gravelly
arg	Argilla
wea	Weath
bro	Broken
occ	Occasi
so	Soft
MH	Mediun
H	Hard
V	Very
sli	Slighth
M	Massiv

MB	Medium Bedded
sol	Solution or Solutioned
cav	Cavity
fr	Fracture or Fractured
vug	Vuggy or Vugs
oxid	Oxidized or Oxidation Stain
foss	Fossiliferous
cal	Calcareous
FG	Fine-Grained
MG	Medium-Grained
dk	Dark
lt	Light
brn	Brown
dia	Diameter
S.C	Started Coring
mod	Moderately
frag	Fragments
incl	Inclusions

Cl · Si · Sd · Gr · LS · wea · foss · fr · Sh Seams · cav

VERTICAL SCALE IN FEET
5 0 5 10

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX
EDWARDS UNDERGROUND RESERVOIR
NUECES RIVER
LOGS OF BORINGS
MONTELL DAM SITE
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC 1964
SUBMITTED | APPROVAL RECOMMENDED | APPROVED
PREPARED | DRAWN BY T.L.W. | CHECKED BY M.G.G.
TO ACCOMPANY SURVEY REPORT ON EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2

46. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Concan Dam site is located approximately one and one-half miles upstream from the intersection of Highway 127 and the Frio River near Concan, Texas. The site is situated on the Edwards Plateau near the northern edge of the Balcones fault zone. The flat, featureless Coastal Plain physiographic province lies to the south. Topographically, the Edwards Plateau consists of a rugged mountain-type land form that includes deeply incised valleys with steep, near vertical bluffs.

47. In the vicinity of the dam site the Frio River has cut its channel through the Edwards and Comanche Peak formations into the underlying Glen Rose formation, the oldest rock exposed in the reservoir and dam site area. The Glen Rose formation, found in the valley floors and a portion of the valley walls, is composed of alternating beds of hard limestone and soft, shaly limestone. When exposed and subjected to differential weathering, the alternating beds form a stairstep-type relief. The Comanche Peak formation overlies the Glen Rose formation and features a hard, light-gray limestone, varying in thickness from 60 to 85 feet. The most distinguishing characteristic is its nodular appearance in weathered outcrops. The Edwards formation overlies the Comanche Peak formation and caps the hills with steep walls of resistant limestone. The rock is fine- to medium-grained, hard, massive, and highly cavernous and/or honeycombed, due to secondary solutioning along joints and fractures. Scattered chert nodules and occasional dolomitic limestone beds are found throughout the formation. The Walnut clay, which has not been recognized at the site, is generally considered absent in Uvalde County.

48. The Comanche Peak limestone and Edwards limestone of the Fredericksburg group have been mapped as one unit, see plate 14. Hydrologically, these formations, together with the overlying Kiamichi and Georgetown formations, are considered as one unit commonly referred to as the Edwards and associated limestones.

49. STRUCTURAL GEOLOGY.- The Balcones fault zone is the controlling structural feature of the Edwards plateau. Typically the zone consists of a series of east-west trending faults and minor folds that have a broad lateral extent and a relatively wide range of displacements. In the northeastern part of Uvalde County, a total displacement of approximately 700 feet across the zone has been reported. To the southwest the zone apparently becomes one of folding and fracturing rather than large faulting and is not easily recognized. Three normal faults, traceable for approximately three miles, are located within two or three miles of the site. These faults were mapped by the Geological Survey during the field work for the Uvalde County report. 25/ Although the faults have no direct relation to the foundation or leakage conditions at the site, they are indicative of the

proximity of the site to the Balcones fault zone. Faulting in the reservoir and at the proposed site is discussed in detail later in this report.

50. Formations in the vicinity of the proposed dam site dip approximately 35 to 45 feet per mile in a southerly direction. The observed dip of the strata becomes distorted near faults but appears to increase towards the south.

51. RESERVOIR LEAKAGE.- Factors affecting leakage; i.e., faulting, fracturing, solutioning, etc., were investigated by geologic mapping, core drilling, and seepage measurements. The geologic mapping conducted by U. S. Geological Survey personnel did not reveal any unusual geologic phenomena that would contribute to excessive reservoir leakage. Several small caves, a few springs, and one sinkhole were noted during the field work. The observed caves included two small openings of less than two feet in diameter located in the right bank of a stream near Cowan Springs and a vertical opening approximately one foot in diameter located at elevation 1400± near the right abutment of the proposed dam site. Field investigations concerning springflows located two small springs between the First and Second Crossing of the Frio River, see plate 14; namely, the Cowan Springs at the contact between the Glen Rose and Comanche Peak formations, and a small unnamed Glen Rose spring on the west bank of the Frio River 1200 feet north of the First Crossing. A small flow was also noted from the Glen Rose-Comanche Peak contact located under Highway 83 approximately 1.2 miles north of its junction with Highway 127. In addition to the above-referenced potential leakage areas, one small sinkhole was located immediately north of Highway 127, approximately 0.35 mile west of the First Crossing. For the location of the caves, springs, and sinkhole see plate 14, Dam Site and Reservoir Geology.

52. Seepage investigations on the Frio River above the stream-gaging station at Concan did not show appreciable streamflow gains or losses in the stream interval traversing the Glen Rose limestone. Low-flow investigations were conducted in January, February, and September of 1955 and July of 1957. The only potentially serious leakage area noted was on the right abutment at the dam site. Here the Edwards and Comanche Peak limestones have been downfaulted to approximately elevation 1300, and water pressure tests have shown the rock is highly permeable. However, as Concan is to be operated as a "dry-pool" reservoir, any leakage through the rock that does not affect the stability of the structure can be tolerated.

53. INVESTIGATIONS.- Concan Dam site was originally explored in February 1962 with the drilling of three NX-size core borings along the proposed dam axis. Two borings were located on each abutment and one boring was located in the valley section. In

April and May of 1963, two additional borings were drilled along the dam axis. Boring 2C-8 was drilled on the right abutment at elevation 1457 to a depth of 229.0 feet. This boring was necessary to delimit the Edwards-Comanche Peak and Comanche Peak-Glen Rose formational contacts. Boring 8A6C-6 was located near the toe of the right abutment to determine the depth to the top of rock. The proposed spillway, located west of the right abutment, was explored with one core boring drilled to a depth of 80.0 feet. In addition to the six core borings, two shallow auger borings were completed for borrow investigations in the valley north of the proposed dike. All of the core borings were hydraulically pressure tested and, where conditions were practical, electric logs were run.

54. Detailed geologic mapping in the vicinity of the dam site was completed in early 1963 by the U. S. Geologic Survey in cooperation with the Corps of Engineers. The area was mapped to locate any potential leakage areas due either to structure (faulting) or rock characteristics.

55. Investigations were initiated in 1925 and 1926 by a private engineering firm on the "Shut-in" Dam site located approximately one and one-half miles downstream, immediately north of Highway 127. This investigation consisted of several churn drill holes that were drilled to depths varying from 75 to 135 feet and were logged by examination of "cuttings", sampled at various intervals. In addition, the U. S. Army Corps of Engineers, Galveston District, drilled one core boring along the axis to check the accuracy of the churn drill holes. The results of this exploration are summarized in a report by the Galveston District entitled "Geology of the Shut-in Dam, Dike and Reservoir Sites, Frio River," dated April 1938. In January 1963, additional investigations were made at this site by five 2-inch diameter core borings, located along the proposed axis. Based on this investigation, it was determined that the site was not suitable and the present axis was selected.

56. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The Glen Rose limestone, Comanche Peak limestone, and Edwards limestone all crop out in the vicinity of the dam site. The Glen Rose formation of the Trinity group, the oldest unit exposed, is found in the valley floor beneath the alluvium and along the canyon walls. The overlying Comanche Peak limestone of the Fredericksburg group forms a band 60 to 70 feet thick along the valley walls. The Edwards formation, also of the Fredericksburg group, caps the hills with easily recognized resistant limestone bluffs. Both abutments are relatively steep and support a heavy growth of shrubs and trees. Faulting in the valley has offset the Comanche Peak-Glen Rose contact approximately 70 feet. The contact on the right abutment was located at approximately elevation 1329, whereas the contact on the left abutment was located at approximately elevation 1400.

b. Lithology.- The Glen Rose formation is composed of alternating beds of hard and soft argillaceous limestones, shaly limestones, and dolomitic limestones. The limestone is tan to gray, thin- to medium-bedded, occasionally includes shale and/or clay seams, and commonly includes fossiliferous zones. Thin zones of limestone, peppered with black, medium-grained, phosphatic nodules, fossil-like in appearance, are found at various horizons throughout the formation. However, correlation of these zones was not possible. The Comanche Peak formation overlies the Glen Rose and features a hard, light-gray, nodular limestone with clay-filled solution channels or borings. Hairline, shaly partings and stylolites are scattered throughout the formation. In boring 2C-8 the Comanche Peak was found to be 58.5 feet thick. The Edwards formation crops out below the maximum pool on the right abutment. The rock is a hard, massive, highly solutioned, fine- to medium-grained limestone and dolomitic limestone. Chert nodules are scattered throughout the formation.

c. Weathering.- Evidence of chemical weathering, represented primarily by solutioning, oxidation, and hydration, is clearly seen in the exploratory core and also in the rock outcrops. Generally, weathering in the valley is shallow, extending only a few feet into the Glen Rose limestone. Boring 2C-3, located on the left abutment, exhibited slight weathering in the Glen Rose to a depth of 39 feet. The Edwards and Comanche Peak formations were very slightly weathered over the entire cored section in boring 2C-8, located on the right abutment. Solutioning is very prominent in the Edwards and Comanche Peak with openings up to 6 inches in diameter being encountered in the borings. Cavernous weathering is also evident in the Glen Rose but to a lesser degree. Oxidation, in the form of iron oxide staining, is present on fracture surfaces to a depth of 141 feet in boring 2C-8. Hydration with subsequent clay coating and deposition on and within fractures is found throughout the weathered rock. Mechanical weathering in the form of tree roots separating and breaking the limestone is present at very shallow depths.

d. Faulting.- Investigations, including both geologic surface mapping and core borings, have revealed considerable faulting in the vicinity of the dam site. In the area between the First and Second Crossing on the Frio River, numerous faults, trending approximately N65°E to N80°E, give the net effect of a graben. In the bluff west of the Second Crossing, a normal fault trending approximately N80°E has offset the Comanche Peak-Glen Rose contact approximately 80 feet. Apparent downthrow was to the east. West of this fault the top of the Glen Rose is at approximately elevation 1380 while east of the fault the top appears to be around elevation 1300. At the dam site location a small fault has been inferred to cut the dam axis between borings 2C-1 and 2C-8 (see Geologic Profile, plate 15). This fault could not be detected on the surface, but distinctive Glen Rose limestone is located approximately 30 feet higher (elevation 1329) in boring 2C-1 than in 2C-8. Other faulting is also inferred at the proposed axis inasmuch as the top of the Glen Rose is approximately 70 feet lower on the right abutment (elevation 1329±) than on the left abutment. Plate 14, Dam Site and Reservoir Geology, shows one of the larger faults projected beneath the alluvium and cutting the dam axis. However, there is no direct evidence that this is the principal fault or the only fault. Field mapping has revealed that most of the faults observed are zones of intense fracturing having several planes of displacement. One such zone was noted cutting the hill immediately north and west of the First Crossing. At this point the Edwards limestone has been downfaulted against the Comanche Peak along a zone more than 60 feet wide that trends N60°E. This fault was graphically projected beneath the proposed dam axis, but the displacement is not believed to be large enough to account for the total offset between the abutments. In addition to the faults shown on plate 14, many minor faults and fracture zones were observed in the Comanche Peak limestone that crops out in the bed of the intermittent stream near Cowan Springs and also in the Glen Rose limestone on the north bank of the Frio River near the Second Crossing. At the present stage of investigation it is not known to what extent the foundation beneath the proposed dam is faulted, and it is possible that additional mapping and drilling will locate several displacements.

e. Overburden.- With the exception of small pockets or areas of residual soil held in place by vegetation, there is little or no overburden on the abutment slopes. Borings 2C-1 and 2C-8 on the right abutment and boring 2C-3 on the left abutment encountered no overburden. In the river valley the maximum thickness of alluvium was 19.6 feet in boring 2C-2. At this point four feet of sandy clay was found overlying 15.6 feet of gravelly sand and cobbles. Previously, it had been thought that the Frio River may have had its channel near the base of the right abutment, but boring 8A2C-6 encountered only 13.0 feet of alluvium at this location. Plate 15, Geologic Profile, shows the projected top of rock across the valley. Boring 2C-7, drilled in the proposed spillway, encountered five feet of highly weathered and broken limestone but no overburden.

f. Leakage.- Hydraulic water pressure tests conducted in the core borings revealed that the Glen Rose and Comanche Peak limestones are relatively impervious. In contrast, the Edwards limestone encountered in boring 2C-8 on the right abutment revealed a highly pervious condition. Within the interval from ground surface to a depth of 80 feet the minimum take was 3.2 cfm at 0 psi. The maximum take was 4.0 cfm (pump capacity) at 2 psi. The remainder of the rock was essentially impermeable. Experience has shown that on the Edwards Plateau leakage generally occurs in the highly weathered and fractured surface rock. An example of this is found in boring 2C-7, located in the proposed spillway. At this location water takes, up to 2.9 cfm at 20 psi, were recorded to a depth of 32 feet. Below this interval the rock (Glen Rose) was impervious. Water pressure test results are shown on plate 17, Logs of Borings.

g. Water levels.- The water level was determined in only one boring at the site. In boring 2C-7 (approximate elevation 1360), located in the proposed spillway, the water level was 49 feet on 23 April 1963 (23 days after completion of hole).

57. CONSTRUCTION MATERIALS.- Flood-plain deposits believed to be suitable for embankment material are available from the valley of the Frio River. However, these deposits appear to be limited and may not be sufficient to construct an earthen embankment. Boring 8A-4 encountered 4 feet of sandy clay overlying 1.5 feet of gravelly clay and refused penetration at 6.0 feet. Boring 8A-5 encountered 6 feet of sandy clay overlying 7 feet of gravel, sand, and clay and refused penetration at 13 feet. A 1938 report by the Galveston District states "an ample supply of material for an earthen dam can be found approximately 4,000 to 6,000 feet below the First Crossing." This report was based on numerous pits and holes excavated in the area by a private engineering firm. Information concerning quantities and laboratory testing of this source is not available. Limestone suitable for random rockfill will be available from required excavation for the spillway and from the rock outcrops of Glen Rose and/or Edwards limestones in the immediate area. Commercial sources of gravel and limestone for concrete aggregate are available in the San Antonio area.

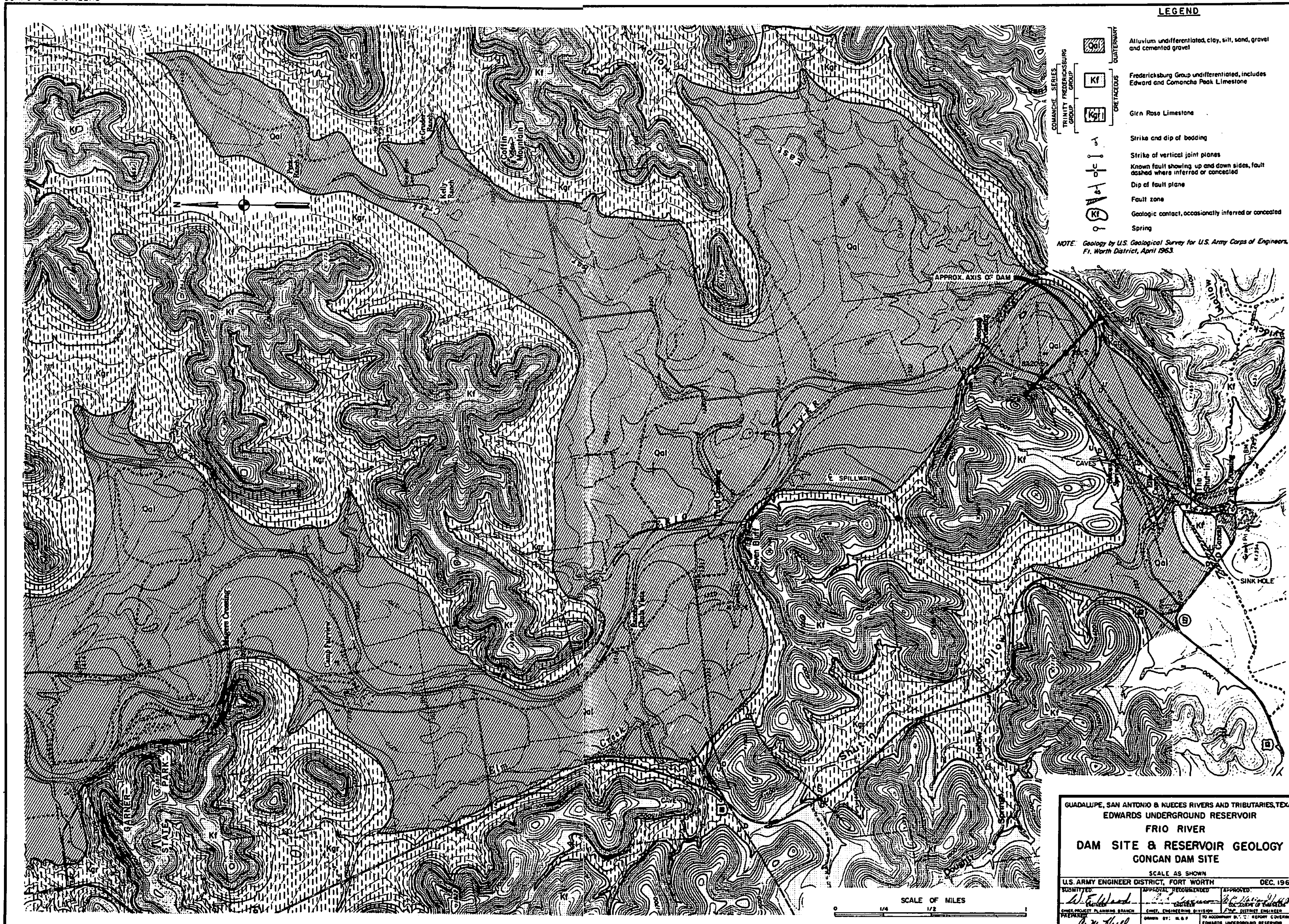
58. CONCLUSIONS AND RECOMMENDATIONS.- The following conclusions and recommendations are based on investigations conducted to date:

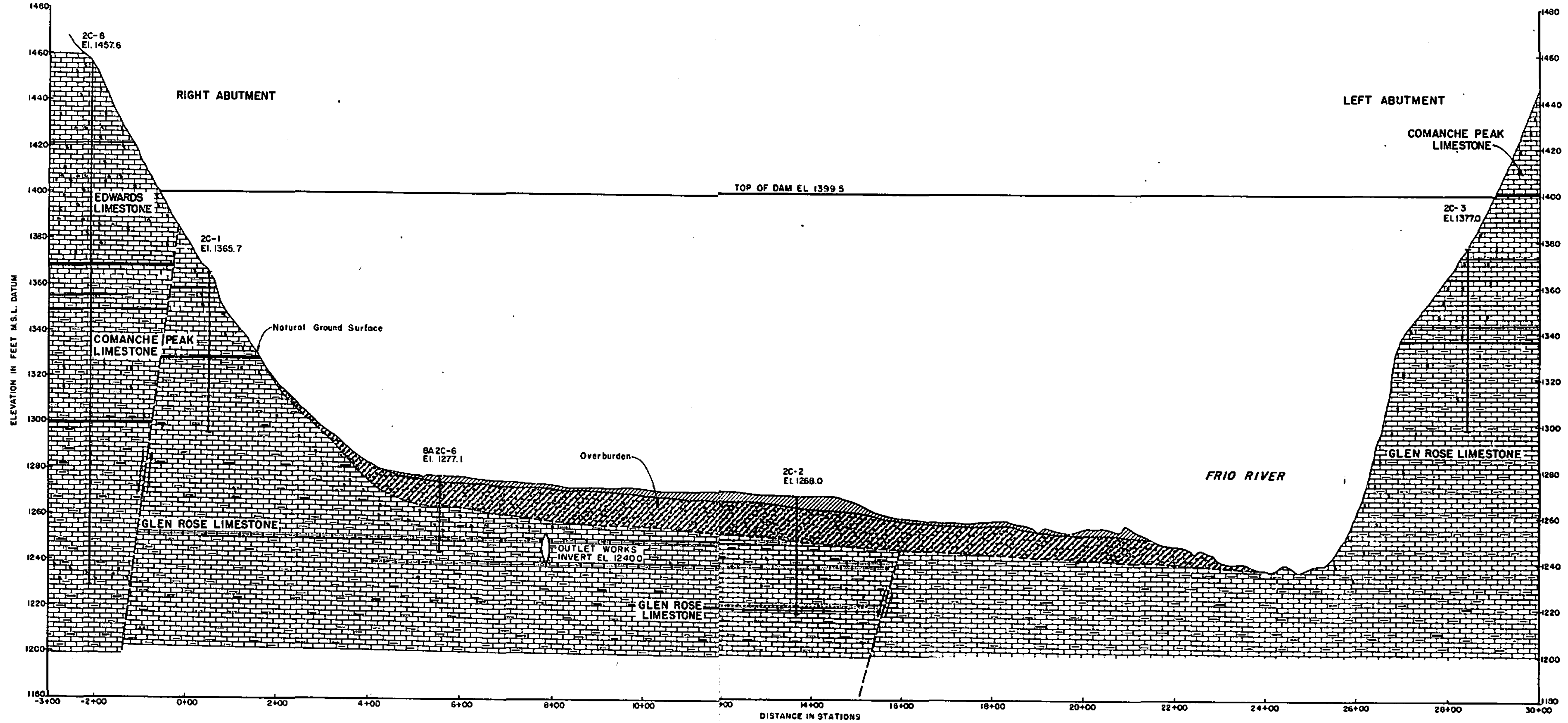
a. Foundation conditions at the Concan Dam site are structurally satisfactory for the proposed project. The Glen Rose limestone comprises the bedrock in the valley section and left abutment; the Glen Rose, Comanche Peak, and Edwards limestones comprise the right abutment; and the Glen Rose limestone underlies the proposed spillway. Minor slaking may occur within the shaly limestones of the Glen Rose but should not cause structural instabilities. Additional investigations will be required to delimit the faulting beneath the proposed dam axis.

b. Leakage through the Glen Rose formation should be nominal based upon information from hydraulic water pressure tests. However, the Edwards limestone on the right abutment is highly permeable. The pressure tests conducted in the Comanche Peak showed the formation to be considerably less permeable than the Edwards limestone. To prevent piping and detrimental underseepage, foundation treatment will be required.

c. Seepage measurements in the Frio River above Concan showed no streamflow losses. Geological mapping did not reveal any unusual leakage conditions. It is not known what influence faulting will have on leakage.

d. Materials suitable for an earthfill embankment may be available in the flood plain of the Frio River. Silt deposits were observed in many areas along the flood plain, and sand and gravel are available in sufficient quantities for use as free draining material. Additional subsurface exploration will be necessary to evaluate borrow areas, and testing will be required to determine the suitability of the sand and gravel for concrete aggregate.


LEGEND
Qal
Alluvium undifferentiated, clay, silt, sand, gravel and cemented gravel
QUATERNARY
COMANCHE SERIES
FREDERICKSBURG GROUP
TRINITY GROUP
CRETACEOUS
Kf
Fredericksburg Group undifferentiated, includes Edward and Comanche Peak Limestone
Kgr
Glen Rose Limestone
Strike and dip of bedding
Strike of vertical joint planes
U
D
Known fault showing up and down sides, fault dashed where inferred or concealed
Dip of fault plane
Fault zone
Geologic contact, occasionally inferred or concealed
Spring
NOTE: Geology by U.S. Geological Survey for U.S. Army Corps of Engineers, Ft. Worth District, April 1963.
APPROX. AXIS OF DAM
E. SPILLWAY
CAVES
SINK HOLE
Coffin Mountain
Kelly Ranch
Qal
Kf
Kgr
SCALE OF MILES
0
1/4
1/2
1
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
FRIO RIVER
DAM SITE & RESERVOIR GEOLOGY
CONCAN DAM SITE
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
SUBMITTED:
ENGINEER
CHIEF, PROJECT PLANNING BRANCH
APPROVAL RECOMMENDED:
ENGINEER
CHIEF, ENGINEERING DIVISION
APPROVED:
DISTRICT ENGINEER
PREPARED:
ENGINEER
CHIEF, FOUNDATION & MATERIALS BRANCH
DRAWN BY: M.S.F
CHECKED BY: M.S.S.
TO ACCOMPANY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
GUAD 707-2



SECTION ALONG AXIS OF DAM

LEGEND

OVERBURDEN

- Sandy Clay, tan
- Gravel, Sand and Clay

PRIMARY STRATA

- Edwards Limestone - Moderately hard to hard, gra medium to massive-bedded, vuggy and solutioned, scattered chert nodules.
- Comanche Peak Limestone - Moderately hard to hard, gray, nodular, fossiliferous, vuggy.
- Glen Rose Limestone - Soft to moderately har tan to tan-gray, thin to medium-bedded, argillaceous, fossiliferous, occasional shale and clay seam.
- Clay seam - Soft, shaly, tan.
- Fossiliferous
- Shale - dark-gray, soft, clayey.
- Weathering
- Chert
- 2C 2" Core boring
- 8A 8" Auger boring
- Inferred fault, arrows show direction of moment.

NOTES:

See Plate NO.17 for pressure test results and data.

Horizontal extent of shale and clay seams shown on section are inferred. Because of small scale not all clay seams are shown in section and lithologic symbols are somewhat generalized.

Absence of ground water levels opposite boring logs does not mean that ground water will not be encountered at the locations or within the vertical reaches of the boring.

See plate 14 for location of borings.

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
FRIO RIVER

GEOLOGIC PROFILE

CONCAN DAM SITE

SCALES AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
ENGINEER	ENGINEER, CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED	DRAWN V.J.M. / CHECKED M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD 707-2

LEGEND

PRIMARY STRATA

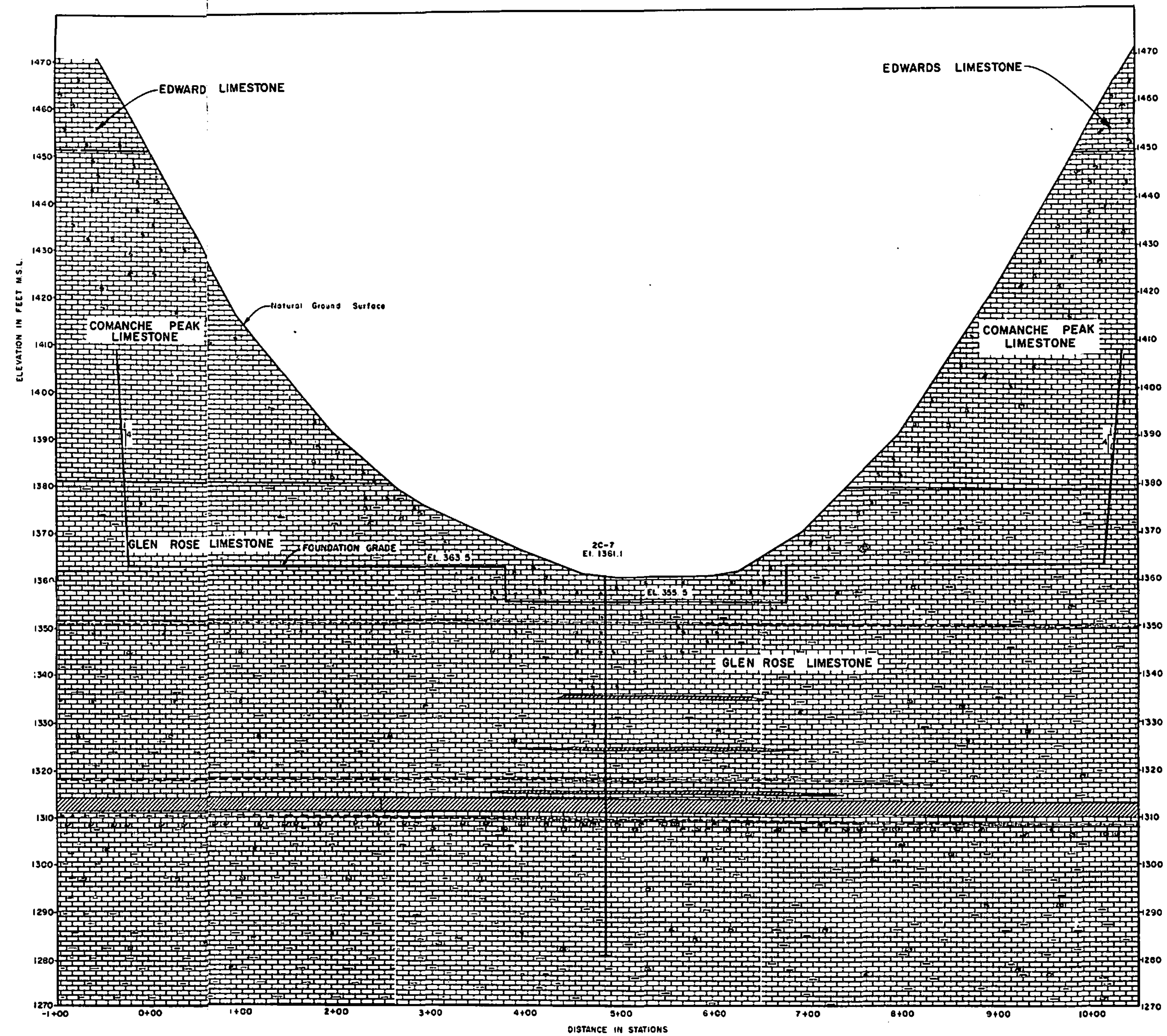
- Edwards Limestone – Moderately hard to hard, gray, medium to massive-bedded, vuggy and solutioned; scattered chert nodules.
- Comanche Peak Limestone – Moderately hard to hard, gray, nodular, fossiliferous, vuggy.
- Glen Rose Limestone – Soft to moderately hard, tan to tan-gray, thin to medium-bedded, argillaceous, fossiliferous; occasional shale and clay seam.
- Clay Seam – Soft, shaly, tan.
- Fossiliferous
- Weathering
- 2C 2" Core Boring

NOTES:

See Plate No. 17 for pressure test results and data.

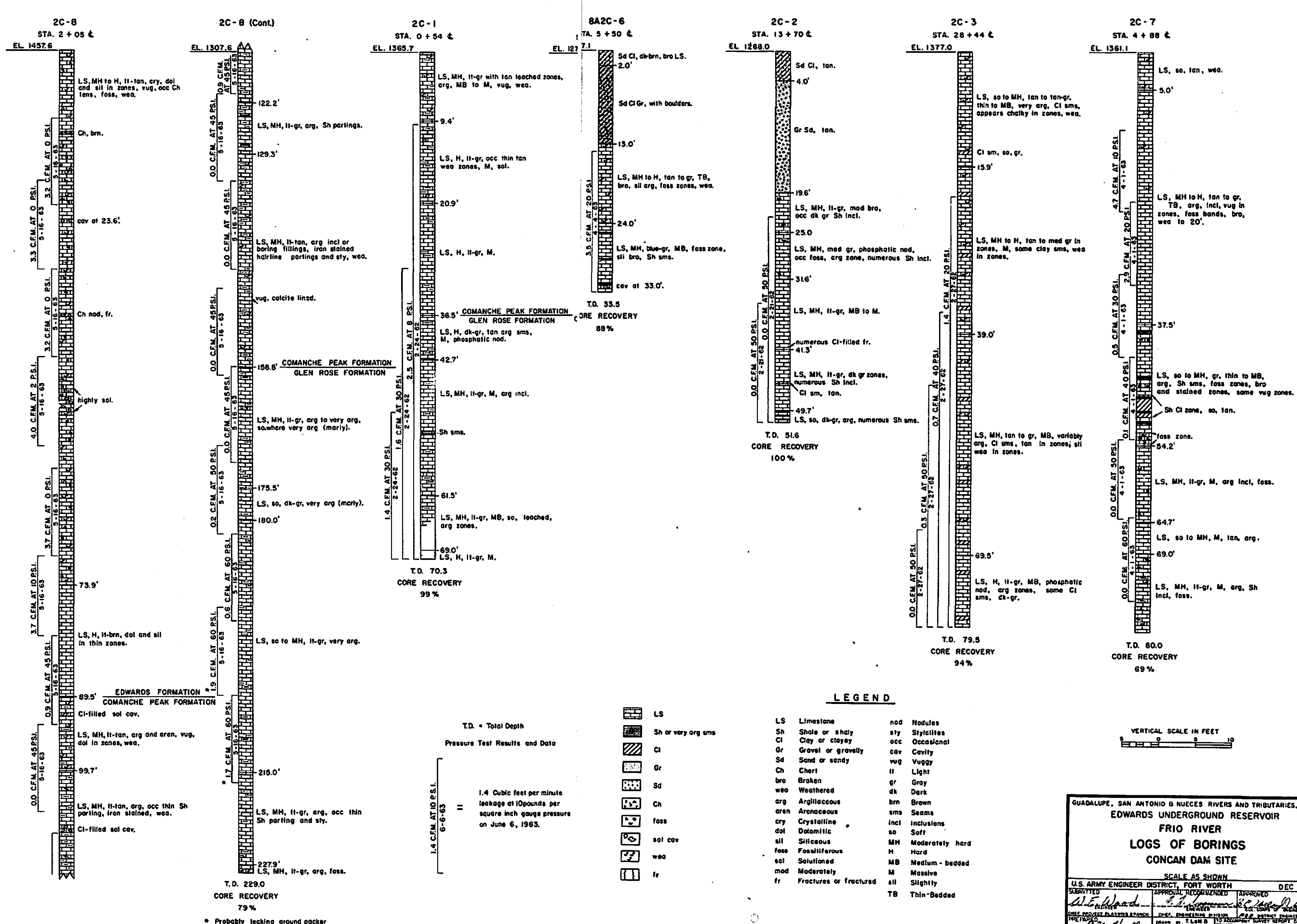
Horizontal extent of shale and clay seams shown on sections are inferred. Because of small scale not all clay seams are shown in the section and lithologic symbols are somewhat generalized.

Spillway section topography was taken from U.S.G.S. 7'30" quad. (Magers Crossing).



SPILLWAY
(LOOKING EAST)

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS EDWARDS UNDERGROUND RESERVOIR FRIO RIVER **GEOLOGIC SECTION** **CONCAN DAM SITE** SCALES AS SHOWN	
U.S. ARMY ENGINEER DISTRICT, FORT WORTH	DEC. 1964
SUBMITTED: W. E. Wood, Engineer, Chief, Project Planning Branch	APPROVAL RECOMMENDED: Engineer, Chief, Engineering Division
APPROVED: Col., Corps of Engineers, District Engineer	
PREPARED: B. M. Hull, Engineer, Chief, Foundation & Materials Br.	DRAWN BY B.G.S. / CHECKED BY M.G.C.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR	FILE GUAD 707-2



LEGEND

Symbol	
	LS
	Sh or very arg sms
	Cl
	Gr
	Sd
	Ch
	foss
	sol cav
	wea
	fr

LS	Limestone	nod	Nodules
Sh	Shale or shaly	sty	Stylolites
Cl	Clay or clayey	occ	Occasional
Gr	Gravel or gravelly	cav	Cavity
Sd	Sand or sandy	vug	Vuggy
Ch	Chert	lt	Light
bro	Broken	gr	Gray
wea	Weathered	dk	Dark
arg	Argillaceous	brn	Brown
aren	Arenaceous	sms	Seams
cry	Crystalline	incl	Inclusions
dol	Dolomitic	so	Soft
sil	Siliceous	MH	Moderately hard
foss	Fossiliferous	H	Hard
sol	Solutioned	MB	Medium-bedded
mod	Moderately	M	Massive
fr	Fractures or fractured	sli	Slightly
		TB	Thin-Bedded

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
FRIO RIVER
LOGS OF BORINGS
CONCAN DAM SITE
SCALE AS SHOWN

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

SUBMITTED: W. E. Wood, CHIEF, PROJECT PLANNING BRANCH | APPROVAL RECOMMENDED: CHIEF, ENGINEERING DIVISION | APPROVED: COL, CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: CHIEF, FOUNDATION & MATERIALS BR. | DRAWN BY: T.L.M.B. | CHECKED BY: M.G.G. | TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD.-707-2

59. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Sabinal Dam site No. 2 is located on the Sabinal River approximately 12 miles north of Sabinal, Texas, Uvalde County. The site is situated in the Edwards Plateau section of the Great Plains physiographic province along the northern edge of the Balcones fault zone. Preliminary subsurface investigations have located faulted intervals and evidence of igneous intrusives. The Glen Rose limestone, the oldest formation exposed in the area, crops out along the valley walls and underlies the valley alluvium. The formation is approximately 900 feet thick and has been divided into an upper and a lower member. The division is based on a fossiliferous zone referred to as the Salenia texana zone. The lower member is composed chiefly of massive limestone beds with thin shale and marly interbeds, whereas the upper member is a thin-bedded argillaceous limestone with many clay, shale, and very marly interbeds. The Comanche Peak formation of the Fredericksburg group overlies the Glen Rose limestone and appears as a thin outcrop belt along the higher ridges and hills. The rock is a hard, nodular limestone commonly disseminated with tubelike openings. Generally the tubes are filled with soft, earthy material. The Edwards formation, a massive, hard, crystalline limestone, overlies the Comanche Peak and caps the higher hills in the area. The rock is generally quite massive and resistant to erosion and is easily recognized by its bluff forming characteristics.

60. Relief in the vicinity of the dam site features rolling hills capped with near vertical bluffs of massive limestone. At the investigated site, the Sabinal River has formed a broad, alluvium-filled valley approximately 3,000 feet wide. The right abutment rises steeply from elevation 1140 to 1380 in less than 800 feet, whereas the left abutment rises gradually as a gently sloping hill. Upstream from the proposed site the valley becomes wider and the relief is not so rugged. Approximately one mile downstream from the investigated dam site, the valley narrows into a V-shaped canyon with steep, relatively vegetation-barren abutments flanking both sides of the river. For the plan of operation of the Edwards Underground Reservoir, whereby water is to be released into the underground as quickly as possible to reduce the effects of evaporation, a dam located along this stretch of river would be more desirable.

61. STRUCTURAL GEOLOGY.- The Balcones fault zone, a belt of intense faulting extending northeast-southwest across Uvalde County, is the principal structural feature in the area. The Geological Survey 25/ reports that in the northeastern part of the county, the total vertical displacement across the zone is approximately 700 feet. The largest single fault in the vicinity of the dam site is located approximately 2,000 feet downstream (see contact aerial photo on plate 18). This fault is an extension of the Woodward Cave fault, prominent in Medina County. The total displacement appears to be

approximately 175 feet and has resulted in the Edwards formation being down-faulted against the Glen Rose formation. Two other faults are located south of the Woodward Cave fault but the displacements are relatively minor. Approximately 2,000 feet northwest of the right abutment a small, normal fault has been mapped but its displacement is unknown. The valley section of the dam site also appears to include a fault as evidenced by approximately 84 feet of stratigraphic displacement between the right and left abutments (see plate 18). This inferred fault, however, is covered with alluvium and has not been accurately located by drilling. Additional investigations may find a relationship between the valley faulting and the igneous plug encountered beneath the valley alluvium.

62. The regional dip of the beds in the area is toward the southeast at a low angle. Considerable steepening occurs adjacent to fault zones.

63. RESERVOIR LEAKAGE.- Geologic investigations to date indicate that the entire reservoir will be included within the Glen Rose limestone. A few igneous dikes or plugs may be intruded into the valley section, causing some seepage through fractures or along the periphery of the intrusives. In the event future subsurface investigations encounter water losses in these areas, it is believed that remedial grouting will be applicable and capable of "tightening" the intervals. Future explorations should be alerted to the need for delimiting the referenced anomalies, and provisions should be made whereby the true water-table conditions can be clearly defined. If subsurface investigation determines a ground-water coning effect in the area of the dikes or plugs, it is possible that the ground water is escaping, and grouting may be required. In 1938, investigations along a proposed dam axis, located approximately 2,000 feet downstream from the present site, revealed three sinkholes in the valley adjacent to the centerline. In a report on the geology of this site it was stated that, in all probability, the sinks connect with and discharge into the "Blue Water Hole," the last permanent pool under normal flow conditions on the Sabinal River. It is not known if the sinks are continuous and founded in the bedrock or are simply formed in the alluvial gravels. Inasmuch as no loss of flow is noted between these sinks and the "Blue Water Hole," it is quite possible that the connection is through bedrock. Although these sinks were noted downstream from the presently proposed axis, associated solutioning phenomena may have developed similar conditions in the site area.

64. From 1934 to 1958 seven low-flow investigations were made on the Sabinal River. The results of these measurements, published in Texas Water Commission Bulletin 5807D, Channel Gain and Loss Investigations Texas Streams, 1918-1958, conclude: "No material water losses were found in the reach on the Glen Rose limestone." Shortly downstream from the gaging station, at a location referred to as "near Sabinal" (actually located a few thousand feet below

the proposed site), the river crosses a series of faults which downfault the Edwards limestone into the riverbed. In April of 1958 the low-flow seepage investigation showed 58 percent of the streamflow was lost between the gaging station "near Sabinal" (river mile 31.4) and the gaging station at Sabinal (river mile 49.0). It may be concluded from these investigations that the Glen Rose limestone in the river valley is apparently capable of containing water, at least at low flow stages of the river.

65. INVESTIGATION.- Sabinal Dam site No. 2 was explored with three NX-size core borings in April and May 1963. Boring 2C-1, located on the right abutment, was drilled to a depth of 182 feet; boring 2C-2, on the left abutment, was drilled to a depth of 208 feet; and boring 8A2C-3, a combination auger and core boring located in the valley, was drilled to a depth of 113.8 feet. Borings 2C-1 and 2C-2 were drilled to explore the characteristics of the rock comprising the abutments and to locate possible faulting. The valley boring was drilled to determine the thickness and type of valley alluvium and the suitability of the underlying bedrock for structure foundations. All of the borings were water-pressure tested. The locations of the borings are shown on plate 18.

66. In 1938, a dam site, located approximately 200 feet downstream from the present site, was explored with seven auger borings drilled along the axis. The borings were designed to locate the top of rock and to explore the nature of the overburden.

67. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The location of the dam site was moved upstream from the site investigated in 1938 primarily to permit the dam and reservoir to be founded entirely on the Glen Rose limestone and outside the recognized limits of intense faulting. Topographically, the site is located as far upstream as is practicable without resorting to an excessively long embankment and reduced reservoir storage capacity. However, as revealed by recent explorations, additional subsurface investigation will be necessary before the present location can be considered a firm site.

b. Lithology.- The Glen Rose limestone of the Trinity group comprises the foundation rock for both abutments and a portion of the valley beneath the alluvium. The formation consists of a soft to moderately hard, argillaceous limestone with thin shale and marly limestone interbeds. The rock is light tan to gray, generally fossiliferous, and includes some solutioning. The rock is generally highly fractured to a depth of 100 feet. Some secondary deposits of clay were encountered on the fracture openings. The included shale beds are generally gray to dark gray, soft, and calcareous. Both 2C-1 and 2C-2, abutment borings, encountered soft, crystalline, white to gray gypsum beds, approximately 9 feet thick, at depths of 141.5 and 113.9 feet, respectively.

(1) Boring 8A2C-3, drilled in the valley on the centerline, encountered an igneous plug or dike beneath the valley alluvium. The rock comprising the plug is an igneous breccia composed of angular to subrounded basalt fragments up to 2 inches in diameter, tightly cemented with calcium carbonate. Light-green serpentine usually forms a thin coating on the basalt fragments. The breccia is massive and soft variable to hard. It is believed that boring 8A2C-3 penetrated the edge of the plug inasumch as the core was highly broken and included some limestone fragments. More exploration will be required to define the areal extent of the breccia and its possible association with faulting.

c. Weathering.- Unusually deep weathering in the form of hydration and oxidation was revealed by subsurface investigations in the abutments. Generally, the limestone was highly weathered, broken, and often included clay fillings in the fractured openings. One possible explanation for the deep weathering in the limestone at this location is the close proximity to faulting and the presence of the igneous plug or dike. Iron oxide staining on the fracture surfaces and bedding planes extends to a considerable depth. Rock penetrated in boring 2C-1 is moderately to highly weathered to 94 feet, and slightly weathered from 94 feet to 128.8 feet. Boring 2C-2 encountered fresh limestone at a depth of 102.5 feet. The rock was only slightly weathered below 91.0 feet. Based on past experience, it may be assumed that weathering extends only a few feet into the bedrock in the valley section. The breccia encountered in boring 8A2C-3 was highly weathered (primarily oxidation) for the first 10 feet but essentially unweathered below this depth.

d. Faulting.- Correlation of the cores taken from borings 2C-1 and 2C-2 infers that a fault or series of faults, with a total displacement of approximately 84 feet, cuts the dam axis, downfaulting the right abutment. Correlation is based on a 9-foot gypsum bed encountered at elevation 1117.5 in 2C-1 and at elevation 1201.2 in 2C-2. The U.S. Geological Survey 25/ notes that two anhydrite beds are persistent throughout Uvalde County and are easily correlatable on electric logs. In the northern part of the county the first bed is approximately 200 feet and the second bed approximately 400 feet below the top of the Glen Rose limestone. The gypsum bed encountered in the borings is, in all probability, the upper evaporite zone. Although the exact location of the fault is unknown, it is believed the fault is associated with the igneous plug encountered in boring 8A2C-3 at station 31+79. This reasoning is based on the possibility that the plug or dike was injected into a zone of weakness, caused by the fault. Plate 18 shows the inferred geology along the dam axis. Additional investigations will be necessary before the inferred faulting can be identified and located.

e. Overburden.- Only one boring was drilled in the valley alluvium along the centerline. This boring (8A2C-3) encountered 35.9 feet of alluvial material consisting of, from top to bottom, 7.0 feet of calcareous, sandy clay, 8.0 feet of clayey, sandy gravel, and 20.9 feet of stiff sandy clay with scattered limestone particles. The abutments are essentially free of any overburden materials except for a thin, spotty mantle of residual soil, held in place by vegetation. Plate 18 shows the inferred vertical and horizontal extent of the overburden along the dam axis centerline.

f. Leakage.- Hydraulic pressure tests conducted in the borings revealed a high leakage condition in the Glen Rose limestone which comprises the abutments. Boring 2C-1, located on the right abutment, recorded takes up to 3.8 cfm to a depth of 43 feet and 6.3 cfm from 83 to 103 feet at 40 psi gage pressure. The remainder of the intervals tested took less than 1.0 cfm. Boring 2C-2, located on the left abutment, took 4.0 cfm from 39 feet to 90 feet and 1.8 to 3.5 cfm from 151 to 194 feet. Losses in other portions of the hole were insignificant. Three short intervals could not be pressure tested because the packer could not be seated. The igneous intrusive encountered beneath the valley alluvium was essentially tight. Only one short test interval recorded a water take. The pressure test results and data are shown on plate 19.

g. Water table.- The ground-water level was recorded at a depth of 167 feet in boring 2C-2, drilled on the left abutment. Ground-water levels were not determined in the valley or right abutment borings.

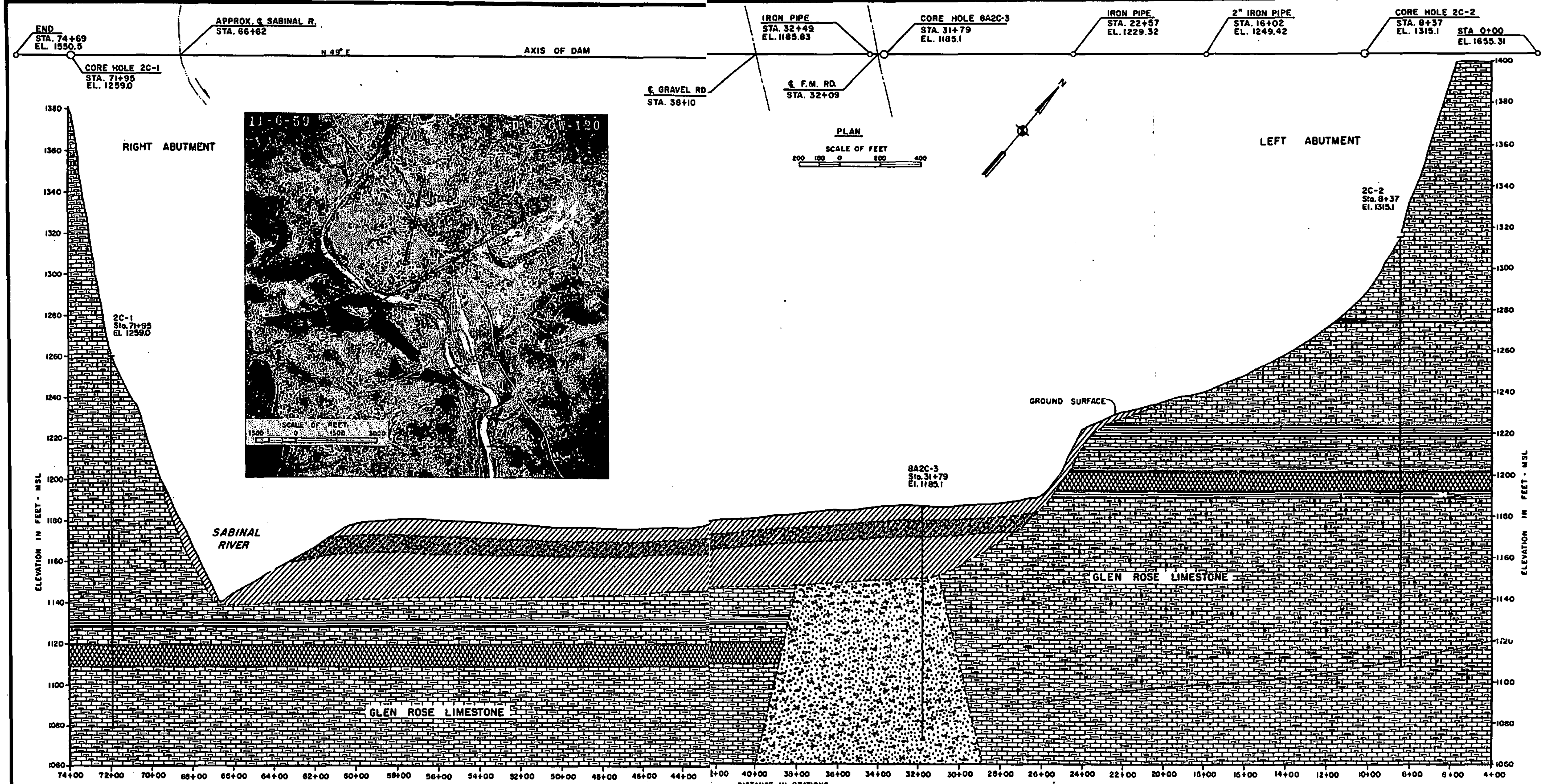
68. CONSTRUCTION MATERIALS.- Material suitable for use as impervious core is probably available from the clayey valley alluvials discussed earlier in this report. However, sufficient quantities for use as earthfill embankment material are questionable. Material suitable for random rockfill or riprap is available in the immediate site vicinity. Several sand and gravel deposits are located locally, are suitable for use as free-draining material, and may be suitable for concrete aggregate. Acceptable tested sources of sand and gravel for concrete are available from the area of San Antonio, Texas.

69. CONCLUSIONS AND RECOMMENDATIONS.- Studies at Sabinal Dam site No. 2 have raised several questions concerning both the suitability of the reservoir to contain water and structural features of the foundation rocks. Conclusions and recommendations concerning these conditions are as follows:

a. Considerably more exploration in the vicinity of the dam site will be required to define the areal extent of the igneous plug or dike and to locate the fault or faults that are inferred to intersect the proposed dam axis. In addition, extensive drilling and pressure testing of the rock will be required to determine to what extent intrusives and/or faulting have ruptured the bedrock. A potentially serious leakage condition exists in the limestone and gypsum comprising both abutments, and along the periphery of the referenced intrusive. The highly soluble gypsum bed encountered at the site will require special foundation treatment.

b. Investigations to date have not been sufficient to permit a realistic evaluation of the reservoir leakage characteristics. Additional studies must be conducted upstream from the dam site to determine the physical characteristics of the rock and to test what effect the igneous activity in the area may have had on the bedrock.

c. Preliminary investigation suggests a sufficient quantity of material is available from the valley alluvium for an impervious core. Additional investigation will be required to determine the quantity available for use as embankment material. Adequate quantities of material for rockfill or riprap are available in the immediate vicinity of the dam site.



ECTION ALONG AXIS OF DAM

(LOOKING UPSTREAM)

LEGEND

OVERBURDEN

- Clay or Gravel, Sand, and Clay mixture.
- Clayey, Sandy Gravel

PRIMARY MATERIAL

- Limestone, Soft to moderately hard Argillaceous
- Shale, soft, gray
- Gypsum, soft, white to gray
- Breccia, soft to hard
- " " Weathering
- " " Fossils

8A 8" Auger boring
2C 2" Core boring

NOTES:

Horizontal extent of shale seams unknown and generalized. Detailed description of material is shown on Plate 22 Logs of Borings.

See Plate 22 for pressure test results and data

Absence of ground water levels opposite boring does not mean that water was not encountered.

Limits of Breccia unknown

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
SABINAL RIVER

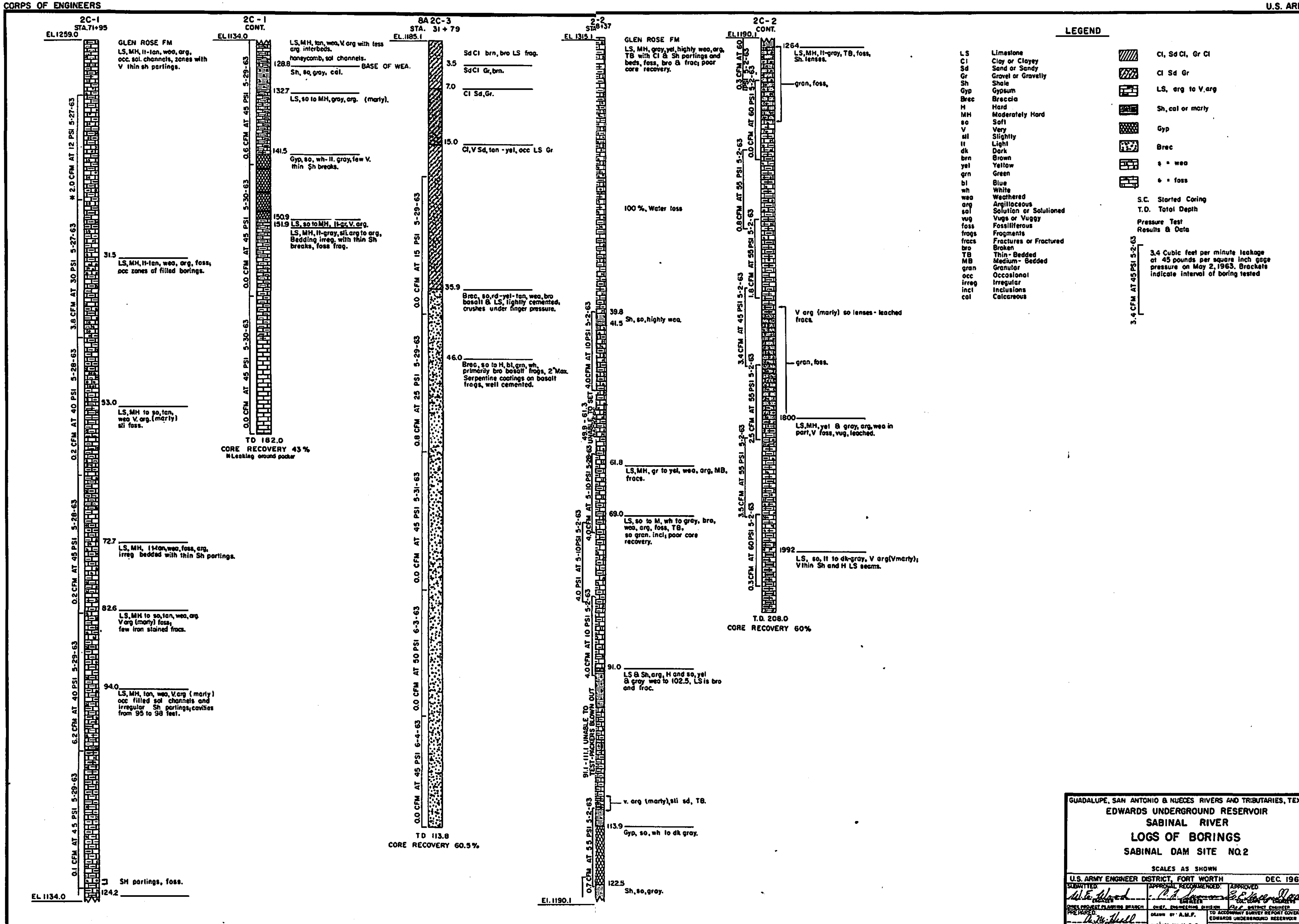
GEOLOGIC PROFILE

SABINAL DAM SITE NO. 2

SCALES AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, Engineer, Chief, Project Planning Branch	Engineer, Chief, Engineering Division	Col. Corps of Engineers, District Engineer
PREPARED: A. M. Hull, Engineer, Chief Foundation & Materials Br.	DRAWN BY: A.M.F. / CHECKED BY: M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE: GUAD: 707-2


2C-1
STA.71+95
EL.1259.0
GLEN ROSE FM
LS, MH, lt-tan, wea, arg, occ. sol. channels, zones with V thin sh partings.
31.5 LS, MH, lt-tan, wea, arg, foss, occ zones of filled borings.
53.0 LS, MH to so, tan, wea V. arg. (marly) sli foss.
72.7 LS, MH, lt-tan, wea, foss, arg, irreg bedded with thin Sh partings.
82.6 LS, MH to so, tan, wea, arg. V arg (marly) foss; few iron stained fracs.
94.0 LS, MH, tan, wea, V.arg (marly) occ filled sol channels and irregular Sh partings; cavities from 95 to 98 feet.
SH partings, foss.
124.2
EL 1134.0
2C-1
CONT.
EL.1134.0
LS, MH, tan, wea, V arg with less arg interbeds.
honeycomb, sol channels.
128.8 BASE OF WEA.
Sh, so, gray, cal.
132.7 LS, so to MH, gray, arg. (marly).
141.5 Gyp, so, wh-lt. gray, few V. thin Sh breaks.
150.9 LS, so to MH, lt-gr, V. arg.
151.9 LS, MH, lt-gray, sli. arg to arg, Bedding irreg. with thin Sh breaks, foss frag.
TD 182.0
CORE RECOVERY 43%
Leaking around packer
8A 2C-3
STA. 31+79
EL.1185.1
SdCl brn, bro LS frag.
3.5 SdCl Gr, brn.
7.0 Cl Sd, Gr.
15.0 Cl, V Sd, tan-yel, occ LS Gr
35.9 Brec, so, rd-yel-tan, wea, bro basalt & LS, lightly cemented, crushes under finger pressure.
46.0 Brec, so to H, bl, grn, wh, primarily bro basalt frags, 2" Max. Serpentine coatings on basalt frags, well cemented.
TD 113.8
CORE RECOVERY 60.5%
2-2
STA. 8+37
EL.1315.1
GLEN ROSE FM
LS, MH, gray, yel, highly wea, arg, TB with Cl & Sh partings and beds, foss, bro & frac; poor core recovery.
100 %. Water loss
39.8
41.5 Sh, so, highly wea.
61.8 LS, MH, gr to yel, wea, arg, MB, fracs.
69.0 LS, so to M, wh to gray, bro, wea, arg, foss, TB, so gran. incl; poor core recovery.
91.0 LS & Sh, arg, H and so, yel & gray wea to 102.5, LS is bro and frac.
v. arg (marly), sli sd, TB.
113.9 Gyp, so, wh to dk gray.
122.5 Sh, so, gray.
El. 1190.1
2C-2
CONT.
EL.1190.1
126.4 LS, MH, lt-gray, TB, foss, Sh. lenses.
gran, foss.
V arg (marly) so lenses - leached fracs.
gran, foss.
180.0 LS, MH, yel & gray, arg, wea in part, V foss, vug, leached.
199.2 LS, so, lt to dk-gray, V arg (V marly); V thin Sh and H LS seams.
T.D. 208.0
CORE RECOVERY 60%
LEGEND
LS Limestone
Cl Clay or Clayey
Sd Sand or Sandy
Gr Gravel or Gravelly
Sh Shale
Gyp Gypsum
Brec Breccia
H Hard
MH Moderately Hard
so Soft
V Very
sli Slightly
lt Light
dk Dark
brn Brown
yel Yellow
grn Green
bl Blue
wh White
wea Weathered
arg Argillaceous
sol Solution or Solutioned
vug Vugs or Vuggy
foss Fossiliferous
frags Fragments
fracs Fractures or Fractured
bro Broken
TB Thin-Bedded
MB Medium-Bedded
gran Granular
occ Occasional
irreg Irregular
incl Inclusions
cal Calcareous
Cl, Sd Cl, Gr Cl
Cl Sd Gr
LS, arg to V. arg
Sh, cal or marly
Gyp
Brec
$ = wea
¢ = foss
S.C. Started Coring
T.D. Total Depth
Pressure Test Results & Data
3.4 CFM AT 45 PSI 5-2-63
3.4 Cubic feet per minute leakage at 45 pounds per square inch gage pressure on May 2, 1963. Brackets indicate interval of boring tested
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX
EDWARDS UNDERGROUND RESERVOIR
SABINAL RIVER
LOGS OF BORINGS
SABINAL DAM SITE NO. 2
SCALES AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
DRAWN BY: A.M.F.
CHECKED BY: M.G.G.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 707-2

SABINAL DAM SITE NO. 1 - SABINAL RIVER

70. GENERAL.- For the plan of operation whereby flood water is to be captured and released into the underground as quickly as possible, a dam site on the Sabinal River was selected about 1 mile downstream from Sabinal Dam site No. 2 and about 2,000 feet downstream from the "Blue Water Hole," the last permanent pool under normal flow conditions. Topography in the area is rugged and well suited for the proposed structure. The river has formed a narrow V-shaped canyon, cut into limestone belonging to the Edwards and Comanche Peak formations. A dam constructed at this location with a top elevation of 1244 will have an axis about 2370 feet long and will create a temporary reservoir that will inundate a small privately-owned concrete dam located about 800 feet upstream from the axis.

71. FOUNDATION CONDITIONS.- There has not been any foundation drilling at Sabinal Dam site No. 1; however, a geological reconnaissance of the area shows the structure will be located in the Balcones fault zone and founded on the Comanche Peak and Edwards limestones. Geologically the structure will be founded on rock similar to that at Medina Dam on the Medina River. The Comanche Peak formation, approximately 50 feet thick, overlies the Glen Rose limestone and occurs as a thin belt, outcropping along the base of the ridges bordering the river. The rock is a hard, nodular limestone distinguished by tubelike borings filled with soft earthy material. The Edwards limestone overlies the Comanche Peak and caps the hills and ridges in the area with a hard, massive, crystalline limestone with chert lenses and nodules scattered throughout. The rock is considered adequate to support the structure. Foundation treatment, however, will be required.

72. With the dam site located in the Balcones fault zone, faulting will not be uncommon. About one-half mile upstream from the axis the Woodward Cave fault has a stratigraphic displacement of approximately 175 feet. In addition to this large fault, two small normal faults, one immediately upstream and one downstream of the dam site, can be seen cutting the rock. Although the displacements are relatively small, they attest to the intensity of the structural disturbance in the area, and minor faulting at the site itself may be discovered as additional exploration is carried out.

73. It may be concluded from the geological reconnaissance that the site is geologically and topographically suited for the proposed structure. Faulting will probably be encountered, but should not be a hazard to the safety of the structure. Alluvium encountered in the river valley will be less than 20 feet thick. Materials for an earthfill structure of the size proposed may be available upstream in the vicinity of the investigated site. If earthfill material is not available in sufficient quantities, then rock for a rockfill structure may be obtained from a nearby source. As the dam site is

located only about 2,000 feet downstream from first measurable flow losses in the Sabinal River, siltation of the reservoir is not expected to significantly reduce the infiltration rate of the surface water into the underground aquifer. Seepage investigations show substantial streamflow losses for the next 17 river miles below the dam site.

SECO DAM SITE NO. 1 - SECO CREEK

74. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Seco Dam site No. 1 is located on Seco Creek in northwestern Medina County, approximately 16 miles northwest of D'Hanis, Texas. Seco Creek is an intermittent stream which has its headwaters in south central Bandera County. The creek flows southward across Bandera and Medina Counties to its confluence with Hondo Creek in north central Frio County. From its headwaters in Bandera County to a short distance downstream from the proposed dam site, Seco Creek flows over the Glen Rose formation, Trinity group. The rock is a moderate slope former and is easily recognized by its "stair-step" topography. Massive bluffs of resistant limestone, belonging to the Fredericksburg group, cap the higher ridges and hills throughout the watershed. A short distance downstream from the dam site the Edwards limestone is downfaulted into the streambed and for the next 2.8 miles the creek flows over the Edwards and Comanche Peak limestones. Throughout its short course, Seco Creek traverses the southern portion of the Edwards Plateau, crosses the Balcones fault zone, and empties onto the flat, featureless Coastal Plain area.

75. STRUCTURAL GEOLOGY.- The dam site is located on the northern edge of the Balcones fault zone, the principal structural feature in Medina County, which trends in a northeasterly direction across the county. Several near parallel normal faults, located downstream of the site, are included in the zone. The U. S. Geological Survey 9/ states that the displacement along the individual faults ranges up to 700 feet, and surface expressions can often be traced for as much as 35 miles. The Woodward Cave fault is the nearest significant fault to the dam site.

76. RESERVOIR LEAKAGE.- Although exploration has shown that the proposed reservoir will be confined within the Glen Rose limestone (usually considered reasonably tight), there is some evidence that the rock at this location is not suitable to contain water without excessive leakage. Foundation drilling at the site showed the rock to be highly weathered and broken, and water pressure tests indicated a relatively high permeability. Drilling has not encountered the water table, suggesting the streamflow may be tributary to the ground-water level. A low-flow seepage investigation to determine flow gains and losses was conducted on Seco Creek from its headwaters in Bandera County to U. S. Highway 90. The investigation was made from April 1 through 4, 1959, and divided the area into four sub-reaches. Subreach 1, the only area this report is concerned with, covers that portion of creek that flows on the Glen Rose limestone above the upper contact of the Edwards limestone. This reach, 16.4 river miles long, contributes most of the flow of Seco Creek. Bulletin 5807D, Channel Gain and Loss Investigations, Texas Streams, 1918-1958, recorded the following results: "The flow increases from 1.5 cfs to

about 33.5 cfs in the upper 13 miles of the reach. The losing section begins about 1 mile above the gaging station near Utopia; about 5.3 cfs was lost from that point to the upper contact of the Edwards limestone 2.0 miles below the gage." The proposed dam site is located about 1.2 miles below the referenced gaging station and about 0.8 mile above the Edwards contact. During the exploratory drilling at the site, drilling water was obtained from Seco Creek approximately 1 mile above the gaging station. At this time it was noted that the creek flow was very low and had ceased flowing before reaching the gaging station located 1.2 miles above the dam site. The results of this one seepage investigation would suggest that some losses will be experienced in the streambed above the dam site. The extent to which construction of a dam and reservoir would increase the leakage in this stretch is conjectural and would require detailed studies. However, it appears reasonable to assume that reservoir losses would be considerably greater than stream losses at low-flow stage.

77. INVESTIGATIONS.- Initial foundation investigation at the site consisted of one NX-size core boring (2C-1) drilled in June 1963. Because of the low percentage of core recovered in this boring, two additional borings were drilled in October 1963. Boring 6C-2 was stepped down from 2C-1 on the right abutment to permit investigation of a full abutment section. Respective depths for these borings were 124.3 feet and 82.0 feet. Boring 8A2C-3 was drilled in the creek valley to a depth of 42.0 feet to explore the nature of the alluvium and the condition of the underlying bedrock. All of the borings were pressure tested. The graphic logs are shown on plate 21.

78. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- Subsurface investigations indicate that the upper member of the Glen Rose limestone comprises the foundation rock for the embankment and appurtenant structures. This stratrigraphic sequence is also found along the valley walls and underlying valley alluvium and is the only formation cropping out within the proposed reservoir. Where investigated, the rock has been found to be broken and highly weathered. The dam site was selected to permit the shortest alignment possible, consistent with locating the reservoir within Glen Rose limestone. This necessitated positioning the site a short distance upstream from the Woodward Cave fault where the permeable Edwards limestone is downfaulted into the creek valley.

b. Lithology.- The Glen Rose limestone at the dam site is composed primarily of highly weathered and broken limestone and shale. The limestone is soft to hard, generally argillaceous and fossiliferous, and sometimes nodular. The shale interbeds, varying in thickness from a few inches to a few feet, are soft and often weathered to a clay. The rock is characterized by numerous hairline fractures healed with veinlets of calcite. In outcrop, the Glen Rose forms a gently sloping, stair-step type topography which reflects the differential weathering of the hard and soft layers within the formation.

c. Weathering.- Chemical weathering, primarily in the form of solutioning, oxidation, and hydration, has extended itself very deep into the foundation bedrock. Foundation drilling on the right abutment and in the valley showed the rock to be weathered throughout the intervals cored. Many of the shale and very marly interbeds have been completely altered to a soft, gray clay and, in general, the rock is highly broken, solutioned, and oxide stained. Further evidence of the extensive weathering was indicated by the continuous caving and the very poor core recovery, especially during the drilling of the NX (3-inch dia.) size holes. Core recovery in the 6-inch diameter hole was much better although fractured conditions in some intervals also resulted in considerable core loss.

d. Faulting.- The Woodward Cave fault, located approximately 0.8 mile below the dam site, is the only recognized fault within a mile of the dam site. It is a normal, high-angle fault with displacement of about 200 feet and downthrow to the south. The trace of the fault is easily recognized because the Edwards is in fault contact with the Glen Rose limestone. The approximate location of the fault trace is shown on the aerial photograph attached to plate 20. From the limited subsurface investigations it is impossible to determine if faulting actually intersects the proposed dam axis. Correlation between the borings was not possible because of the poor core recovery and the highly weathered condition of the rock. However, it is assumed that there is some faulting in the area as the rock is badly fractured, weathered, and is in close proximity to the Balcones fault system.

e. Overburden.- The maximum thickness of the alluvial overburden in the Seco Creek valley is unknown but, based on the subsurface information from boring 8A2C-3, it is believed to be in the range of 16 to 18 feet. Boring 8A2C-3, located at station 50+90, encountered 12.0 feet of sandy clay and clayey sand, overlying 3.8 feet of sand and gravel. A thin, spotty mantle of residual overburden, held in place by vegetation, occurs on the abutments. The profile of the overburden at the dam axis is shown on plate 21.

f. Leakage.- Hydraulic pressure tests conducted in the borings showed the bedrock at the site to be highly permeable. This condition is not typical of the Glen Rose limestone tested at other sites in the Edwards Plateau region, and suggests the effect of structural disturbances in the dam site vicinity. Whereas the majority of the valley borings at other sites have been "tight," the valley boring (8A2C-3) at this site recorded a take of 4.6 cfm (pump capacity) at 5 psi for full depth. The left abutment borings, 2C-1 and 6C-2, recorded takes exceeding 3.3 cfm in all intervals tested except from 36.0 to 56.0 feet in boring 6C-2. The take in this interval was insignificant. The cores from the borings showed the rock to be highly broken and weathered, and the drilling water return was generally lost at shallow depths.

g. Water table.- A ground-water level was not encountered in the investigational borings at the proposed site. Two existing water wells, located within a mile of the site (Glen Rose wells), are reportedly 310 feet and 475 feet deep with static water levels at 188.3 and 158.3 feet deep, respectively. These water-level readings were taken in March 1951, and October 1950 9/.

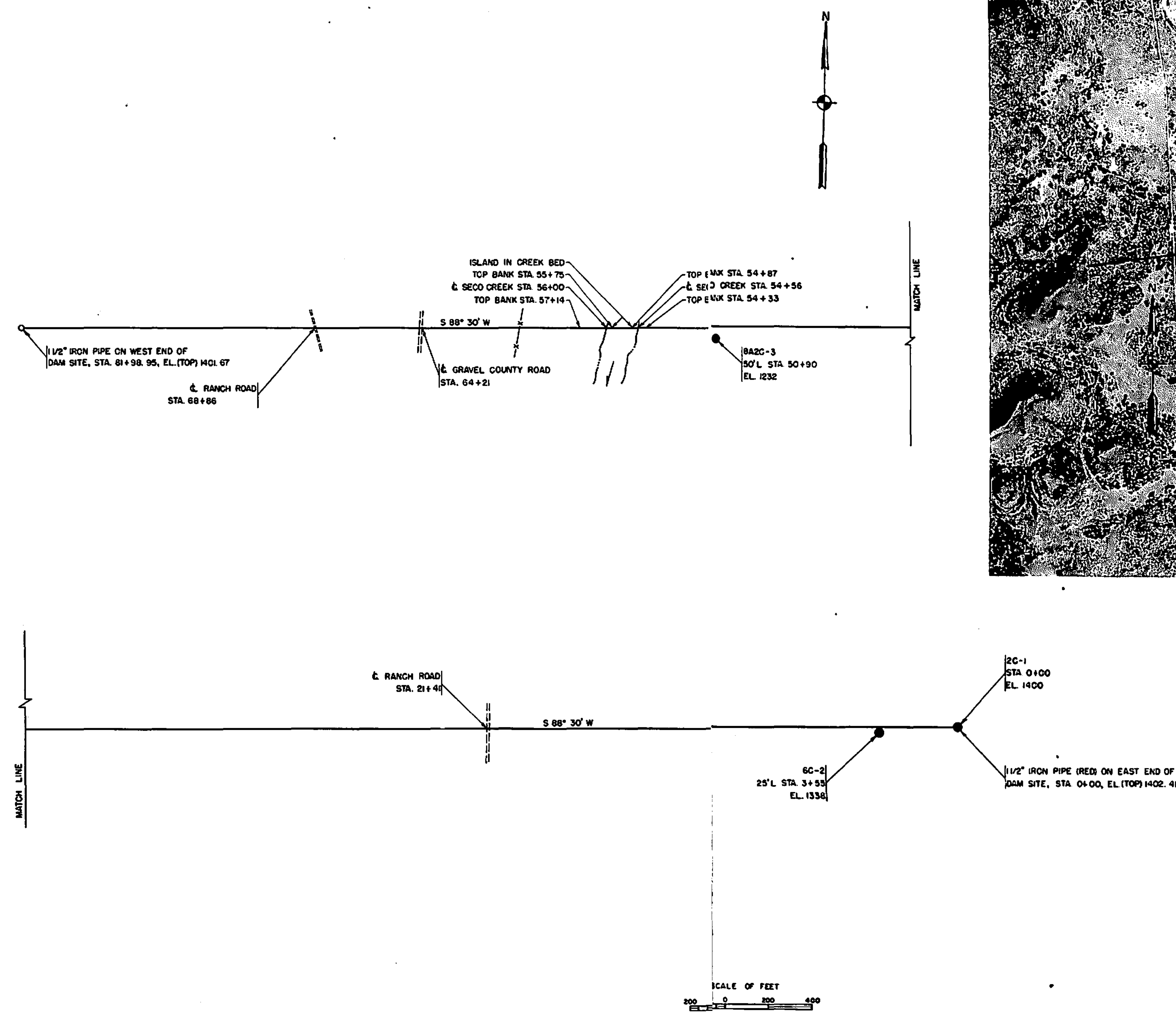
79. CONSTRUCTION MATERIALS.- From the present investigation it is not believed that a sufficient quantity of alluvium is available for an earthfill embankment, but the quantity may be adequate for impervious core or blanket use. Material for a random rockfill embankment is available from the Glen Rose outcrops within the immediate vicinity. However, the physical condition of this rock is somewhat questionable because of the clay content, and will require testing before approval. It is believed that a better quality rock is available from the Edwards limestone, which has been downfaulted and exposed in the creekbed approximately one-half mile south of the site, and also from the cap rock in the general area. Approved sources of concrete aggregate are available from the general vicinity of San Antonio, Texas. Local sources may be acceptable but have not been tested.

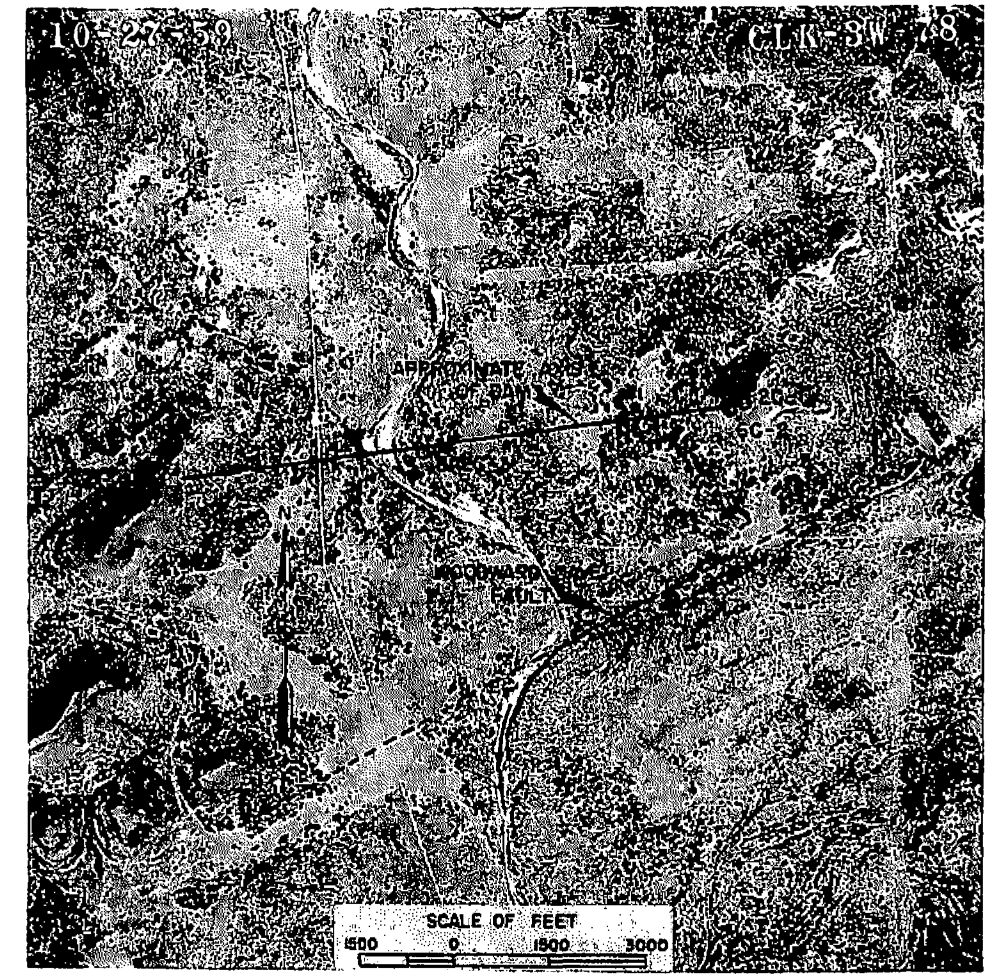
80. CONCLUSIONS AND RECOMMENDATIONS.- Based on the very limited geological and hydrological investigations to date the following conclusions and recommendations are presented:

a. The suitability of the Glen Rose bedrock for a foundation is questionable. The rock is badly broken and fractured, and has been intensely weathered to great depths. Extensive foundation treatment would be required.

b. A low-flow seepage investigation has shown that there is leakage in the Glen Rose limestone above the dam site. The absence of a ground-water table within the depths of the borings at the site and the relatively high water takes in the pressure tests tend to indicate that leakage may be excessive.

c. A sufficient quantity of materials for a random rockfill type dam is available within a reasonable haul distance. Additional investigation will be required to delineate specific areas and to secure samples for testing.





GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.

EDWARDS UNDERGROUND RESERVOIR

SECO CREEK

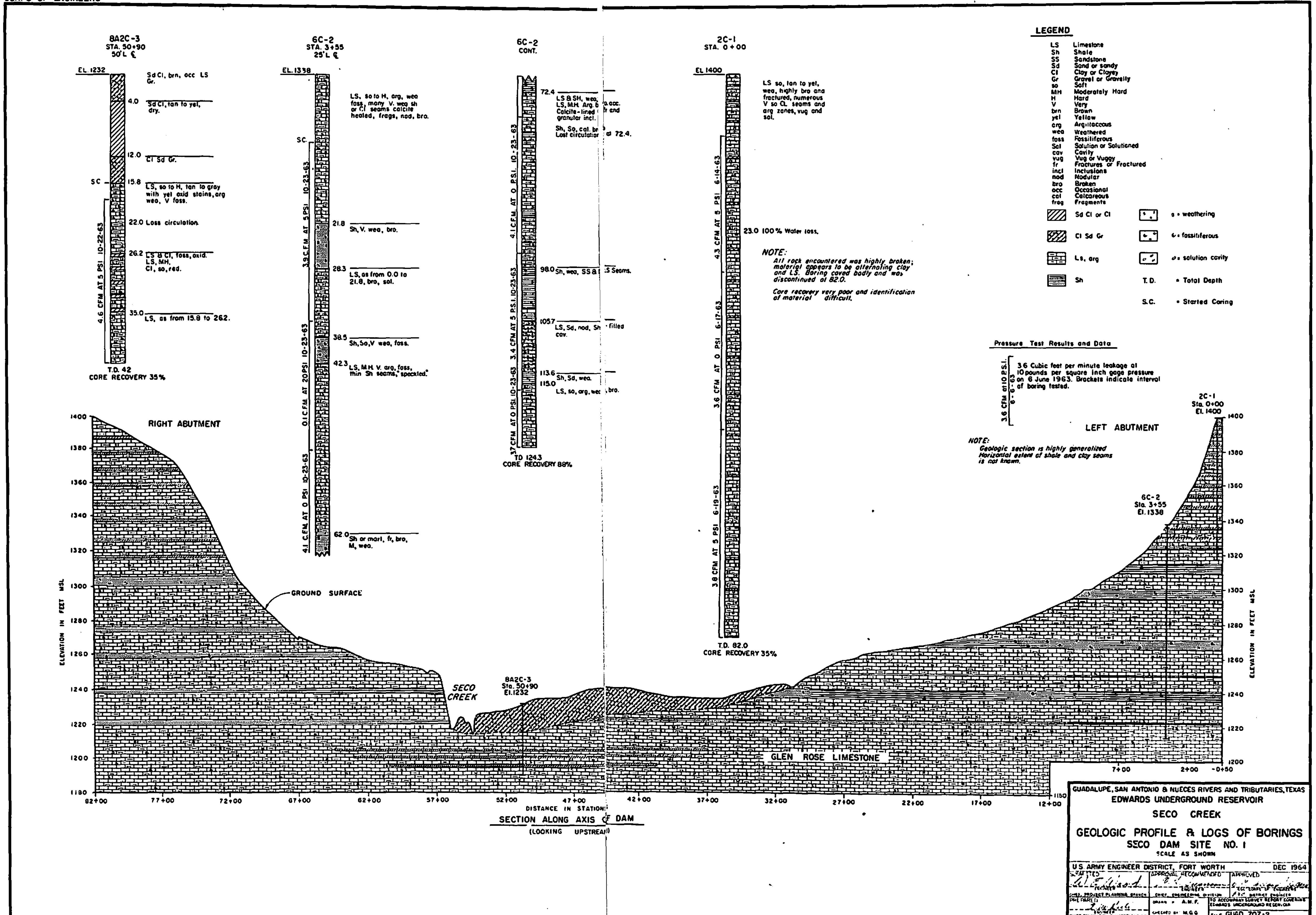
PLAN OF ALIGNMENT

SECO DAM SITE NO. 1

SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS, FOR DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF, FOUNDATION & MATERIALS BR.	DRAWN BY: T.L.M. CHECKED BY: M.O.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE: GUAD 707-2



8A2C-3
STA. 50+90
50'L ℄
EL. 1232
Sd Cl, brn, occ LS Gr.
4.0 Sd Cl, tan to yel, dry.
12.0 Cl Sd Gr.
SC
15.8 LS, so to H, tan to gray with yel oxid stains, arg wea, V foss.
22.0 Loss circulation.
26.2 LS & Cl, foss, oxid. LS, MH. Cl, so, red.
35.0 LS, as from 15.8 to 26.2.
4.6 CFM AT 5 PSI 10-22-63
T.D. 42
CORE RECOVERY 35%
6C-2
STA. 3+55
25'L ℄
EL. 1338
LS, so to H, arg, wea foss, many V. wea sh or Cl seams calcite healed, frags, nod, bro.
SC
21.8 Sh, V. wea, bro.
28.3 LS, as from 0.0 to 21.8, bro, sol.
38.5 Sh, So, V wea, foss.
42.3 LS, M.H. V. arg, foss, thin Sh seams, "speckled."
62.0 Sh or marl, fr, bro, M, wea.
6C-2
CONT.
72.4
98.0
105.7
113.6
115.0
TD 124.3
CORE RECOVERY 88%
2C-1
STA. 0+00
EL. 1400
LS so, tan to yel, wea, highly bro and fractured, numerous V so CL seams and arg zones, vug and sol.
23.0 100% Water loss.
NOTE: All rock encountered was highly broken; material appears to be alternating clay and LS. Boring caved badly and was discontinued at 82.0.
Core recovery very poor and identification of material difficult.
T.D. 82.0
CORE RECOVERY 35%
LEGEND
LS Limestone
Sh Shale
SS Sandstone
Sd Sand or sandy
Cl Clay or Clayey
Gr Gravel or Gravelly
so Soft
MH Moderately Hard
H Hard
V Very
brn Brown
yel Yellow
arg Argillaceous
wea Weathered
foss Fossiliferous
Sol Solution or Solutioned
cav Cavity
vug Vug or Vuggy
fr Fractures or Fractured
incl Inclusions
nod Nodular
bro Broken
occ Occasional
cal Calcareous
frag Fragments
Sd Cl or Cl
Cl Sd Gr
LS, arg
Sh
weathering
fossiliferous
solution cavity
T.D. = Total Depth
S.C. = Started Coring
Pressure Test Results and Data
3.6 Cubic feet per minute leakage at 10 pounds per square inch gage pressure on 6 June 1963. Brackets indicate interval of boring tested.
NOTE: Geologic section is highly generalized. Horizontal extent of shale and clay seams is not known.
RIGHT ABUTMENT
LEFT ABUTMENT
GROUND SURFACE
SECO CREEK
GLEN ROSE LIMESTONE
ELEVATION IN FEET MSL
DISTANCE IN STATIONS
SECTION ALONG AXIS OF DAM
(LOOKING UPSTREAM)
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
SECO CREEK
GEOLOGIC PROFILE & LOGS OF BORINGS
SECO DAM SITE NO. 1
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
FILE GUAD. 707-2

HONDO DAM SITE - HONDO CREEK

81. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Hondo Dam site is located approximately 17 miles northwest of Hondo, Texas, in Medina County. The site is situated in the Balcones fault zone near the southern portion of the Edwards Plateau section of the Great Plains physiographic province. Relief in the site area features rolling hills, generally capped with massive, steep bluffs of limestone.

82. The Glen Rose limestone, the oldest formation exposed in the area, crops out in the creek valley and along the confining valley walls. The formation is comprised of a soft to moderately hard, argillaceous limestone, including thin shale and clay interbeds. Fossiliferous zones are scattered throughout the section. The Walnut clay, the lowest formation of the Fredericksburg group, conformably overlies the Glen Rose. The Walnut clay is composed of a sandy, highly argillaceous limestone 4 to 12 feet thick and is very similar in appearance to the underlying Glen Rose. The Comanche Peak formation overlies the Walnut clay and consists of a nodular, argillaceous, light-gray, massive limestone ranging from 25 to 45 feet thick. The Edwards limestone, the uppermost unit of the Fredericksburg group, conformably overlies the Comanche Peak. In the reservoir and dam site vicinity, the Edwards caps the hills and ridges with massive beds of gray, hard, brittle limestone. Chert and flint nodules and lenses are found at various horizons throughout the formation.

83. STRUCTURAL GEOLOGY.- The Balcones fault zone is the principal structural feature in the area. The related faulting has developed a prominent escarpment that extends east-west across Medina County, marking the surface expression of a fault or series of faults with as much as 200 feet of displacement. The U. S. Geological Survey 9/ reports that the displacements on individual faults in the county vary up to 700 feet and are traceable for a distance of 35 miles. The Woodward Cave fault is the nearest major traceable fault to the site. The fault enters Medina County from Uvalde County, intersects Seco and Spring Creeks, and thereafter appears to split into two branches which continue for approximately eight miles to the east. The southernmost branch of the fault, located about one mile below the proposed dam axis, provides a fault contact between the Glen Rose and the overlying Edwards and Comanche Peak. It is believed that displacement along this fault is approximately 80 feet. Water in Hondo Creek generally ceases to flow once it crosses the fault zone onto the outcrops of the downthrown Edwards limestone. The northern branch of the Woodward Cave fault is normal, downthrown to the south, and cuts the proposed reservoir approximately 0.8 mile above the dam axis. The surface expression along this fault is more difficult to trace because only the Glen Rose formation is exposed. The regional dip of the formations is very gentle, and toward the south. A considerable increase in the dip occurs near large faults.

84. RESERVOIR LEAKAGE.- The reservoir would be founded entirely within the Glen Rose limestone, an argillaceous limestone generally believed capable of storing water without appreciable losses. Foundation drilling at the site has shown the Glen Rose limestone to be relatively impermeable except for a relatively thin weathered zone that occurs in its upper limits. Faulting is known to exist in the proposed reservoir area, and one large fault, the Woodward Cave fault, has been located cutting the reservoir approximately 0.8 mile above the dam site. There is no evidence of leakage into this fault zone. Bulletin 5807D, Channel Gain and Loss Investigations, Texas Streams, 1918-1958, would tend to support this conclusion. From April 5 to 7, 1958, a low-flow investigation was conducted on Hondo Creek from the headwaters in Bandera County, approximately 6 miles above Tarpley, to U. S. Highway 90. The area of investigation was divided into three sub-reaches. Sub-reach 1 is an interval of Hondo Creek 12.2 miles long, contained entirely on the Glen Rose formation and extending from the headwaters to a short distance downstream from the proposed dam site. The report on the investigation states, "No losses were found in this reach and the flow increased from 7.1 cfs to 58.8 cfs." Many springs and seeps were noted within this sub-reach. Below the dam site, where Hondo Creek crosses the lower branch of the Woodward Cave fault, the Edwards is faulted down against the Glen Rose. Investigation for the next 11.9 miles showed a streamflow loss of approximately 50 percent. During the dry seasons there is little or no flow below the faulted Edwards-Glen Rose contact. This is believed to be a result of streamflow into the Edwards limestone, a highly cavernous limestone and prolific water bearer.

85. INVESTIGATIONS.- Investigations were conducted at the dam site in June 1963. Four NX-size core borings were drilled along the dam and spillway-dike axes to explore foundation conditions. Borings 2C-2 and 2C-4, located on the abutments, were drilled to 142.5 and 131.0 feet, respectively; boring 8A2C-3, located in the valley section, was drilled to 56.0 feet; and boring 8A2C-1, located on the spillway-dike axis, was drilled to 61.9 feet. The borings were used to determine the depth of overburden, character of bedrock, and were hydraulically pressure tested to determine the relative permeability of the bedrock. The location of the borings is shown on plate 22, and the geologic logs are shown on plate 24.

86. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The Glen Rose limestone comprises the foundation for the proposed dam site. The overlying Walnut clay, Comanche Peak limestone, and Edwards limestone are exposed in the vicinity, but the outcrops are above the maximum pool level of the proposed reservoir.

b. Lithology.- The Glen Rose limestone at the dam site is a soft to moderately hard, tan to dark-gray, fossiliferous, argillaceous limestone including shale and clay interbeds and stylolites. The limestone often has a "salt and pepper" appearance, due to concentrations of fossil fragments, and is generally thin to medium bedded. Occasional beds containing pinpoint porosity, solution cavities, and caliche-lined vugs are encountered.

c. Weathering.- Oxidation and hydration, the two primary types of weathering found at the proposed dam site, were evident in both abutment borings and for the first 4.0 feet drilled in the spillway-dike boring. Boring 2C-2, located on the steep right abutment, exhibited a moderate degree of weathering to a depth of 42 feet. Below 42 feet the weathering was relatively insignificant, consisting chiefly of thin intervals of oxidation stains on fracture surfaces and bedding planes. The rock encountered in boring 2C-4, located on the left abutment, was weathered (primarily oxidation) to a depth of 34.4 feet. The limestone is tan to yellow and generally highly broken and fractured. Lack of deep weathering in the creek valley can be attributed to the fact that the highly weathered rock has been removed by stream action.

d. Faulting.- Core borings did not reveal any physical evidence of faulting between the abutments at the Hondo Dam site. Boring 2C-2, located on the right abutment, showed 42 feet of limestone that appears very similar to the Walnut and Comanche Peak formations and, if classified as such, would indicate some displacement. From present investigations, however, there is insufficient evidence to place a contact at this location. Faulting of considerable magnitude (see Structural Geology) does exist in the area, and it would be reasonable to assume that some minor faults will be discovered with more detailed investigations.

e. Overburden.- Boring 8A2C-3, located at station 25+52 on the dam axis, encountered 17.5 feet of alluvium overlying bedrock. From ground surface to a depth of 10.5 feet, the alluvium consists of a sandy clay and clayey sand underlaid by 7.0 feet of sand and gravel. A hardpan layer caps the bedrock from 16.3 to 17.5. Boring 8A2C-1, located at station 17+00 on the spillway-dike centerline, encountered 2.2 feet of firm, dry, dark-brown clay overlying 10.9 feet of clay, sand, and gravel. Limestone boulders up to 2.0 feet in diameter were encountered near the base of the overburden. Although no overburden is shown on the abutments, there may be a thin residual layer held in place by vegetation. Plate 23 shows the inferred horizontal and vertical extent of the overburden.

f. Leakage.- Hydraulic pressure tests conducted in the four core borings at the site revealed the bedrock to be relatively impermeable except for the upper weathered zone (15-42 feet thick) in the abutment areas. The valley borings on the dam and spillway-dike axes indicated only minor weathering and took no water with gage pressures up to 35 psi. Abutment boring 2C-2 was essentially tight except for an interval between 22.5 to 42.5 feet where a take of 4.8 cfm at 20 psi was recorded. An interval between 102.5 to 122.5 feet also recorded a loss, but packer leakage may have occurred during the test. Boring 2C-4, located on the left abutment, recorded its largest take between the depth of 7.7 to 24.5 feet. In this interval the bedrock accepted 1.7 cfm of water at 8 psi gage pressure. Pressure test results and the intervals tested are shown on plate 24.

g. Water table.- The ground-water level was not determined at the time of drilling, but measurement on December 11, 1963, recorded water levels at elevation 1190 in boring 2C-2 and elevation 1257 in boring 2C-4. No explanation is available for the difference in the water levels between the two abutment borings, and additional investigation will be required.

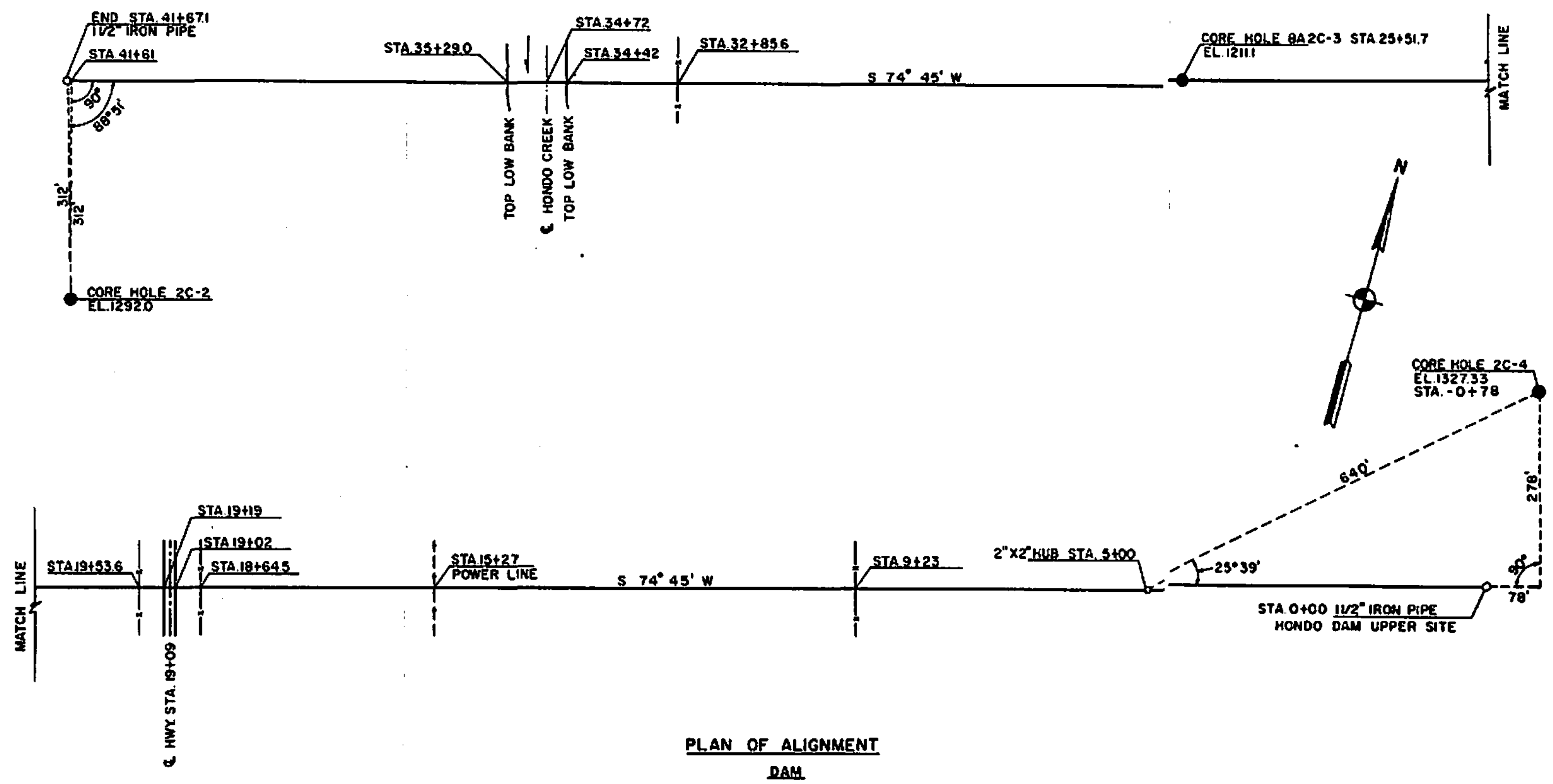
87. CONSTRUCTION MATERIALS.- Preliminary field investigations indicate that flood-plain alluvium, suitable for an impervious core, may be available in the broad flood plain contiguous to and upstream from the dam site. Boring 8A2C-3, located along the proposed dam axis in the valley, encountered 10.5 feet of sandy clay and clayey sand. Scattered deposits of sand and gravel are also available for use as free-draining material. Laboratory testing of these materials has not been conducted, and more exploration will be required to determine the quantity and quality of the materials. An acceptable source of sand and gravel for concrete aggregate is available from the general area of San Antonio, Texas. Riprap or rockfill material is available from the Glen Rose or Edwards limestones. Use of the Glen Rose limestone may require some selective quarrying.

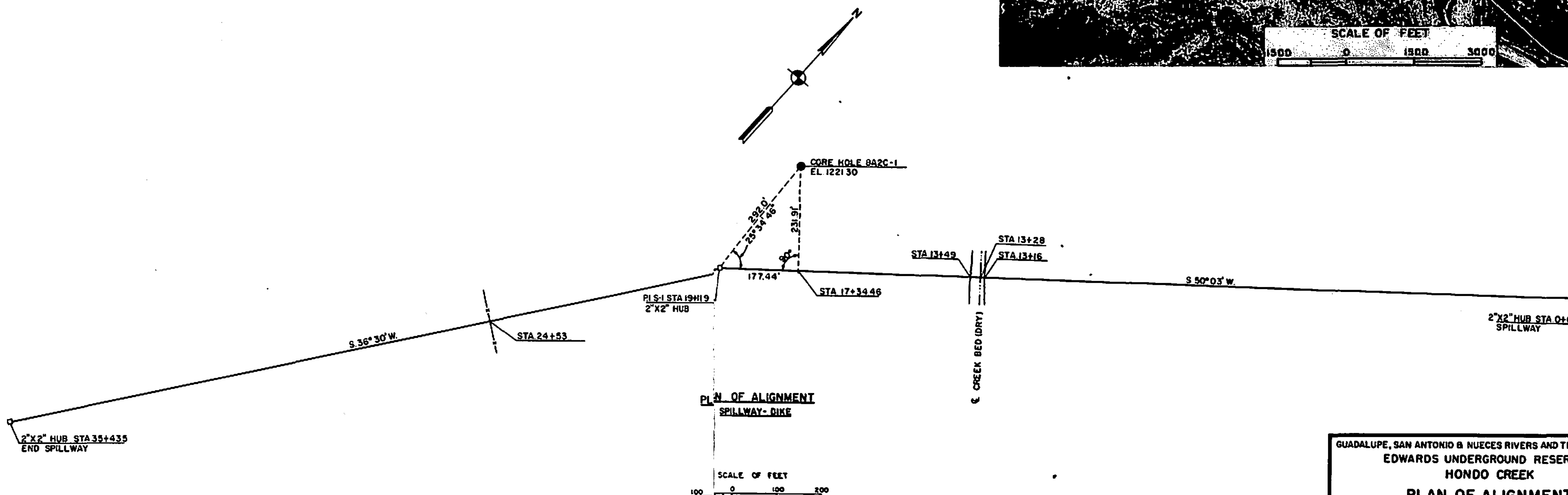
88. CONCLUSIONS AND RECOMMENDATIONS.- On the basis of the investigations completed at the site, the following conclusions are presented:

a. The bedrock is suitable for the proposed structure. Some slaking of the shaly zones in the Glen Rose may be anticipated, but it is not expected to present a construction problem. Hydraulic pressure tests revealed a leakage condition in boring 2C-2, right abutment, from 22.5 to 42.5 feet and more exploration will be required in this area. Some faulting may be revealed with more detailed investigations. Foundation treatment will be required.

b. The proposed reservoir will be confined entirely within the Glen Rose limestone, an earthy limestone believed capable of containing water. A fault cuts the reservoir about 0.8 mile above the proposed axis, and additional investigations will be required to determine its leakage characteristics.

c. Earthen materials for the embankment may be scarce. Detailed investigations in the flood plain are needed to evaluate the quality and quantity of available materials. Ample quantities of the Glen Rose or Edwards limestone can be quarried locally for use as rockfill.





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

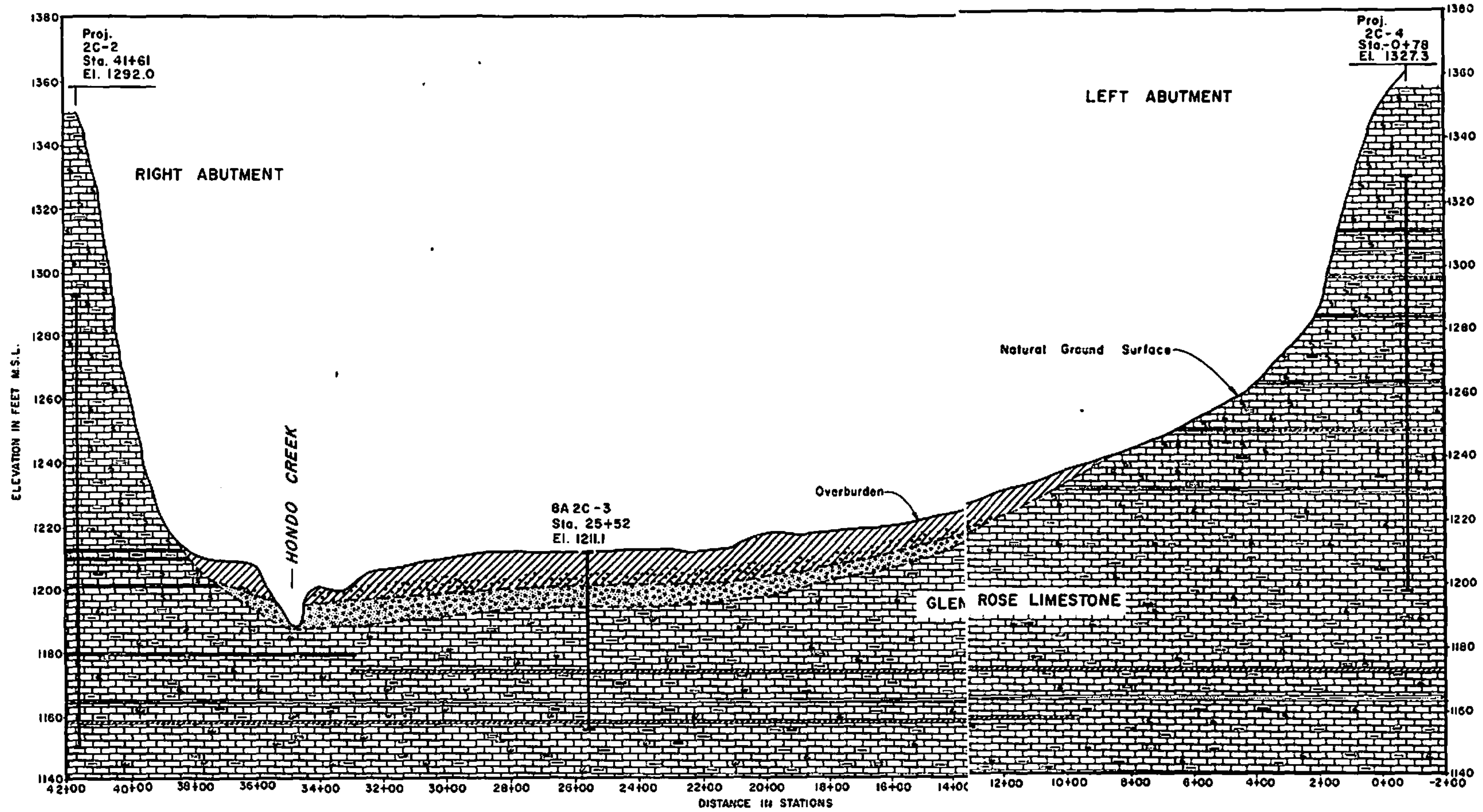
PLAN OF ALIGNMENT

HONDO DAM SITE

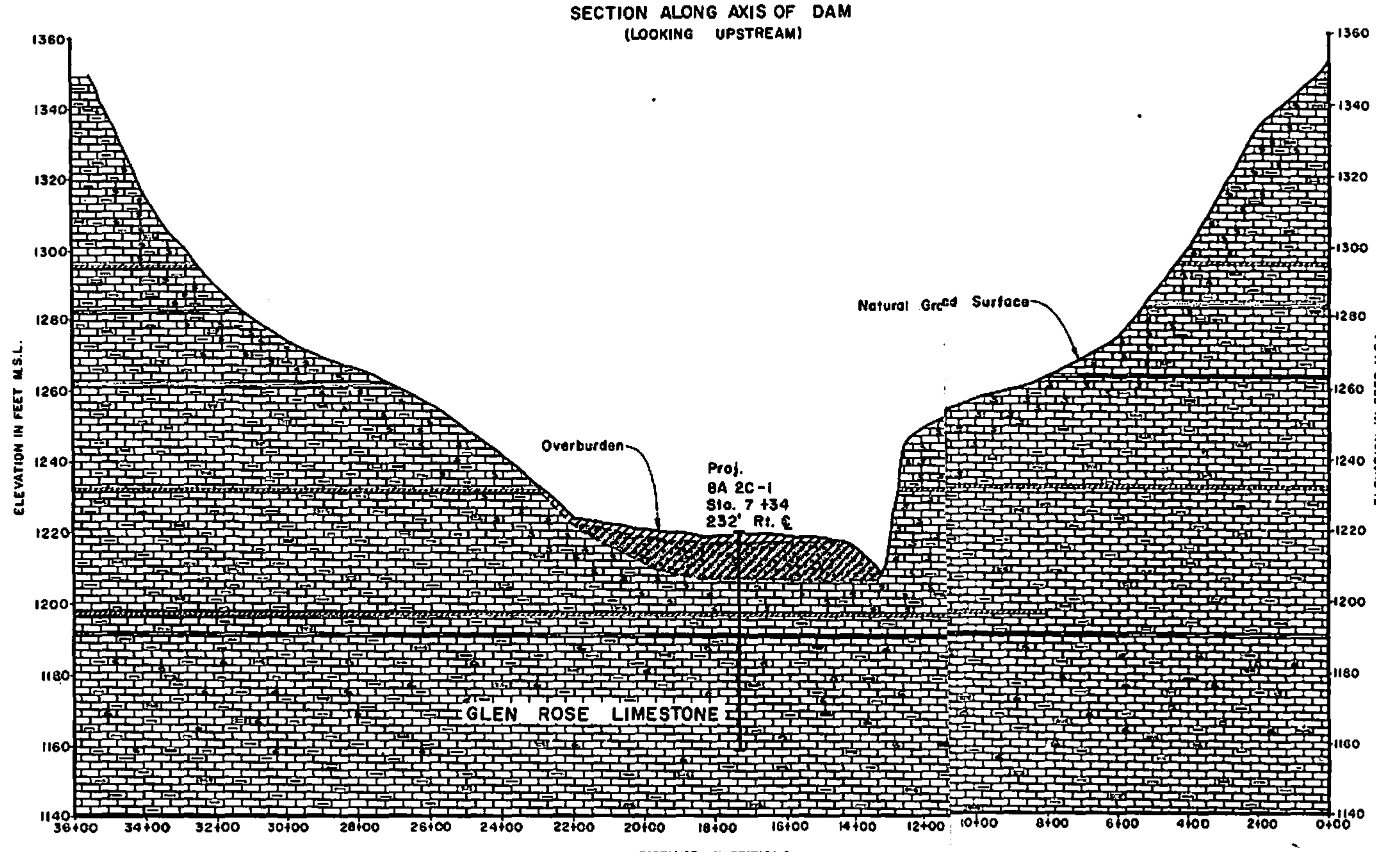
SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, CHIEF, PROJECT PLANNING BRANCH	CHIEF, ENGINEERING DIVISION	DISTRICT ENGINEER
PREPARED: CHIEF, FOUNDATION & MATERIALS BR.	DRAWN BY: J.L. / CHECKED BY: M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE: GUAD 707-2



SECTION ALONG AXIS OF DAM
(LOOKING UPSTREAM)



SECTION ALONG AXIS OF SPILLWAY - DIKE
(LOOKING UPSTREAM)

LEGEND

OVERBURDEN

- Clay or Sandy Clay
- Clayey Sand
- Sandy Gravel
- Clay Sand and Gravel

PRIMARY STRATA

- Limestone, soft to moderately hard, gray, argillaceous, fossiliferous; clay and shale seams.
- Weathering
- Fossils
- Clay seam
- Shale seam
- 8A — 8" Auger boring
- 2C — 2" Core boring

NOTES:

Horizontal extent of shale and clay seams unknown and generalized. Plate 24, Logs of Borings gives a detailed description of the material.

See Plate 24, for pressure test results and data.

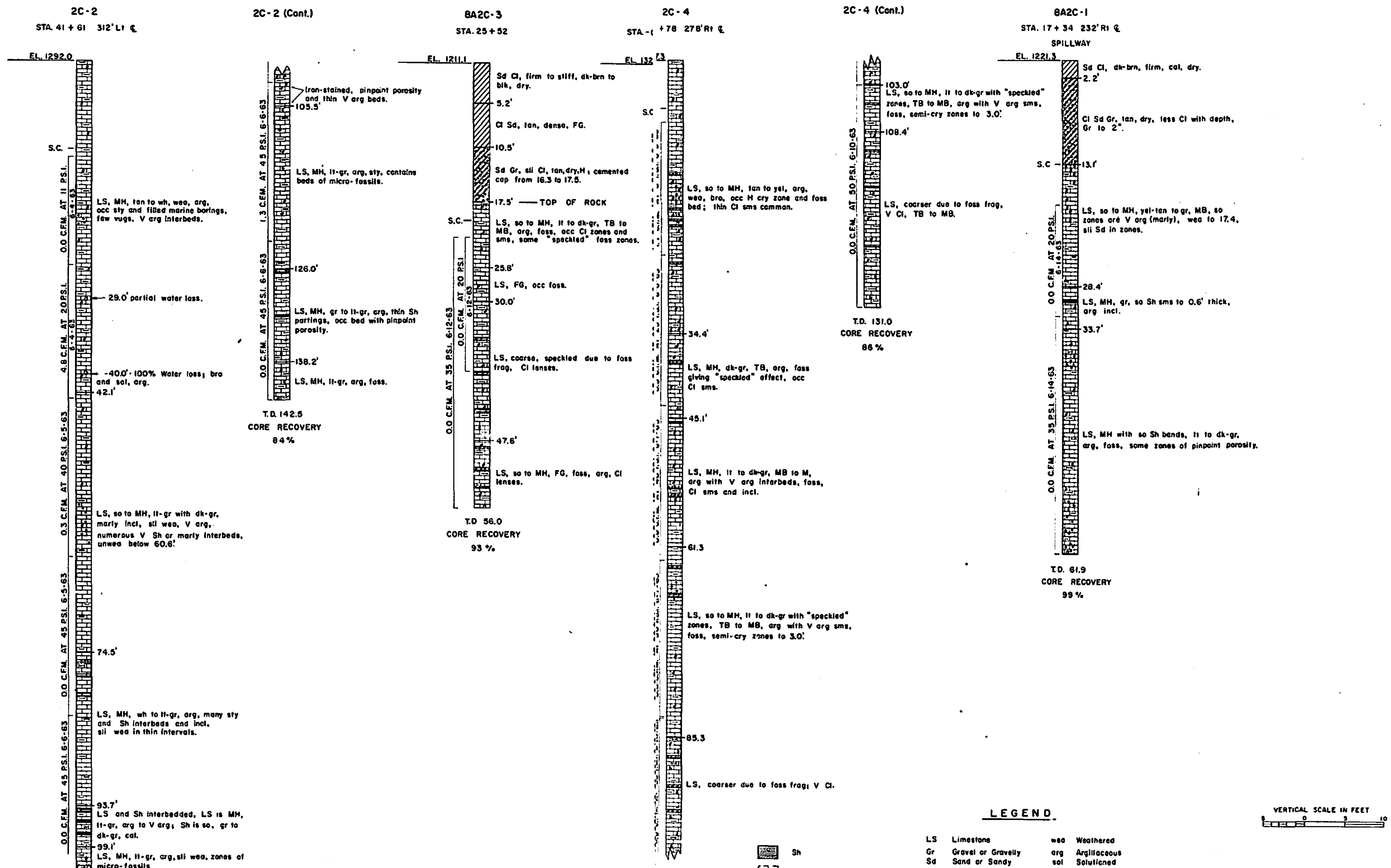
Absence of ground water levels opposite borings does not mean that water was not encountered.

For location of borings see plate 22

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
HONDO CREEK
GEOLOGIC PROFILES
HONDO DAM SITE
SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood	C. L. ...	...
PREPARED	DRAWN BY B.G.S. / CHECKED BY: M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2



SC = Start Coring
T.D. = Total Depth

Pressure Test Results and Data

1.4 C.F.M. AT 10 P.S.I. 6-6-63 = 1.4 Cubic feet per minute leakage at 10 pounds per square inch gauge pressure on June 6, 1963. Brackets indicate interval of boring tested.

LEGEND

LS	Limestone	wea	Weathered
Gr	Gravel or Gravelly	arg	Argillaceous
Sd	Sand or Sandy	sol	Solutioned
Cl	Clay or Clayey	cal	Calcareous
Sh	Shale or Shaly	foss	Fossiliferous
so	Soft	cry	Crystalline
MH	Moderately Hard	frag	Fragments
H	Hard	incl	Inclusions
V	Very	sms	Seams
sli	Slightly	bro	Broken
lt	Light	sty	Stylolite or stylolitic
dk	Dark	vug	Vuggy or vugs
gr	Gray	occ	Occasional
wh	White	FG	Fine-Grained
blk	Black	TB	Thin-Bedded
brn	Brown	MB	Medium-Bedded
yel	Yellow	M	Massive

Symbols: Sh, LS, Cl, Gr, Sd, foss, sol cav, wea

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.

EDWARDS UNDERGROUND RESERVOIR

FRIO RIVER

LOGS OF BORINGS

HONDO DAM SITE

SCALE AS SHOWN

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

SUBMITTED — APPROVAL RECOMMENDED — APPROVED

CHIEF, PROJECT PLANNING BRANCH — CHIEF, ENGINEERING DIVISION — DISTRICT ENGINEER

PREPARED — DRAWN BY T.L.M.B. — CHECKED BY M.G.G.

CHIEF, FOUNDATION & MATERIALS BR.

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD 707-2

BAT CAVE DAM SITE - CIBOLO CREEK

89. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Bat Cave Dam site is located on Cibolo Creek approximately 6 miles northwest of Bracken, Texas. Cibolo Creek, which marks the boundary between Bexar and Comal Counties, is an intermittent stream flowing in a southeasterly direction to its confluence with the San Antonio River in northwestern Karnes County. The dam site is situated within the Balcones fault zone southeast of the Hidden Valley and Bear Creek faults and northwest of the Bat Cave and Hueco faults. Topography along the creek is characterized by relatively steep, near vertical bluffs, and at the right abutment of the dam site, exhibits a near vertical 120-foot exposure of parts of the Lower Cretaceous Glen Rose, Comanche Peak, and Edwards limestone formations. The Glen Rose crops out in the streambed and along the lower part of the valley walls; the Comanche Peak crops out in the canyon walls and on the steep hill sides; and the Edwards caps the higher hills as a massive resistant limestone. The Walnut clay, which overlies the Glen Rose, was not identified at the site. The areal geology is shown on plate 25.

90. STRUCTURAL GEOLOGY.- The area comprising the proposed dam site and reservoir is situated in a zone of intense faulting related to the movements in the Balcones fault system. The U. S. Geological Survey 6/ reports that in Comal County the Balcones fault zone includes seven normal, high angle faults, downthrown to the southeast. The faults trend from S45°W to S60°W and are traceable across most of Comal County. The location of the dam site with respect to the faults is shown on plate 25. Within the area of the Bat Cave fault, the upper member of the Glen Rose limestone has been faulted into contact with the Edwards formation. It is estimated that the maximum displacement along the fault is 300 feet. 6/ Displacements along the Bear Creek fault and the Hidden Valley fault are unknown but are believed to be less than that of the Bat Cave fault. Geologic mapping by U. S. Geologic Survey revealed the presence of many minor shears or faults in the immediate area. Approximately 1/2 mile downstream from the proposed dam axis, a faulted zone, comprised of two closely spaced parallel faults, was noted to displace about 65 feet of the section. It was also determined that approximately 2.4 miles of the river channel, located in the upper reaches of the reservoir between elevation 920 and 940, have been affected by faulting. Displacements within this interval are believed to be approximately 200 feet. The direction of stratigraphic throw for the referenced faults has been predominantly to the south. The regional formational dip is southeastward. Locally, however, the attitude of the beds is very close to horizontal. Field inspection of the faulting has generally shown an abundance of badly broken, jointed, fractured, and folded rock adjacent to and parallel to the fault planes.

91. RESERVOIR LEAKAGE.- The location for the proposed dam and reservoir site was selected after a search of existing literature

showed stream losses to be relatively minor between the Bulverde gaging station, located approximately 14.5 river miles upstream from the dam site, and the Bracken gaging station, located at the dam site. However, subsequent detailed geologic mapping and foundation drilling have inferred several potential leakage areas within this interval. For example, drilling at the dam site has indicated faulting, jointing, and solutioning which could furnish avenues of leakage, and water-table checks have shown that the elevation of the water table is below the channel of the creek. The low water table and high permeability of portions of the channel undoubtedly account for the several dry stretches in the creek. The few relatively permanent pools of water are usually spring fed, and situated on massive, unfractured, and impermeable bedrock. Proof of relatively large water losses is established by the fact that immediately after heavy rains, local landowners have observed rapid underground drainage of the rain fed pools. Springs and caves are numerous in the area. Most of the springs in the reservoir issue from joints or fractures in the upper member of the Glen Rose limestone and flow less than 5 gpm. The source of the springs is believed to be the honeycombed Edwards limestone that caps the hills. After heavy rainfall the water absorbed by the porous Edwards percolates downward into the Upper Glen Rose and vents through available openings. Two large caves, Bat Cave and Natural Bridge Cavern, are located in the immediate area. Both caves have their entrances in the Edwards formation and extend down into the Upper Glen Rose. Bat Cave, located in grid 62-84 (see plate 25), although not extensively mapped, contains at least one room approximately 150 feet deep (base elevation 890). Natural Bridge Cavern, which has its entrance in grid 63-84, is under development as a commercial cavern. Reports from the developers indicate the cavern is as much as 270 feet deep (base elevation 730), and extends 5,300 feet in a N10°W direction (magnetic). If these reports are correct, the northernmost end of the cave is about 750 feet south of Cibolo Creek and about 170 feet lower in elevation than the creek channel. Backing water into the Cibolo Creek valley could possibly flood the Natural Bridge Cavern. Several other small caves and sinkholes were noted during the mapping of the reservoir.

92. INVESTIGATIONS.- In June, 1963, three NX-size core borings were drilled along the alignment for the proposed dam. Borings 2C-1 and 2C-3, located on the left and right abutments, respectively, were drilled to investigate foundation conditions, leakage potential, and stratigraphic contacts. Boring 2C-2, located in the valley, was drilled to a depth of 50 feet through the alluvium and into the underlying bedrock. All of the borings, shown in summary form on plate 27, were pressure tested.

93. In addition to the foundation exploration at the dam site, a geologic map of the reservoir area was prepared by the U. S. Geological Survey in cooperation with the Corps of Engineers. The reservoir was mapped to determine the leakage characteristics of the formations comprising the reservoir.

94. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The many wide meanders and broad terraces formed by Cibolo Creek suggest that the creek has reached a geologically mature stage and has been subjected to several cycles of erosion since early Pleistocene time. Many caves and sinkholes have undoubtedly been formed by the solution action of meteoric water, and it is probable that they offer an underground escape route for the intermittent flow of Cibolo Creek.

b. Lithology.- Lower Cretaceous Glen Rose limestone of the Trinity group and the Comanche Peak and Edwards formations of the Fredericksburg group crop out in the vicinity of the dam site. The Glen Rose (60 to 75 feet exposed at the site) occurs in the valley and along the valley walls. The formation is composed of a soft to moderately hard, argillaceous limestone. The rock is light tan to light brown and contains thin seams of yellow to gray clay. Many of the beds are fossiliferous, featuring the pelecypod Exogyra texana and casts of large molluscs commonly called "ox hearts." Occasional zones of pinpoint porosity and small solution cavities occur in the Glen Rose. The overlying Comanche Peak is about 65 feet thick (from a measured section on the left bank of the creek 0.2 miles downstream from the site) and is composed chiefly of massive, sometimes argillaceous, limestone. The lower half of the formation consists predominantly of a tan to light-tan, fine to coarsely crystalline, massive, bluff-forming limestone. The upper half of the formation consists of a nodular, argillaceous limestone that is generally a slope former. The rock is distinguished from the overlying Edwards by its nodular appearance and many calcite segregations and veinlets. The Edwards consists primarily of a hard, massive, extensively honeycombed and pitted limestone. The most distinguishing characteristics of the rock are the flint and chert nodules scattered throughout the formation. Approximately 140 feet of Edwards limestone cap the hills and ridges at the dam site. The bases of the formation is at approximate elevation 995.

c. Weathering.- The abutment borings at the dam site indicate that the rock is weathered over the entire interval cored. Cores taken from boring 2C-2 in the valley showed weathering effects to a depth of 35 feet. Chemical weathering in the forms of oxidation, solutioning, and hydration, is most prominent in the rock. This weathering was more evident in the Edwards and Comanche Peak formations than in the Glen Rose formation.

d. Faulting.- The proposed Bat Cave Dam site is located in an area of intense faulting and may possibly include minor faulting contiguous to or intersecting the proposed alignment. Geologic contacts, determined from the abutment core holes, showed the Comanche Peak-Glen Rose contact at elevation 912.5 in the right abutment and elevation 931 in the left abutment. Geologic surface mapping showed these respective contacts at approximately elevation 930. The slight discrepancy in elevation of these contacts indicates that small displacement may occur between the abutments but is not indicative of major structural disturbance.

e. Overburden.- The valley configuration at the proposed dam site is relatively narrow and does not include deep alluvial deposits. Boring 2C-2 encountered only 4 feet of gravelly clay overlying bedrock on the left bank of the creek, and a thin, spotty mantle of residual soil has been noted on the left abutment. With these exceptions the area is essentially void of cover (see plate 26).

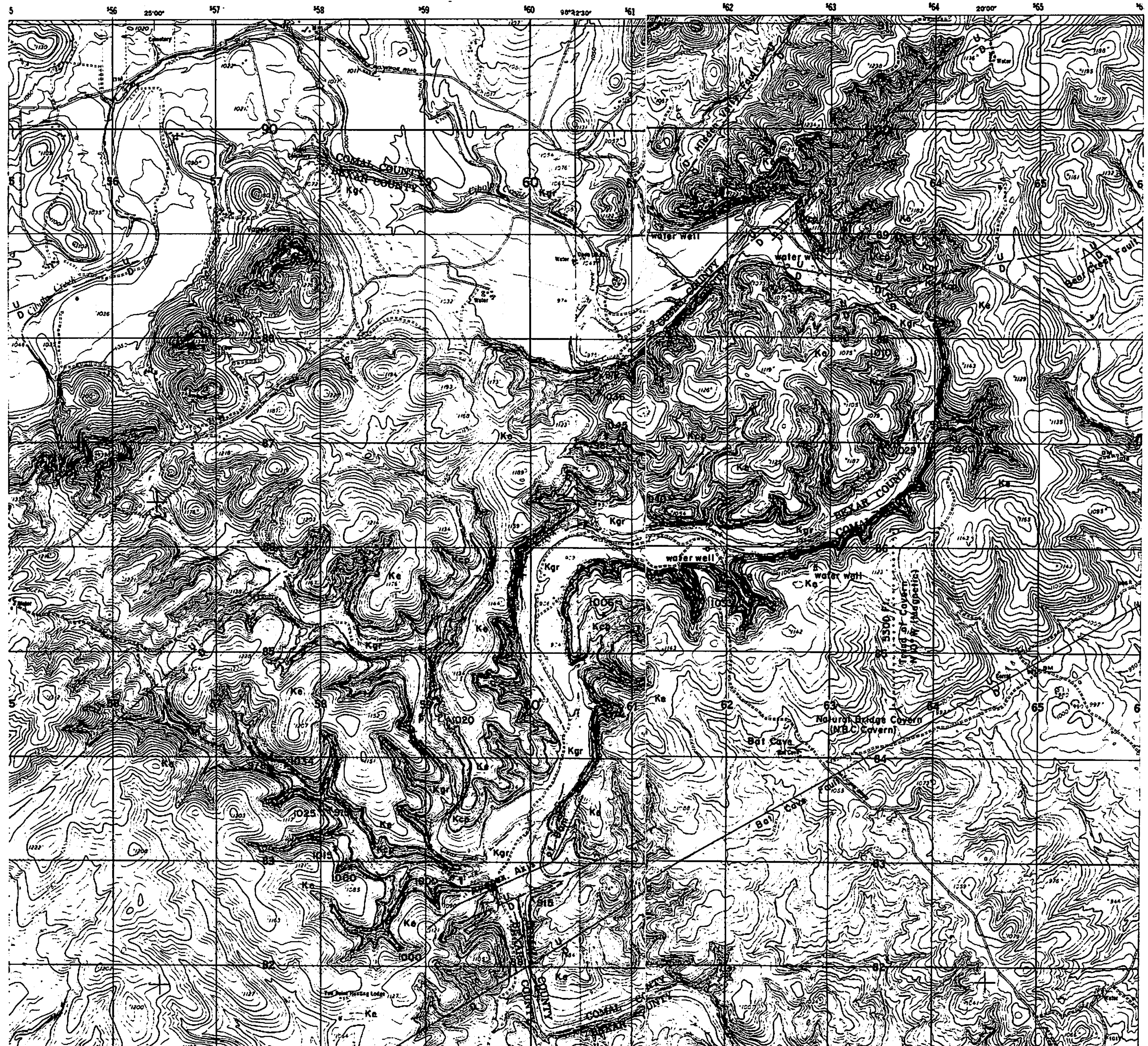
f. Leakage.- The results of hydraulic pressure testing indicate potential leakage conditions in left abutment boring 2C-1 and right abutment boring 2C-3. Valley boring 2C-2 was relatively tight throughout. Boring 2C-1 encountered leakage conditions from depths of 9.0 to 31.3 feet and from depths of 41.4 to 61.1 feet. Remaining intervals of the hole were relatively tight. The interval from the ground surface to 9 feet was not tested. Boring 2C-3 encountered leakage conditions from depths of 12.5 to 42.5 feet and 63.0 to 83.0 feet. Water losses from 42.5 feet to 63.0 feet were insignificant and the interval from the ground surface to 12.5 feet was not tested. Pressure test data are shown on plate 27.

g. Water table.- Borings on the abutments did not encounter a ground-water level. However, a ground-water level was established in valley boring 2C-2 at a depth of 33 feet, elevation 833.5. Based on the above information, it appears that the water table along the proposed dam axis is depressed below the base level of the stream approximately 32 feet.

95. CONSTRUCTION MATERIALS.- Subsurface investigations at the dam site do not indicate an adequate source of material for construction of an earthen embankment. However, approximately 4 air miles upstream, the Cibolo valley widens and appears to include a relatively large alluvial flood-plain deposit. Free draining and impervious core materials are believed available from this area. Material suitable for construction of a rockfill embankment can be obtained locally from the Edwards limestone. Some selective quarrying and screening may be necessary, but for the most part the rock is sound and durable. Gravel for concrete aggregate is available from

several commercial sources in the area of San Antonio, Texas.

96. CONCLUSIONS AND RECOMMENDATIONS.- Preliminary geologic investigations indicate the foundation conditions at the dam site are adequate to support the proposed structure. However, obvious leakage conditions at the site, as well as throughout the course of the Cibolo Creek, preclude the development of a permanent storage reservoir. In the event excessive leakage can be tolerated, as in the case of projects for flood control or recharge, the proposed site would be both topographically and structurally suitable.



N

LEGEND

FREDERICKSBURG GROUP	Ke	LOWER CRETACEOUS	EDWARDS LIMESTONE
	Kcp		COMANCHE PEAK LIMESTONE
TRINITY GROUP	Kgr		GLEN ROSE LIMESTONE

Known fault showing up and down side. Dashed where inferred or concealed.

Geologic contact, dashed where inferred or concealed.

Spring

Cave

X 1000 Indicates approximate elevation of geologic contacts.

NOTE:

Geology by U.S. Geological Survey for U.S. Army Corps of Engineers, Ft. Worth District, June 1963. Base map is portion of Bulverde and Bat Cave quads.

SCALE OF FEET

2000 0 2000 4000 6000

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.

EDWARDS UNDERGROUND RESERVOIR

CIBOLO CREEK

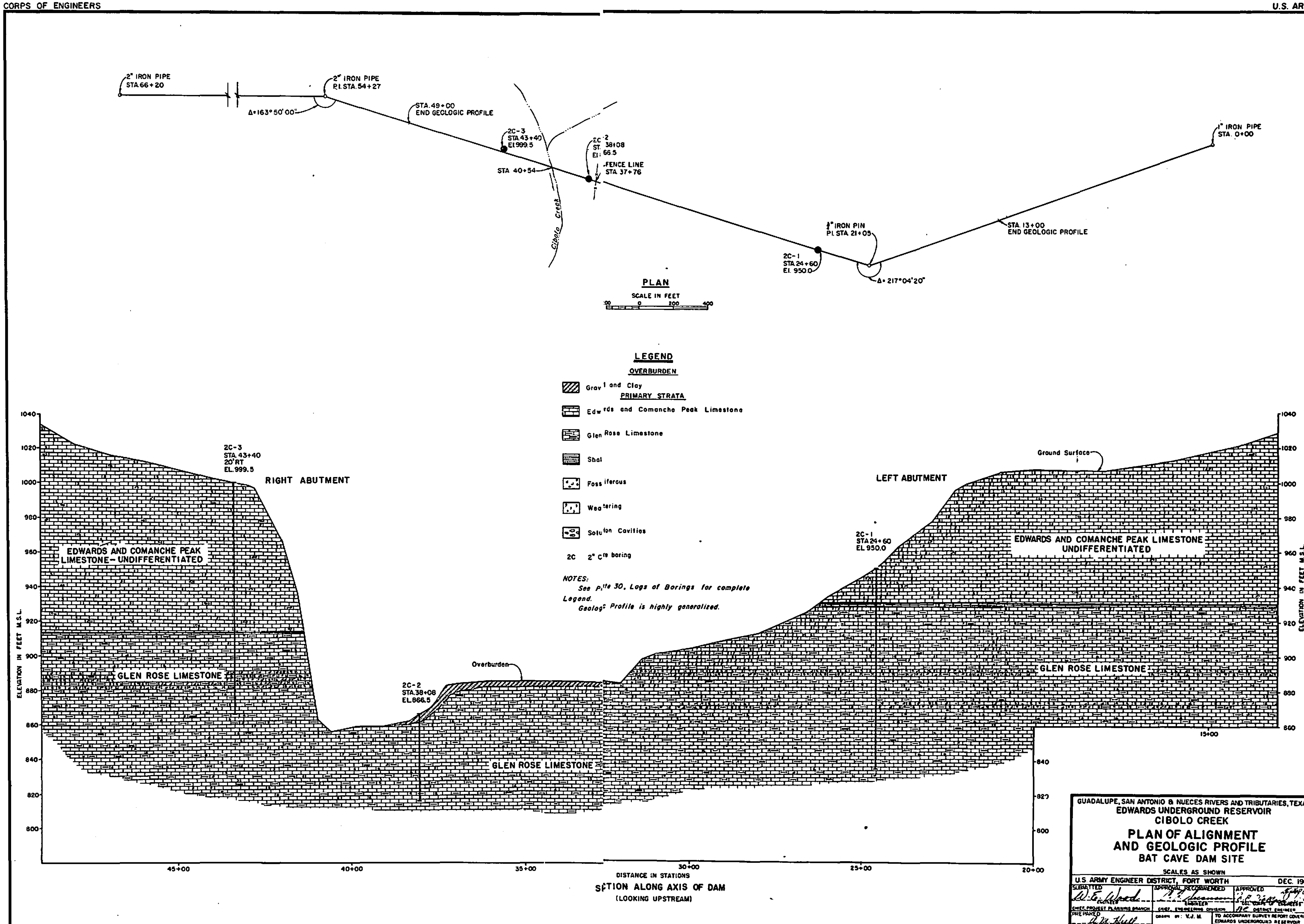
DAM SITE AND RESERVOIR GEOLOGY

BAT CAVE DAM SITE

SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	C. J. [signature], ENGINEER, CHIEF, ENGINEERING DIVISION	[signature], COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: A. M. Hull, ENGINEER, CHIEF, FOUNDATION & MATERIALS BR.	DRAWN BY: A.M.F. CHECKED BY: M.G.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE: GUAD. 707-2



GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
CIBOLO CREEK

PLAN OF ALIGNMENT AND GEOLOGIC PROFILE

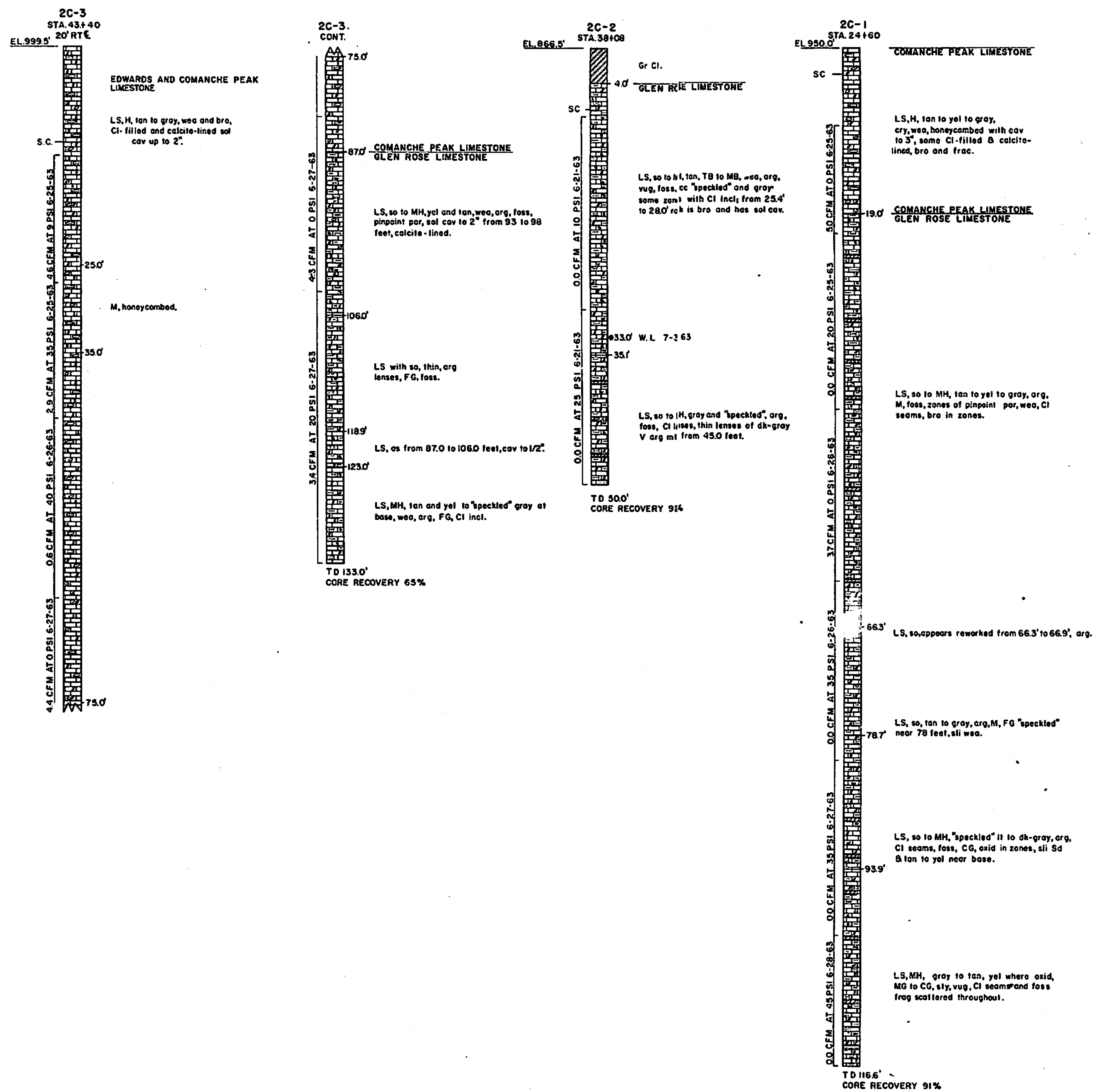
BAT CAVE DAM SITE

SCALES AS SHOWN

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

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE: GUAD. 707-2



LEGEND

Symbol	
[hatched]	Gr Cl
[brick]	LS
[cavity]	sol cav
[foss]	foss
[seam]	Cl seam
[wea]	wea

TD Total Depth
SC Started Coring
WL Water Level

Pressure Test Results and Data

4.3 CFM AT 10 PSI 6-29-63 — 4.3 Cubic feet per minute leakage at 10 pounds per square inch gage pressure on 29 June 63. Brackets indicate interval of boring test.

Abbrev.	Meaning
LS	Limestone
Cl	Clay or Clayey
Sd	Sand or Sandy
Gr	Gravel or Gravelly
so	Soft
MH	Moderately Hard
H	Hard
V	Very
sli	Slightly
yel	Yellow
oxid	Oxidation or Oxidized
wea	Weathered
arg	Argillaceous
cry	Crystalline
incl	Inclusion
bro	Broken
frac	Fractures or Fractured
foss	Fossiliferous
sol	Solution
cav	Cavity
vug	Vug or Vuggy
por	Porosity
occ	Occasional
FG	Fine-Grained
MG	Medium-Grained
CG	Coarse-Grained
TB	Thin-Bedded
MB	Medium-Bedded
M	Massive
mtl	Material
sty	Stylolitic
frag	Fragments

VERTICAL SCALE OF FEET

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
CIBOLO CREEK
LOGS OF BORINGS
BAT CAVE DAM SITE

SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964
SUBMITTED: CHIEF, PROJECT PLANNING BRANCH — APPROVAL RECOMMENDED: CHIEF, ENGINEERING DIVISION — APPROVED: DISTRICT ENGINEER
PREPARED: CHIEF, FOUNDATION & MATERIALS BR. — DRAWN BY J.L. — CHECKED BY M.G.G.
TO ACCOMPANY SURVEY REPORT ON [illegible] EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 707-2

COMFORT DAM SITE - GUADALUPE RIVER

97. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Comfort Dam site is located on the Guadalupe River in Kerr County, approximately 2 miles west of the Kerr-Kendall County line and approximately 3 miles west of Comfort, Texas. The site is situated on the Edwards Plateau section of the Great Plains physiographic province. Although the topography of the general area is quite rugged, the relief contiguous to and including the reservoir is more subdued, exhibiting a broad river valley with relatively gentle valley slopes.

98. The Glen Rose limestone of the Trinity group is the only formation outcropping in the proposed reservoir. The formation has been arbitrarily divided into an upper and lower member with the division placed at the top of a prominent fossil zone known as the Salenia texana zone. This fossil zone generally underlies a very thin resistant limestone ledge, containing large numbers of Corbula, which is in turn overlain by an evaporate bed. At the dam site the contact between the upper and lower members is at approximately elevation 1418, or about riverbed level. Because of this stratigraphic position, a dam constructed at the presently proposed site would, in all probability, create a reservoir confined entirely in the upper member of the Glen Rose limestone.

99. STRUCTURAL GEOLOGY. Preliminary surface and subsurface investigations have not revealed any structural anomalies in the immediate area of the proposed dam and reservoir site, and at this stage of investigation, it is believed the site is located outside of the influence of the Balcones fault system. Correlation of a gypsum zone encountered in both abutment borings suggests that, at least locally, the strata dip approximately 10 feet per mile in a southerly direction.

100. RESERVOIR LEAKAGE.- A dam constructed on the Guadalupe River at the selected location would permit a reservoir to be confined in the upper member of the Glen Rose limestone. Experience, records, and subsurface investigations have generally found the Glen Rose to be relatively impervious. However, investigations to date have not been sufficiently detailed to assume that minor seepage will not occur, and before a full report can be made, additional studies will be required.

101. INVESTIGATIONS. In April of 1963, four NX-size core borings and two eight-inch auger borings were drilled at the proposed dam site. Core borings 2C-1 and 2C-3, completed to the respective depths of 205 and 200 feet, were abutment borings designed primarily to evaluate the foundation conditions at each respective location. Boring 8A2C-2, located on the right bank of the Guadalupe River and drilled to a depth of 62.6 feet, investigated the valley alluvium and

bedrock characteristics. Boring 2C-4, located in a shallow valley north of the left abutment, was drilled to a depth of 103 feet to determine bedrock conditions at a proposed spillway site. The spillway site was subsequently moved to the right abutment. All of the core borings were hydraulically pressure tested.

102. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- The upper member of the Glen Rose limestone will, for the most part, comprise the bedrock for the embankment. The only exception will be in the core trench crossing the valley, where the lower member of the Glen Rose will be exposed. As illustrated on plate 28, the base of the gypsum bed, which constitutes the boundary between the upper and lower members, varies from elevation 1413 to elevation 1436. Stream erosion by the Guadalupe River has removed the gypsum bed and a portion of the Lower Glen Rose in the river valley. Foundation drilling and pressure testing to date indicate that both the upper and lower members of the formation are equally suitable foundation rock for the proposed structures. The spillway excavations in the right abutment will be founded on the argillaceous limestones, marls, and shale beds of the Upper Glen Rose limestone.

b. Lithology.- The lower member of the Glen Rose limestone is a light- to dark-gray, moderately hard, generally fossiliferous, occasionally vuggy, thin- to medium-bedded limestone, including shale partings, sandstone beds, and sandy phases. The often referred to fossil, Salenia texana, was not identified in the cores. However, a fossil tentatively identified as Corbula was found scattered throughout the cores for the first few feet underlying the gypsum bed. The upper member of the Glen Rose formation is an argillaceous, soft to moderately hard limestone, with numerous calcareous shale interbeds. Many of the beds are extremely fossiliferous (primarily micro-fossils), and contain small vugs or pinpoint porosity. Occasionally a thin, calcareous sandstone bed is encountered, as well as beds of arenaceous limestone. The rock is light to dark gray when fresh and tan when weathered. Based on the limited field work at the site, the thickness of the upper member is about 370 feet, with the top of the Glen Rose placed at approximately elevation 1780 (the contact identified by an overlying fossil zone that is traceable throughout the area).

c. Weathering.- The bedrock at the site is not extensively weathered. Boring 2C-1, located on the right abutment, exhibits weathering (primarily oxidation) to a depth of approximately 22 feet. Minor staining on the fracture surfaces was noted to a depth of 46.2 feet. Although the top of rock was placed at 12.4 feet in this boring, the material from the surface to 12.4 feet has rock-like structure and is probably a reworked or highly weathered shale or marl. The cores from boring 2C-3, located on the left abutment, exhibited slight weathering effects to a depth of 56 feet. The rock is moderately to highly weathered, with both the effects of hydration and oxidation noticeable, to a depth of 23.3 feet. Below this depth the weathering is negligible, consisting chiefly of fracture staining. Boring 8A2C-2, located on the right bank of the river, showed the bedrock underlying the valley alluvium to be essentially unweathered.

d. Faulting.- Correlation of the bedrock between the abutments did not reveal any evidence of faulting. This conclusion is based, however, on very limited exploration, and more detailed work may reveal minor structural anomalies in the site area.

e. Overburden.- Overburden in the Guadalupe River valley was explored with three borings. Boring 8A2C-2 encountered 9.8 feet of sandy clay and broken limestone fragments overlying 23.2 feet of clayey sand and gravel. Two additional borings, 8A-5 and 8A-6, encountered boulders (auger refusal) at depths of 17.8 and 15.0 feet, respectively. Sandy clay and gravels comprised the greater portion of the overlying alluvium. These shallow auger borings probably did not reach the top of rock. Overburden on the abutment areas is variable. Only a thin mantle of residual sandy clay covers the left abutment, but the right abutment supports as much as 12.4 feet of sandy, shaly clay (possibly reworked bedrock). The shaly clay is gray to yellow, soft, calcareous, and includes scattered limestone bands and traces of black carbon. Plate 28 shows the inferred vertical and horizontal extent of the overburden along the proposed dam axis.

f. Leakage.- Hydraulic pressure testing at the dam site was difficult to complete because of the drilling characteristics of the bedrock. However, where the rock condition in the borings permitted testing, the leakage was generally minor. Boring 2C-1, tested in increments from 88.4 feet to 205.0 feet (bottom of the hole), recorded water takes varying from 0 cfm at 50 psi to 2.8 cfm at 0 psi. The 2.8 cfm take represents all accumulated leakage between the interval from 154.0 to 205.0 feet. Only one water pressure test was made in valley boring 8A2C-2. Results of this test recorded a take of 1.3 cfm at 30 psi from 38.5 feet to 62.6 feet (bottom of the hole). In boring 2C-3, where it was possible to test, the highest take was 0.5 cfm at 60 psi from 154.7 feet to 200 feet (bottom of the hole). Boring 2C-4, north of the left abutment, initially intended as a spillway exploration boring, was tight. Conclusions concerning the permeability of the bedrock at the dam site are not easily resolved from the very limited investigations. However, based on the work completed to date, it appears that the right abutment is more pervious than the left, and that grouting would be required. Pressure test results are shown on plate 29.

g. Water table.- The ground-water level at the dam site was located in boring 2C-3 (left abutment) and boring 2C-4 (north of left abutment) at depths of 84.0 feet and 51.0 feet, respectively. The water level was not determined in the other borings.

103. CONSTRUCTION MATERIALS.- Materials suitable for an earthfill embankment are available at the dam site from the alluvial deposits included in the flood plain. Thirty-three feet of sand and clay, including scattered gravels, were encountered in the valley boring along the dam axis. Somewhat more shallow deposits of earthfill materials were found immediately upstream of the axis on the left bank of the Guadalupe River. Laboratory tests have not been performed on the materials to date, but indications are that the material should be suitable for random compacted fill. Preliminary investigations do not indicate that local deposits of sand and gravel are suitable for concrete aggregate. The nearest commercial sources are located in the general area of San Antonio, Texas. Riprap for slope protection can be quarried from the Edwards limestone that caps the higher hills in the general area.

104. CONCLUSIONS AND RECOMMENDATIONS.- The following conclusions and recommendations are based on investigations completed to date:

a. The proposed reservoir will be confined in the upper member of the Glen Rose limestone. Minor surficial weathering has been noted in the upper 20+ feet of the Glen Rose but the rock appears to be structurally sound and relatively impervious.

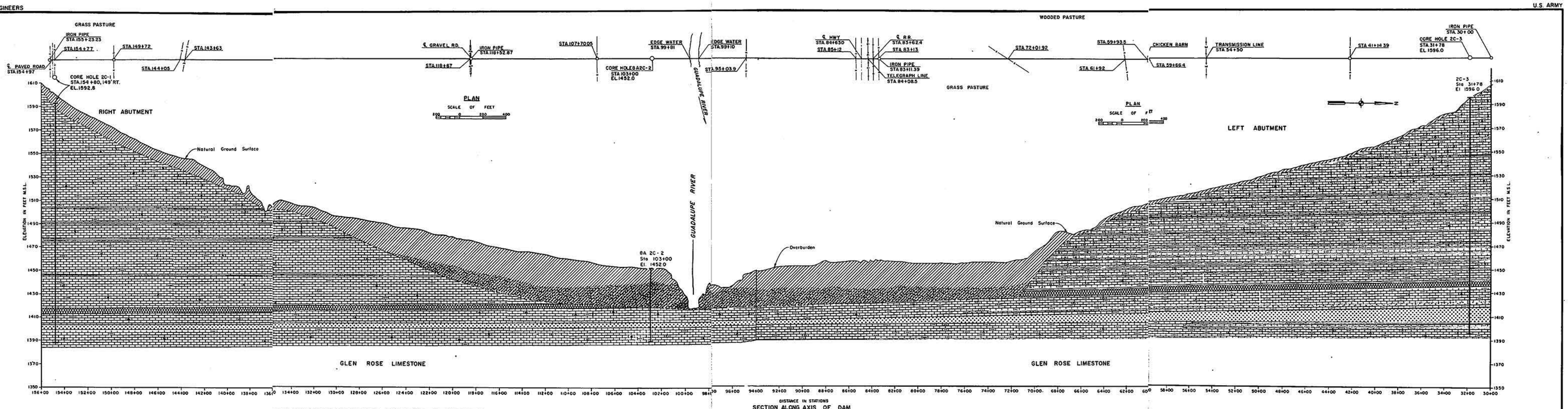
b. Consideration should be given to protecting the excavated shaly beds against drying, and any gypsum or gypsum beds encountered in the foundations or core trench should be removed. Where gypsum is exposed and excavation is not practicable, the bed should be given the same protection as the shaly beds.

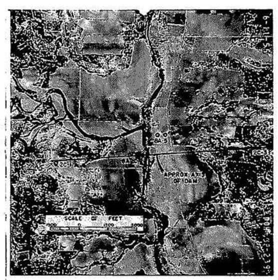
c. Although pressure testing revealed the rock to be slightly permeable, it is not anticipated that leakage will be excessive. Foundation treatment maybe required at the abutments and in the cutoff trench.

d. A sufficient quantity of suitable material for an earthfill embankment is probably available in the Guadalupe River valley, within economical hauling distance of the site. Additional investigations will be required before specific locations can be delineated. Commercial sources of material for concrete aggregates are available from the San Antonio area. Local sand and gravel deposits may be suitable for use as free draining material. Riprap material for slope protection is available from the Edwards limestone.

CORPS OF ENGINEERS

U.S. ARMY





LEGEND

OVERBURDEN

- Clay or Gravelly Sandy Clay
- Gravelly Clayey Sand

PRIMARY STRATA

- Limestone, soft to moderately hard, argillaceous
- Shale, soft, gray
- Sandstone, moderately hard, friable
- Gypsum, soft
- Weathering
- Fossiliferous
- 8A 8" Auger boring
- 2C 2" Core boring

NOTES:

Horizontal extent of shale and sandstone seams unknown and generalized on this section.

Detailed description of material is shown on Plate 33, Logs of Borings.

See Plate 33 for pressure test results and data.

Absence of ground water level opposite borings does not mean that water was not encountered

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

GUADALUPE RIVER

GEOLOGIC PROFILE

COMFORT DAM SITE

IN 2 SHEETS | SCALE AS SHOWN | SHEET NO 1

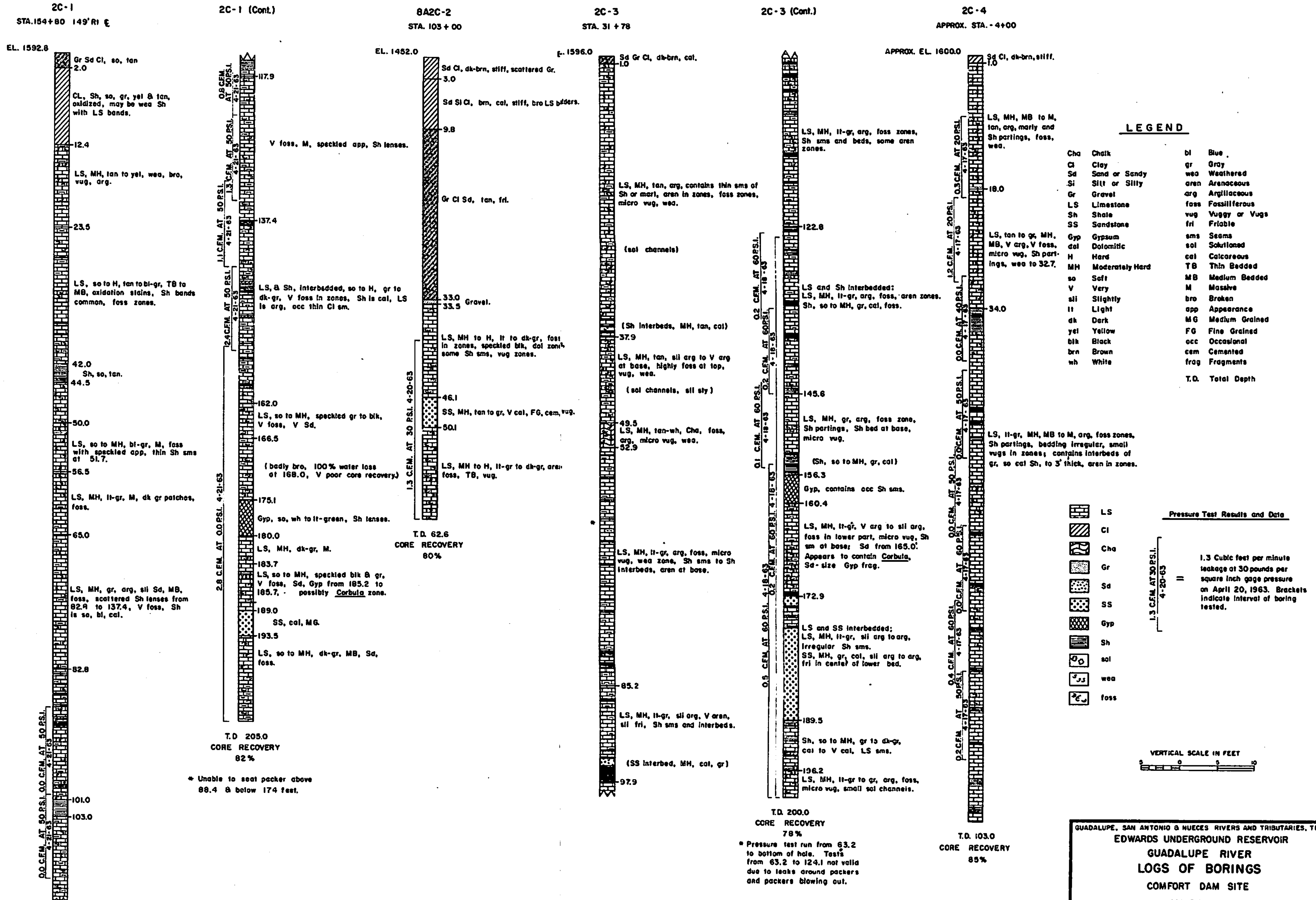
U S ARMY ENGINEER DISTRICT, FORT WORTH — DEC 1964

SUBMITTED: Chief, Project Planning Branch — APPROVAL RECOMMENDED: Chief, Engineering Division — APPROVED: District Engineer

PREPARED: Chief, Foundation & Materials Br. — DRAWN BY B G S — CHECKED BY M G G

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD. 707-2



GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX

EDWARDS UNDERGROUND RESERVOIR

GUADALUPE RIVER

LOGS OF BORINGS

COMFORT DAM SITE

SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	[illegible], ENGINEER, CHIEF, ENGINEERING DIVISION	[illegible], COL, CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED A. M. [illegible], ENGINEER, CHIEF FOUNDATION & MATERIALS BR.	DRAWN BY T.LeM.B. CHECKED BY M.G.O.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE GUAD. 707-2

CLOPTIN CROSSING DAM SITE - BLANCO RIVER

105. PHYSIOGRAPHY AND GENERAL GEOLOGY.- Cloptin Crossing Dam site is located on the Blanco River, approximately two miles southwest of Wimberley, Texas. Physiographically, the site is located near the eastern edge of the Edwards Plateau region and the western edge of the Balcones fault zone. The fault zone forms the transition between the rugged hill country of the Edwards Plateau and the flat Coastal Plain area to the southeast.

106. The Travis Peak and Glen Rose formations of the Trinity group, Lower Cretaceous age, are the only formations cropping out within the dam site and reservoir areas. The Travis Peak is divided into three members, the Sycamore, Cow Creek, and Hensell. The Sycamore and Cow Creek members are not exposed in the project vicinity, but the Hensell crops out in the Blanco River west of Wimberley (see plate 30). In this area the Hensell exhibits 20 to 30 feet of fine-grained sandstone or siltstone that grades downward into a variably argillaceous limestone, followed by a crystalline limestone. The limestones are characteristically olive gray, dense, and massive, and are similar throughout the exposed intervals except for variations in the weathering characteristics. The weathered surfaces of the argillaceous limestone are generally quite rough and irregular, whereas the lower crystalline limestone is generally quite smooth. The total thickness of the Hensell member is reportedly 85 feet.

107. The Glen Rose limestone has been divided into upper and lower members, with the division placed at the top of the Salenia texana zone. Both members crop out within the reservoir area but only the upper member comprises the bedrock at the dam site. The basal portion of the lower member, which thins rapidly toward the northwest, is a massive limestone that contains numerous large oyster shells and moundlike masses of corals. The upper portion of the Lower Glen Rose is composed of alternating beds of dolomitic limestone and argillaceous or shaly limestones. The Lower Glen Rose is approximately 200 feet thick in the Blanco River valley, seven miles northwest of Wimberley, and approximately 250 feet thick at Wimberley. The upper Glen Rose limestone has a known thickness of 355.5 feet at the dam site and is characterized by its "stairstep" topography which reflects differential weathering between the limestone and dolomite. Lithologically, the upper member can be described as a hard, dense, fine-grained to aphanitic limestone, including some dolomitic limestone, with thin shale partings. The topographic ridges are generally the hard, dense limestone and the slopes are generally the shaly phase.

108. The following composite geologic section, located near the right abutment, was measured by the U. S. Geological Survey during the reservoir and dam site mapping:

Description	Thickness (Feet)
Section A-B	
Comanche Peak limestone	
Limestone, pale-orange, hard, micrycrystalline, honeycombed----------------------------------	3.8
Dolomitic limestone, limonitic color, soft, deeply weathered, nodular appearance, scattered fossils-------------------------------------	10.2
Covered---	3.5
Limestone, buff, medium-bedded, partially covered-------------------------------------	5.8
Limestone, very pale-orange, hard, microcrystalline, pitted--------------------------------------	1.2
Walnut clay	
Covered slope with small limestone ledge in middle, pale yellowish-orange, scattered fossils-------------------------------------	5.7
Debris covered slope containing abundant _Exogyra_--	8.6
Glen Rose limestone Upper Member	
Limestone, pale-orange, hard, medium-bedded, cavernous-----------------------------------	11.8
Limestone, pale-orange, crystalline, cavernous---	1.8
Limestone, pale-orange, hard, massive, shaly in lower part------------------------------	1.8
Covered---	5.0
Limestone, pale-orange, hard, brittle, pitted and weathered--------------------------	3.0
Limestone, pale-orange, hard, microcrystalline, shale partings, pitted, weathers medium-gray---	1.8
Covered---	14.5

Description	Thickness (Feet)
Dolomite, pale-orange to light-gray, microcrystalline, thin-bedded, silty-----------	3.5
Dolomite, light-gray, aphanitic, medium-bedded to massive---------------------------------------	10.0
Limestone, grayish-orange, hard, crystalline, massive, caliche covered in part---------------	2.8
Limestone, very pale-orange, hard, brittle, scattered fossils, prominent ledge former------	0.5
Limestone and dolomite, slope former, appears silty, upper part thin-bedded and fissile, remainder is massive----------------------------	9.2
Limestone, massive, slope former, partially covered-------------------------------	9.8
Limestone, very pale-orange, hard, massive, prominent ledge former-------------------------	0.5
Limestone, yellowish-gray, hard, aphanitic, generally massive, pitted----------------------	12.5
Limestone, yellowish-gray, loose rubble cover, limonite staining------------------------------	4.0
Dolomite, yellowish-gray, aphanitic, massive, vuggy, fossiliferous----------------------------	1.0
Limestone, shaly, microcrystalline, thin-bedded--	0.5
Limestone, light-gray, scattered limonite specks, microcrystalline, massive--------------	7.5
Dolomitic limestone, medium-gray, soft, limonite stained, vuggy------------------------	1.2
Limestone, light-gray, fissile, slope former-----	0.5
Dolomitic limestone, ledge former, chunky--------	5.0
Limestone, brownish-tan, brittle, microcrystalline, locally fissile, scattered limonite specks-----	5.5
Dolomite, medium-gray, breaks easily, microcrystalline, pitted, ledge former---------	1.8

Description	Thickness (Feet)
Dolomite, light-gray, soft, limonitic stains common, pitted, slope former, silty, deeply weathered	6.7
Limestone, slightly dolomitic, thin shaly interbeds, pale yellowish-gray, limonitic stained, pitted	1.1
Limestone, very pale-orange, crystalline, hard, weathers to fissile flakes	1.7
Limestone, yellowish-brown, limonitic stained, fine-grained, crystalline, silty	0.5
Limestone, pale-buff, soft to moderately hard, locally thin and fissile, silty, slope former	1.0
Covered	1.0
Limestone, reddish-brown, microcrystalline, slope former	2.7
Shale, soft, poorly exposed	0.5
Dolomitic limestone, light olive-gray, limonitic stained pits, silty, partings at 6" to 8" intervals	3.5
Limestone, pale yellowish-tan, micrycrystalline, massive, silty	2.7
Limestone, buff, silty, slaggy, ledge former	1.5
Covered	2.0
Limestone, yellowish-brown, hard, massive, limonite specks, minutely crystalline	1.0
Covered	2.0
*Limestone, very pale-orange, crystalline, massive, weathers to whitish gray, pitted and honeycombed, scattered limonitic specks	1.5
Limestone, very pale-orange, microcrystalline, silty, breaks in 2-to 3-inch layers, weathers to buff	3.5

Description	Thickness (Feet)
Limestone, pale-buff to tan, silty, ledge former----------------------------------	0.4
Limestone, pale-buff, massive, slope former, weathers to medium gray, lower 2' shaly--------	9.0
Covered---	6.0
Limestone, pale-buff to yellowish-tan, scattered fossils---------------------------------------	3.5
Limestone, pale-brown, microcrystalline, ledge former----------------------------------	0.4

Section C-D

Section C-D was measured on the right abutment west of boring 2C-1.

*The equivalent of the top of the unit, noted by an asterisk in the above section, is identified as the top of the following section.

Description	Thickness (Feet)
Section C-D	
Glen Rose limestone	
Upper Member	
*Limestone, pale yellowish-orange, hard, upper surface slightly pitted------------------	1.0
Limestone, yellowish-orange, hard, shaly locally-------------------------------	3.9
Limestone, yellowish-orange, silty, thick-bedded, fossiliferous, nodular weathered surface--------	17.5
Limestone, pale-orange, hard, dense, slight limonitic staining----------------------------	0.4
Limestone, highly argillaceous, highly fossiliferous, poorly exposed------------------	9.1
Limestone, pale-orange, aphanitic to fine-grained, honeycombed, ledge former--------	1.2

Description	Thickness (Feet)
Covered--	7.5
Limestone, poorly exposed, argillaceous, fossiliferous----------------------------------	6.5
Covered--	15.5

The color terms used to describe the limestones conform to the appropriate USGS color chart for rocks.

Summary of formations:

Total Comanche Peak limestone measured----------	24.5
Total Walnut clay measured----------------------	14.3
Total Glen Rose limestone measured--------------	206.0
Total section measured--------------------	244.8

109. The Fredericksburg group, represented by the Walnut clay, Comanche Peak limestone and Edwards limestone, has been mapped as one unit (see plate 31). The formations in this group do not crop out within the reservoir area, but cap the hills in the vicinity of the dam site. A generalized geologic section is shown on plate 30.

110. STRUCTURAL GEOLOGY.- The area bedrock is essentially horizontal except for local monoclinal flexures that result in relatively high formational dips. Some low, reversed dips occur locally in the upper limits of the reservoir. Principal jointing trends show a conjugate joint system with the major set parallel to the major faulting. Faulting in the vicinity of the reservoir and dam site is common, featuring several normal faults with variable displacements. The major faults strike N45°E with downthrow predominantly to the southeast. In many places the faulting is represented by wide zones of fracturing and may include several closely related or en echelon faults rather than a single displacement. Topographic expression of faults in the Glen Rose is almost non-existent and several faults have been mapped primarily by their association with eroded or deepened sections in the river channel. These surface scars have been developed by post-faulting erosional processes. Detailed field mapping of the reservoir eliminated or shortened several previously mapped faults by recognizing the formational deformations to be simple monoclinal flexures.

111. The Wimberely fault, which cuts the left abutment of the dam site, was previously mapped as one fault, extending from central Hays County into Comal County (see plate 30). Detailed mapping at the dam site determined that the fault zone consists of three near vertical, parallel faults trending about N46°E. The displacement of these faults could not be measured by field mapping but is probably small. Surface evidence that would permit extention of the Wimberley fault to the southwest into Comal County is also lacking. Contiguous to and southwest of the Blanco River, the Tom Creek fault is associated with a series of parallel faults. At least four of these faults displace the upper and lower members of the Glen Rose limestone. The northernmost fault, striking N46°E and dipping 62°SE, has a vertical displacement of 5 to 10 feet. The next fault to the southeast has the same general trend and displaces the Corbula bed approximately 25 feet. The southernmost fault in the series is the principal fault, but displacement could not be determined by field mapping. A fourth fault, trending almost normal to the parallel faults, intersects the principal fault near the Hays-Comal County line. In this vicinity the bedrock near the river is warped into a position whereby the dip (18° west) does not conform to the regional southeast dip.

112. The Spring Branch fault system, located in the upper limits of the proposed reservoir, has a total displacement of approximately 35 feet. However, the fault splits near the Blanco River and continues to the northeast as two separate faults. The northern segment has displaced the Corbula bed outlier about 24 feet. The southern segment shows a vertical displacement of about 10 feet in the northeastern bluff of the Blanco River.

113. Approximately one mile upstream from the Spring Branch fault a small fault with about 8 feet of displacement cuts the west bluff of the Blanco River. Upstream from this point the massive beds of the Lower Glen Rose limestone become highly broken and fractured and the formation dips approximately three degrees to the southeast. No displacement is apparent in this area, but highly weathered and oxidized fracture zones are common.

114. RESERVOIR LEAKAGE.- Seepage measurements on the Blanco River do not show measurable net losses upstream of the Balcones fault zone. If water losses occur in this interval, the water apparently reappears as springflow before reaching the referenced fault zone. During the field mapping in late 1962 and early 1963 the river was dry for approximately 1-1/4 miles above the "dry point," shown on plate 31. This dry stretch of channel exposes highly fractured bedrock in both the riverbed and the confining bluffs. Although alluvial deposits occur at higher elevations in the valley, they do not appear to control seepage paths and any leakage would necessarily be through the bedrock. Small, apparently discontinuous caves are also common in the area. One such cave occurs near the

westward-trending fault located above the Spring Branch fault. This cave is confined in the lower member of the Glen Rose limestone and follows a large fracture, trending N70°E, approximately 15 feet into the face of the bluff. No displacement can be seen along the fracture. Downstream from the "dry point," at approximately elevation 950, the river is fed by small springs issuing from the contact between the Hensell member of the Travis Peak formation and the lower member of the Glen Rose formation. Riverflow is re-established at this point. According to local residents, the river has never stopped flowing below the "dry point." Additional subsurface information will be required to resolve the effects a reservoir head will impose on the previously referenced dry stretch of the river channel. From present investigations it is apparent that the riverflow reappears downstream, but several hydraulic uncertainties remain concerning the controlling gradients and flow paths.

115. Between the "dry point" and the dam site the Blanco River flows over the Hensell member of the Travis Peak formation and the upper and lower members of the Glen Rose formation. These formations and members are considered as being relatively tight except for the upper weathered and fractured zone and a basal limestone sequence in the lower member of the Glen Rose. The basal limestone reportedly supplies water for wells in the vicinity of Wimberley. Information concerning the permeability characteristics of the referenced formations is available from the Texas Water Commission, Bulletin 6004, "Geology and Ground-Water Resources of Hays County, Texas," and from Corps of Engineers drilling and hydraulic pressure testing at the dam site.

116. Leakage through faults within or traversing the reservoir is believed negligible as the faults are not considered avenues of free flow. This conclusion was reached by Guyton and Rhoades in a July 1955 report entitled "Proposed Canyon Reservoir, Guadalupe River."16/

117. INVESTIGATIONS.- Initial investigations on the Blanco River were made in 1940 by the U. S. Army Engineer District, Galveston. Investigations consisted of several auger borings at three dam sites located between river miles 20 and 24. Results are compiled in a report entitled "Geology of the Proposed Dam Sites in the Blanco River in the Vicinity of Wimberley, Texas," dated June 26, 1940. Investigations at the proposed site were initiated in December 1961, at which time six 2-inch diameter core borings were drilled along the proposed dam axis and two wash borings were completed on the left river bank. Three additional 2-inch diameter core borings were drilled in July 1962 to explore conditions at alternate spillway sites north of the left abutment. Locations of borings are shown on plate 31, and boring data are shown on plate 33.

118. A geologic surface map of the dam site and reservoir was prepared by the U. S. Geological Survey, through cooperative agreement with the Corps of Engineers. The purpose of geologic mapping was to determine the location of stratigraphic and structural conditions that could be considered areas of potential leakage.

119. DAM SITE GEOLOGY AND FOUNDATION CONDITIONS.

a. General.- On the steep right abutment, rock outcrops form typical "stairstep" topography reflecting erosion and weathering of hard and soft layers in the Glen Rose. In contrast, as shown on plate 32, the left abutment features a very gentle slope with the rock cropping out only intermittently. Both abutments support a relatively heavy growth of shrubs and trees. Stratigraphically, the site is located near the top of the Upper Glen Rose limestone, which locally is about 400 feet thick. The Corbula bed was not encountered in subsurface investigations at the dam site.

b. Lithology.- The Upper Glen Rose consists of alternating beds of argillaceous and arenaceous limestones, shaly limestones, and dolomite. The limestones are tan to gray, medium to thick bedded, fossiliferous, and soft to moderately hard. The formation also contains soft partings, clay and shale seams, and solution pits. A sequence of gypsiferous marls and shales reportedly occurs about 200 feet above the Corbula bed but to date they have not been recognized at the site.

c. Weathering.- The limestone at the dam site has been subjected to both mechanical and chemical weathering. Mechanical weathering is exhibited only at shallow depths by the action of tree roots separating and breaking the limestone. Chemical weathering is represented by solution, oxidation, and hydration, with subsequent clay coating and deposition on and within fractures. Core borings reveal from 10 to 35 feet of moderately to highly weathered limestone below the rock surface. Clay seams, solution pits and clay-filled cavities are common and in some horizons the limestone shows a pronounced pitted and honeycombed weathered surface. The honeycombing does not appear to be laterally constant, and may not have sufficient lateral extent to cause serious leakage. The beds displaying cavernous solutioning are generally hard, brittle, and form pronounced ledges. The honeycombed cavities range in diameter from 1/4-inch to 3 inches.

d. Faulting.- The limited investigations completed to date have not revealed definite evidence of major faulting at the dam site. However, field mapping did show evidence that a minor fault cuts the left abutment and closer spaced borings may reveal nominal displacement in the area. Boring 2C-3, located at station 35+13, and boring 2C-4, located at station 45+00, showed slickensided partings at elevation 888 and 930, respectively, suggesting some structural adjustments in the vicinity.

e. Overburden.- Two types of material comprise the overburden at the dam site. A thin, discontinuous mantle of residual clay and broken limestone fragments covers the abutments, and a relatively thick alluvial deposit of clayey sand and sandy clay covers the valley section. The alluvium appears to reach a maximum depth of about 32 feet on the left bank of the river. The residual material is considerably thinner, ranging in thickness from 0 to 5 feet. Rock outcrops occur in the river channel.

f. Leakage.- Hydraulic pressure testing along the proposed dam axis indicates that the foundation rock is relatively impervious. Small water losses were recorded in the upper 15-20 feet (weathered zone) of borings 2C-3, 2C-5, and 2C-9; otherwise, losses were insignificant. Depths of testing ranged from 50 feet in the valley section to 85 feet in the deepest abutment boring. Hydraulic pressure test data are shown on plate 33.

g. Water table.- Water-level readings were obtained from seven of the eleven borings drilled at the dam site. Three borings, 2C-9, 2C-10, and 2C-11, located in the vicinity of the spillway saddle, were cased through the overburden so that long-term readings could be obtained. In July 1962, the water level was 36.5 feet in boring 2C-9. In January 1963, the water level varied from 9.0 feet in 2C-9 to 13.1 feet in 2C-10. Water-level readings taken in December 1961 in the borings along the centerline showed the water table to be at depths varying up to 27 feet (boring 2C-1). From the above information it appears that the water table is tributary to the river, but is not static, and fluctuates with the seasonal changes. Water-level readings are shown on plate 32.

120. CONSTRUCTION MATERIALS.- The Blanco valley includes several moderate-sized alluvial deposits of clay, silt, sand, and gravel (see plate 31). In addition, scattered deposits composed chiefly of sand and gravel occur along the riverbed and in the area where the river emerges from the Edwards Plateau, near San Marcos, Texas. The local deposits have not been evaluated, but deposits on the Blanco River, approximately three miles from San Marcos, have been tested and are considered suitable for concrete aggregate. Ample quantities of sand and gravel for free draining materials are available in the site vicinity.

121. The clayey alluvium included in the Blanco River valley is believed suitable for use as impervious core or blanket material, but it is doubtful if a sufficient quantity exists for construction of an

earthfill type embankment. Limestone suitable for rockfill material may be quarried in unlimited amounts from the spillway excavation and adjacent bedrock. This rock is a relatively hard, argillaceous, dolomitic limestone that includes abundant shale partings and will be suitable if provisions are made to waste the shaly material and objectionable fines.

122. CONCLUSIONS AND RECOMMENDATIONS.- From the exploration and geologic mapping completed to date, the following conclusions and recommendations are presented:

a. The Glen Rose limestone, which comprises the bedrock material at the site, is considered to be structurally sound. It is not anticipated that instabilities from slaking will be significant within the shaly limestone beds.

b. Based on hydraulic pressure tests along the dam axis, leakage through the bedrock at the dam site will be very slight. However, some foundation treatment may be required.

c. The water table is tributary to the river and fluctuates with the seasons. Some ground water may be encountered in deep excavations, but it is not expected to present a serious construction problem.

d. Geologic mapping in the reservoir and at the dam site has not revealed any unusual leakage conditions. Seepage measurements show that the water lost in the upper reservoir limits is regained downstream before reaching the dam site. The Edwards and associated limestones, prolific water-bearing formations throughout the area, do not crop out within the limits of the maximum pool.

e. Structural information developed to date suggests that leakage through the fault zones should be small. There is, however, a noticeable increase in the base flow of the Blanco River where the Spring Branch and Wimberley faults cross the river, and it is possible that a reservoir head could affect this condition to some extent.

f. A comparison of the Canyon Reservoir with the proposed Cloptin Crossing Reservoir shows that essentially the same formations underlie the reservoirs. A July 1955 report by Rhoades and Guyton 16/ concludes that there will be some reservoir leakage from the Canyon Reservoir, but the amount will be moderate. The same conditions will probably prevail at Cloptin Crossing.

g. It is recommended that pumping tests be performed at selected locations in the upper limits of the reservoir to determine the permeability and transmissibility of the lower member of the Glen

Rose formation and the Travis Peak formation. This information is believed necessary to evaluate reservoir leakage in the referenced area.

h. A source of material for both free draining and impervious core material can probably be obtained from scattered flood-plain deposits along the Blanco River valley. The rock obtained from the spillway excavation will be suitable for rockfill if provisions are made for wasting the clay, shale, and objectionable fines. Approved sources of concrete aggregate are available in the vicinity of San Antonio, Texas.

SYSTEM	SERIES	GROUP	FORMATION		DEPOSITIONAL THICKNESS (FEET)		GENERAL LITHOLOGIC DESCRIPTION
CRETACEOUS	COMANCHE	WASHITA	BUDA LIMESTONE		30-60		Tan and gray massive hard nodular limestone.
			GRAYSON SHALE		40-60		Blue-gray to tan gypsiferous, ferruginous calcareous shale.
			GEORGETOWN LIMESTONE		10-30		Light-gray and white argillaceous nodular limestone and tan calcareous shale.
		FREDERICKSBURG	EDWARDS LIMESTONE		400±		Gray, siliceous, massive, honey-combed limestone.
			COMANCHE PEAK LIMESTONE		30-40		Light-gray argillaceous, nodular limestone.
			WALNUT LS		5-15±		Blue-gray sandy or calcareous clay; light-gray to white argillaceous nodular limestone.
		TRINITY	GLEN ROSE LIMESTONE	UPPER MEMBER	500-900		Hard limestone alternating with argillaceous limestones and calcareous shales. Massive biostromal limestones.
				LOWER MEMBER			
			TRAVIS PEAK FORMATION	HENSELL MEMBER	85±		Fine-grained siltstone, and argillaceous limestones.
				COWCREEK LIMESTONE MEMBER	60-70		Massive detrital limestone
				SYCAMORE SAND MEMBER	50		Conglomerate and sand.

LEGEND

- Q — ALLUVIUM Clay, Silt, Sand and Gravel
- Kw — WASHITA GROUP Undifferentiated
- Kf — FREDERICKSBURG GROUP Undifferentiated
- Kgru — GLEN ROSE LIMESTONE FM Upper member; Alternating Beds of Shale and Limestone
- Kgrl — GLEN ROSE LIMESTONE FM. Lower member. Massive Limestone, Shale, and Thin-Bedded Limestone.
- Ktp — TRAVIS PEAK FORMATION Includes Hensell Member, Cow Creek Limestone Member and Sycamore Sand Member
- CONTACT, dashed where approximately located
- FAULT, dashed where approximately located U-upthrown side, D-downthrown side

Areal geology, reproduced from Texas Board of Water Engineers Bulletin 6004, Geology and Ground Water Resourses of Hays County Texas, and Geological Survey Water-Supply Paper 1138, Geology and Ground-Water Resources of Comal County, Texas. Areal Geology plate not altered to agree with Dam Site and Reservoir Geology plate

SCALE IN MILES

0 .5 1 2

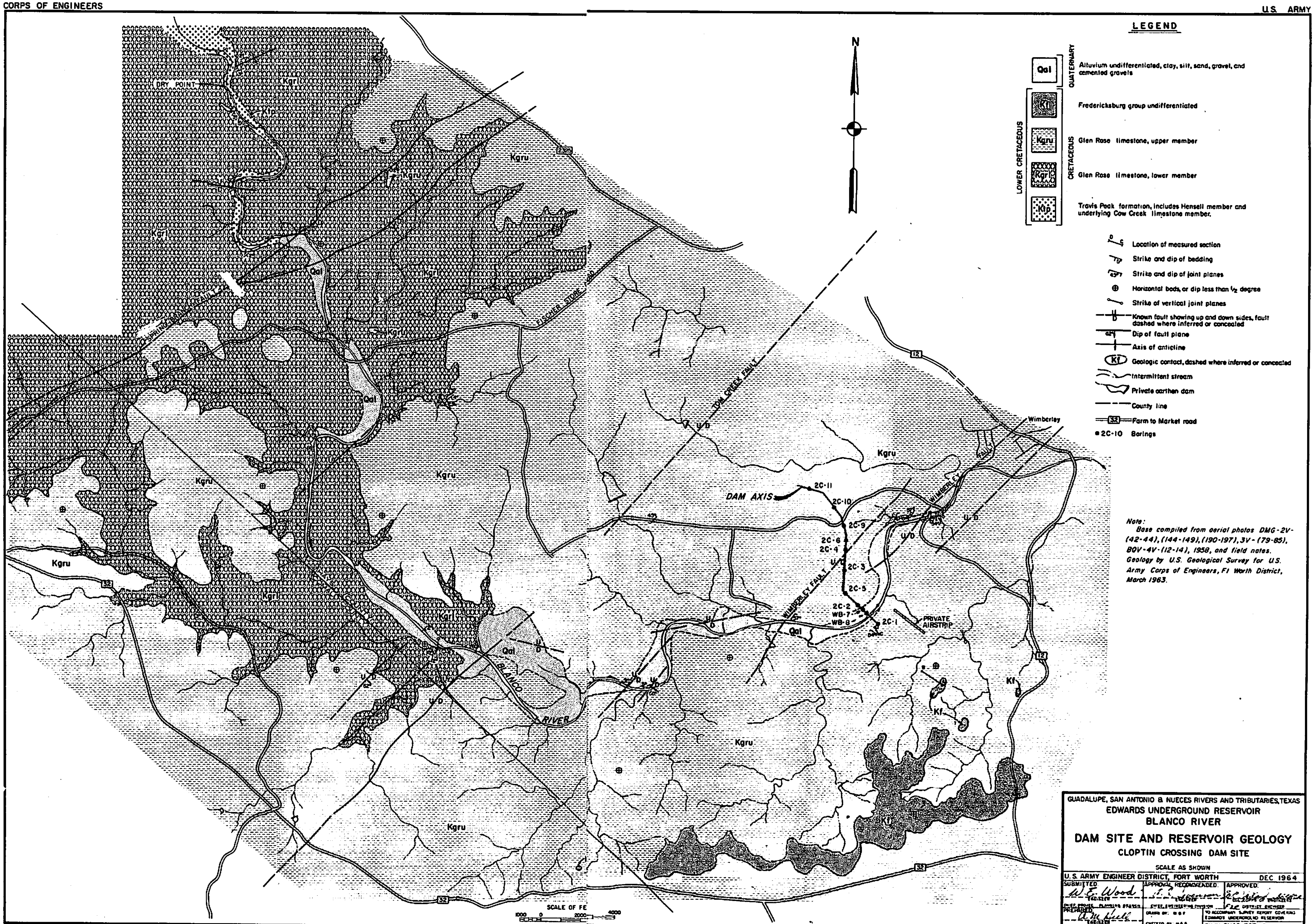
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER

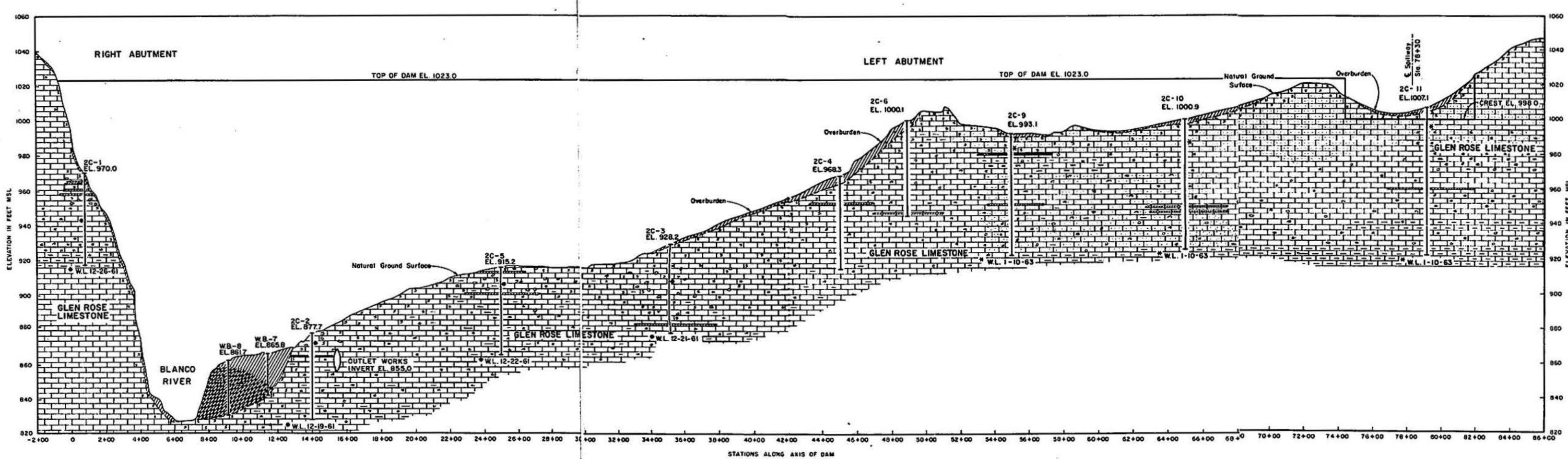
AREAL GEOLOGY
CLOPTIN CROSSING DAM SITE

SCALE AS SHOWN

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

SUBMITTED: W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION	APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: A. M. Hull, ENGINEER, CHIEF, FOUNDATION & MATERIALS BR.	DRAWN BY: E.M.P. CHECKED BY: M.B.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE: GUAD 707-2


LEGEND
QUATERNARY
Qal
Alluvium undifferentiated, clay, silt, sand, gravel, and cemented gravels
LOWER CRETACEOUS
CRETACEOUS
Kf
Fredericksburg group undifferentiated
Kgru
Glen Rose limestone, upper member
Kgrl
Glen Rose limestone, lower member
Ktp
Travis Peak formation, includes Hensell member and underlying Cow Creek limestone member.
Location of measured section
Strike and dip of bedding
Strike and dip of joint planes
Horizontal beds, or dip less than ½ degree
Strike of vertical joint planes
Known fault showing up and down sides, fault dashed where inferred or concealed
Dip of fault plane
Axis of anticline
Geologic contact, dashed where inferred or concealed
Intermittent stream
Private earthen dam
County line
Farm to Market road
2C-10 Borings
N
Note:
Base compiled from aerial photos DMG-2V-(42-44), (144-149), (190-197), 3V-(79-85), 8OV-4V-(12-14), 1958, and field notes. Geology by U.S. Geological Survey for U.S. Army Corps of Engineers, Ft Worth District, March 1963.
DRY POINT
Kgrl
Ktp
Kgru
Qal
Kgru
Kgru
Kgru
Kgrl
Kgru
Kf
Wimberley
DAM AXIS
2C-11
2C-10
2C-9
2C-6
2C-4
2C-3
2C-5
2C-2
WB-7
WB-8
2C-1
PRIVATE AIRSTRIP
WIMBERLEY FAULT
TOM CREEK FAULT
FISCHER STORE
BLANCO RIVER
SCALE OF FE
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER
DAM SITE AND RESERVOIR GEOLOGY
CLOPTIN CROSSING DAM SITE
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
SUBMITTED:
W. E. Wood
APPROVAL RECOMMENDED:
APPROVED:
PREPARED:
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 707-2



LEGEND

OVERBURDEN

- Clay–Black to brown, sandy, organic, limestone fragments
- Sand–Brown to tan, fine to medium-grained, clayey.

PRIMARY STRATA

- Limestone–Gray to dark-gray, medium hard to hard, argillaceous, arenaceous, thin to massive-bedded, stylolitic, vuggy with occasional solution cavity.
- Shale–Gray, medium hard, calcareous, slightly sandy
- Clay–Gray to brown, soft to medium hard, medium to highly plastic, calcareous.
- Shaly Limestone
- Arenaceous Limestone
- Fossiliferous
- Weathering
- * W.L. Water Level on Date Indicated
- W.B. Wash Boring
- 2C 2" Core Boring

NOTES:

Elevations from Stations 0+00 to -2+00 taken from Plane Table sheet

See Plate No.33 for pressure test results and data.

Horizontal extent of clay seams shown on Geologic Profile is unknown but will be delineated by additional borings. Because of small scale not all clay seams are shown in Profile but appear on Plate33, Logs of Borings.

Absence of ground water levels opposite boring logs does not mean that ground water will not be encountered at the locations or within the vertical reaches of the borings.

For location of borings see plate 31.

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER

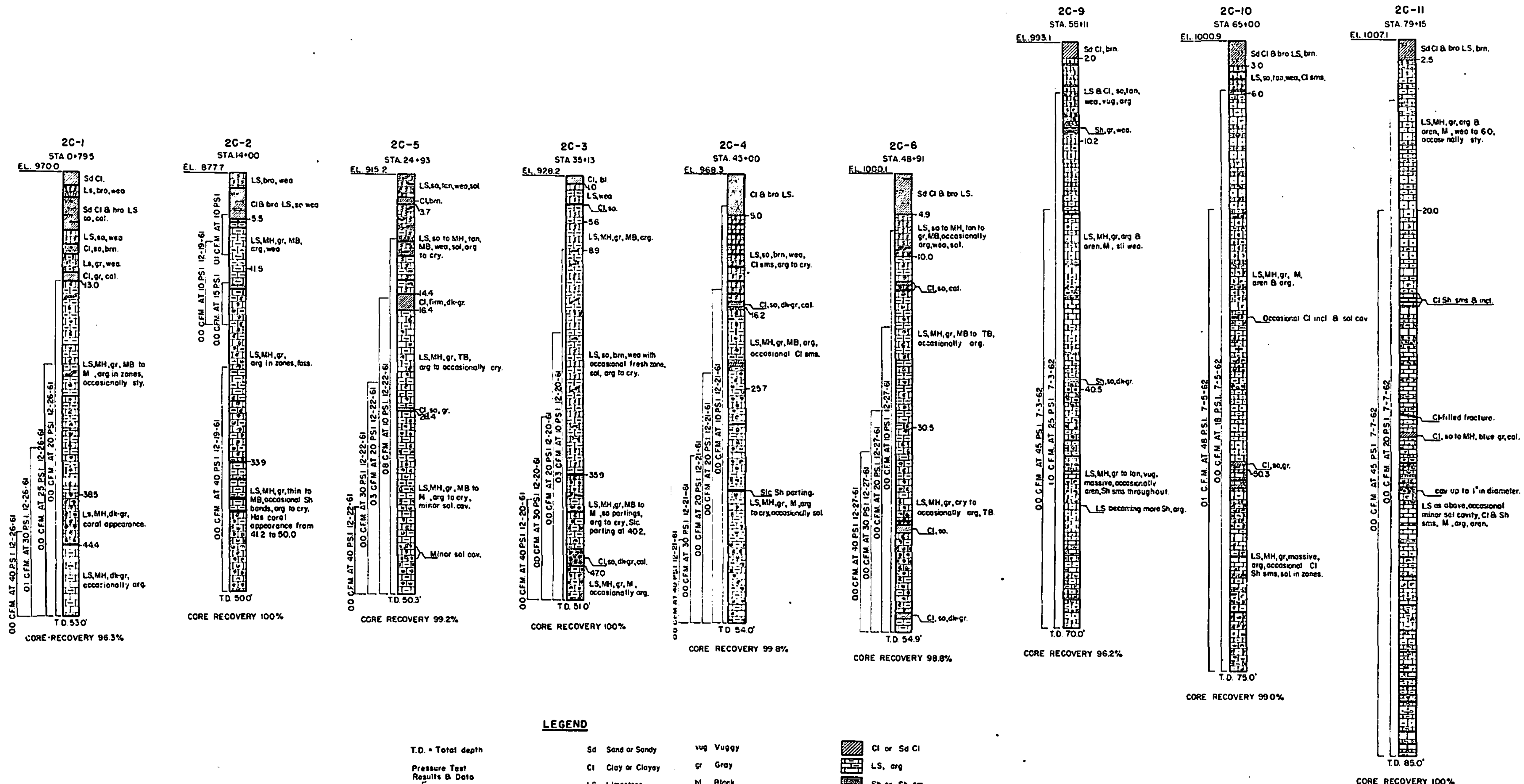
GEOLOGIC PROFILE

CLOPTIN CROSSING DAM SITE

SCALE AS SHOWN

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

SUBMITTED:	APPROVAL RECOMMENDED:	APPROVED:
W. E. Wood, Engineer	Engineer	Colonel, Corps of Engineers, District Engineer
PREPARED: A. M. Hull, Engineer	DRAWN BY: RC & DE; CHECKED BY: M.G.O.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE: GUAD 707-2



LEGEND

T.D. = Total depth

Pressure Test Results & Data

0.0 C.F.M. AT 10 PSI. 12-21-61

• 0.0 Cubic feet per minute leakage at 10 pounds per square inch guage pressure on December 21, 1961. Brackets indicate interval of boring tested

Sd	Sand or Sandy	vug	Vuggy
Cl	Clay or Clayey	gr	Gray
LS	Limestone	bl	Black
Sh	Shale or Shaly	dk	Dark
bro	Broken	brn	Brown
wea	Weathered	sms	Seams
Slc	Slickensided	incl	Inclusions
arg	Argillaceous	sty	Stylolitic or Stylolites
aren	Arenaceous		
cry	Crystalline	so	Soft
cal	Calcareous	MH	Medium hard
foss	Fossiliferous	M	Massive
sol	Solutioned	MB	Medium-bedded
cav	Cavities		
sli	Slightly		

Cl or Sd Cl
LS, arg
Sh or Sh sm
foss
wea
sol

VERTICAL SCALE IN FEET
5 0 5 10

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER

LOGS OF BORINGS

CLOPTIN CROSSING DAM SITE

U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC 1964
SUBMITTED: CHIEF, PROJECT PLANNING BRANCH
APPROVAL RECOMMENDED: CHIEF, ENGINEERING DIVISION
APPROVED: DISTRICT ENGINEER
PREPARED: A. N. Hall, CHIEF, FOUNDATION & MATERIALS BR.
DRAWN BY A.O.W. CHECKED BY W.S.S.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD 707-2

DAM NO. 7 - GUADALUPE RIVER

123. GENERAL.- The geology of Dam No. 7 has been investigated both by geologic mapping and core boring exploration. The results of these investigations can be found in the geology appendix of the report by Forrest and Cotton, entitled "Proposed Guadalupe River Dams No. 7 and No. 8," dated June 1963. The geology appendix was prepared by Mason-Johnston and Associates of Dallas, Texas. The Corps of Engineers did not conduct foundation studies at the site. The following discussion is a review of the geology as presented in the above-referenced report.

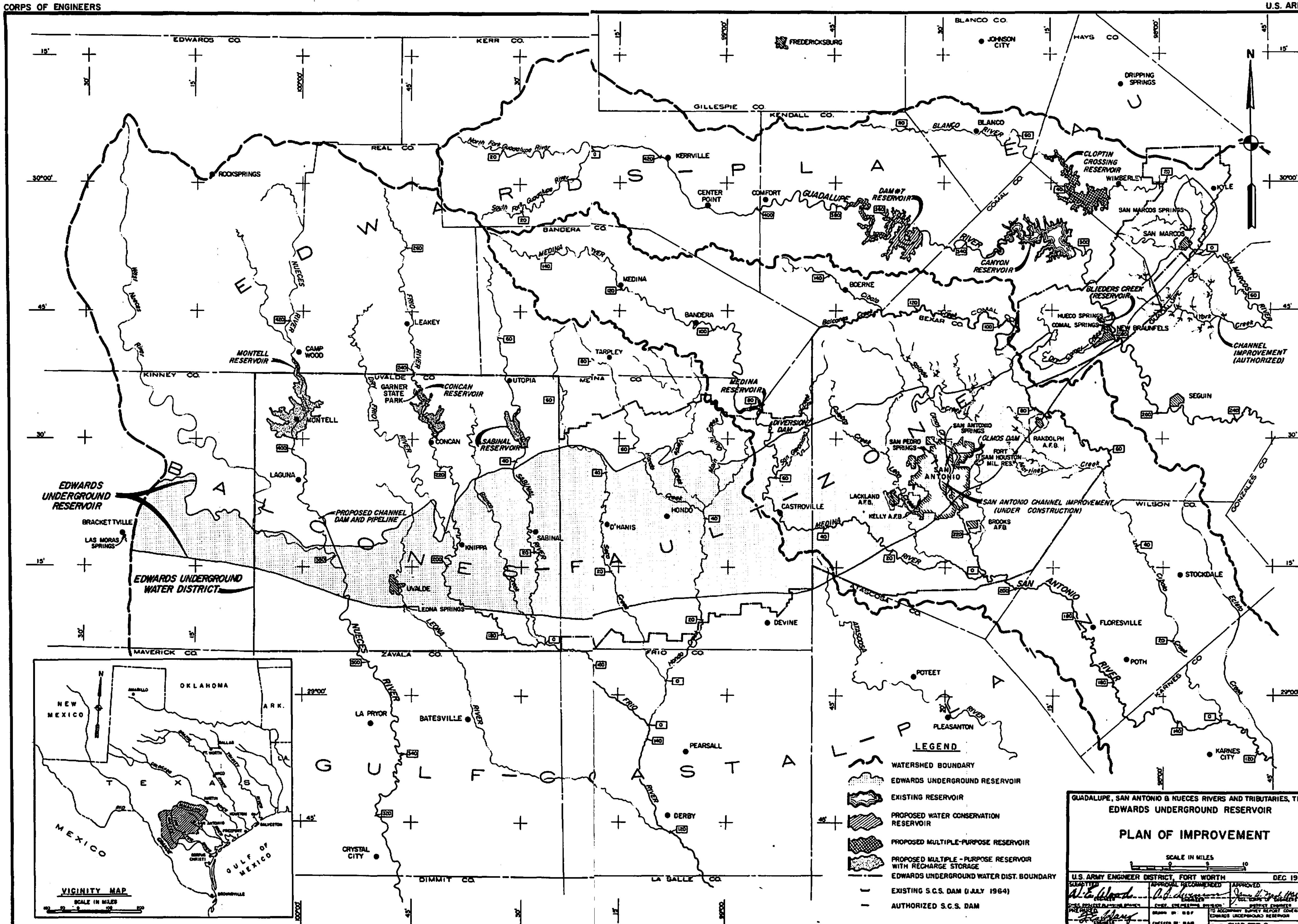
124. FOUNDATION CONDITIONS.- Dam No. 7 will be founded on the Cow Creek and Hensell members of the Travis Peak formation and the lower member of the Glen Rose formation. The Cow Creek and Hensell members occur as inliers in the streambed while the lower member of the Glen Rose forms the valley walls and caps the abutments. The members are composed chiefly of limestone and dolomite and are considered adequate to support the dam and its appurtenant structures. Grouting will be required to prevent underseepage through the rock underlying the embankment and spillway, but this should not present any major construction problems. It is anticipated that the highest grout takes will occur on the left abutment where joint planes are well developed and solutioning has occurred. There are no known faults in the reservoir or dam site vicinity.

125. RESERVOIR LEAKAGE.- To study leakage conditions in the reservoir, Mason-Johnston investigated solution channels, underground voids, water wells, caves, and springs in the area. During the course of the study it was determined that the major joint trend (along which most solutioning has occurred) consists of a conjugate system. The major set strikes approximate N50°E, and the secondary set strikes N40°W. Solutioning channels are best developed near the Guadalupe River valley, and abundant open cavities were encountered during the foundation drilling at the dam site, especially in the left abutment. A large commercial cave, "Cave Without A Name," is outstanding evidence that considerable solutioning has taken place in the reservoir.

126. Springflows in the area were noted at two principal levels; a lower level emitting from the Glen Rose-Hensell contact, and an upper level emitting from the thin fossiliferous limestone ledge commonly called the "*Corbula* Bed.' The uppermost springs are subject to considerable flow changes, depending on the rainfall, while the lower springs are perennial and apparently are not dependent on seasonal rainfall.

127. While all of these factors will contribute to reservoir leakage, Forrest & Cotton feels that they will be insignificant. Evidently the ground-water level is approximately the same as

and tributary to the ground-water level of the Guadalupe River. It is also believed that, if leakage occurs from the Dam No. 7 reservoir, most of the water would be recaptured before reaching Canyon Dam. Detailed investigations will be required to determine the capability of the reservoir to contain water without appreciable losses, or that the water would re-enter the Guadalupe River before reaching Canyon Dam.


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 (I JULY 1964)
AUTHORIZED S.C.S. DAM
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
PROPOSED CHANNEL DAM AND PIPELINE
MONTELL RESERVOIR
CONCAN RESERVOIR
SABINAL RESERVOIR
MEDINA RESERVOIR
DIVERSION DAM
DAM #7 RESERVOIR
CANYON RESERVOIR
CLOPTIN CROSSING RESERVOIR
BLIEDERS CREEK RESERVOIR
CHANNEL IMPROVEMENT (AUTHORIZED)
SAN ANTONIO CHANNEL IMPROVEMENT (UNDER CONSTRUCTION)
OLMOS DAM
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF-COASTAL PLAIN
EDWARDS CO.
KERR CO.
REAL CO.
BANDERA CO.
KENDALL CO.
GILLESPIE CO.
BLANCO CO.
HAYS CO.
COMAL CO.
BEXAR CO.
KINNEY CO.
UVALDE CO.
MEDINA CO.
GUADALUPE CO.
WILSON CO.
GONZALES CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
ATASCOSA CO.
KARNES CO.
DIMMIT CO.
LA SALLE CO.
ROCKSPRINGS
KERRVILLE
CENTER POINT
COMFORT
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
WIMBERLEY
KYLE
SAN MARCOS
SAN MARCOS SPRINGS
NEW BRAUNFELS
HUECO SPRINGS
COMAL SPRINGS
SEGUIN
BOERNE
MEDINA
BANDERA
TARPLEY
UTOPIA
LEAKEY
CAMP WOOD
MONTELL
GARNER STATE PARK
CONCAN
LAGUNA
BRACKETTVILLE
LAS MORAS SPRINGS
UVALDE
LEONA SPRINGS
KNIPPA
SABINAL
D'HANIS
HONDO
CASTROVILLE
DEVINE
SAN ANTONIO
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
PEARSALL
DERBY
CRYSTAL CITY
NUECES RIVER
WEST NUECES RIVER
FRIO RIVER
DRY FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
SAN ANTONIO RIVER
LEONA RIVER
ATASCOSA RIVER
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
SCALE IN MILES

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ATTACHMENT

REPORT BY ISOTOPES, INC.

Technical Report

TRITIUM ANALYSES OF SURFACE, SPRING AND WELL WATER FROM THE SAN ANTONIO AREA, TEXAS

Prepared for

The U. S. Army Engineer District,
Fort Worth
Corps of Engineers
Fort Worth 4, Texas

Revised

September 1, 1964

ISOTOPES, INC.

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ISOTOPES, INCORPORATED
123 Woodland Avenue
Westwood, New Jersey

ABSTRACT

About 100 river, spring and well water samples from the region of the Edwards Underground Reservoir, Texas, were analyzed for tritium. No enrichment of the samples was performed before analysis. The river samples ranged from 441 tritium units (T.U.) to 118 T.U., the spring samples ranged from 275 T.U. to < 50 T.U., and the well samples from 103 T.U. to < 30 T.U. About three fourths of the samples were collected in early August 1963 following a period of low rain-fall and about one fourth in late October following a fairly heavy rain. Not only the river samples, but also three deep well samples recovered from depths of 715, 1300 and 1600 feet in Medina County contained high tritium activities. The results of this study are considered encouraging and more work is suggested.

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Introduction

It was the purpose of this study to suggest steps toward achieving a better knowledge of the underground water flow in the Edwards Reservoir, Texas. The U.S. Army Engineer District, Fort Worth, is investigating 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.

The Edwards Reservoir is the only source of water in the San Antonio area. Hundreds of water wells have been drilled into the Edwards and associated limestones, which comprise the storage rock. In addition to withdrawals through wells, large volumes of water flow from the Reservoir through several large springs, some of which provide water for industrial use.

The lower(southern) boundary of the Edwards Underground Reservoir is identified in Figure 1. The upper boundary is the Balcones fault zone, which is located along the southernmost boundary of the outcrop of the Edwards and associated limestones. The fault zone is the area where the Edwards aquifer is recharged from the streambeds. The springs discharging from the aquifer are located near its southern and eastern boundaries.

The greatest recharge to the Edwards Reservoir is derived from inflow from channels of the Nueces, San Antonio, Medina and Sabinal rivers and their tributaries which cross the cavernous limestones that constitute the surface rock over the Edwards Reservoir. The flow in these streams varies significantly from season to season and from year to year, depending upon rainfall on the Edwards Plateau to the north and west of the Reservoir. According to information supplied by the Corps of Engineers, the construction of surface reservoirs is intended, in order to curb seasonal high runoff on some of the streams, thus smoothing the stream flow and providing more uniform recharge of the Edwards Reservoir.

However, the directions and rates of water flow in the reservoir are only incompletely known. Available data indicate a net movement of water in the entire area toward the east and northeast. Observation of water levels in a large number of wells support this conclusion. However, considerable uncertainty remains concerning local conditions in this extensive area. A better knowledge of rates and directions of movement of water could pinpoint certain areas or specific stream channels through which recharge would be particularly effective with respect to the replenishment of water withdrawn by the major consumer, the San Antonio area proper.

Tracer experiments can be very useful in studying problems of this type. Among the many potential tracers for water, the hydrogen isotope tritium stands out because of its chemical identity with hydrogen, which is a constituent of the water molecule. Naturally-produced tritium has always been present in rain water to the extent of about 1 to 20 tritium units (T.U.), that is one to twenty tritium atoms per 10^{18} hydrogen atoms. However, since the advent of atmospheric nuclear testing, bomb-produced tritium has at times increased the tritium activity levels of rain water to hundreds or even thousands of tritium units. A discussion of bomb-produced tritium in rain and ground water is given in the Appendix to this paper.

In a preliminary study by Isotopes, Incorporated, it was established that the stream waters in the San Antonio area contain sufficient tritium to render them traceable. On the other hand, analysis of one spring sample (Comal Springs) yielded no detectable tritium activity, indicating that that particular sample of water had been stored underground for a considerable time and had not been mixed with recent recharge water. At the outset of this study program, it was hoped that natural tritium levels in some recharge waters of the Edwards Underground Reservoir would be high enough to render them traceable by tritium analyses. A calculation of natural tritium levels in the Edwards underground reservoir was made, assuming homogeneous mixing of all water at all times. The data are presented in the Appendix, Table 5. The average activity for all Edwards storage waters, if they were completely mixed, would be between 30 and 80 T.U., depending on assumptions regarding the depth of the reservoir. Because the annual rate of turnover is most likely on the order of a few percent, water with activities of about 100 T.U. should be present in the system, since in actuality complete mixing does not occur.

It was decided that about 100 water samples should be taken and analyzed. A sampling plan was set up, based on a study of all the available literature on the subject. The

U.S. Army Engineer District, Fort Worth, in cooperation with the U.S. Geological Survey, San Antonio, provided the samples requested, and these were subsequently analyzed for tritium at Isotopes, Inc.

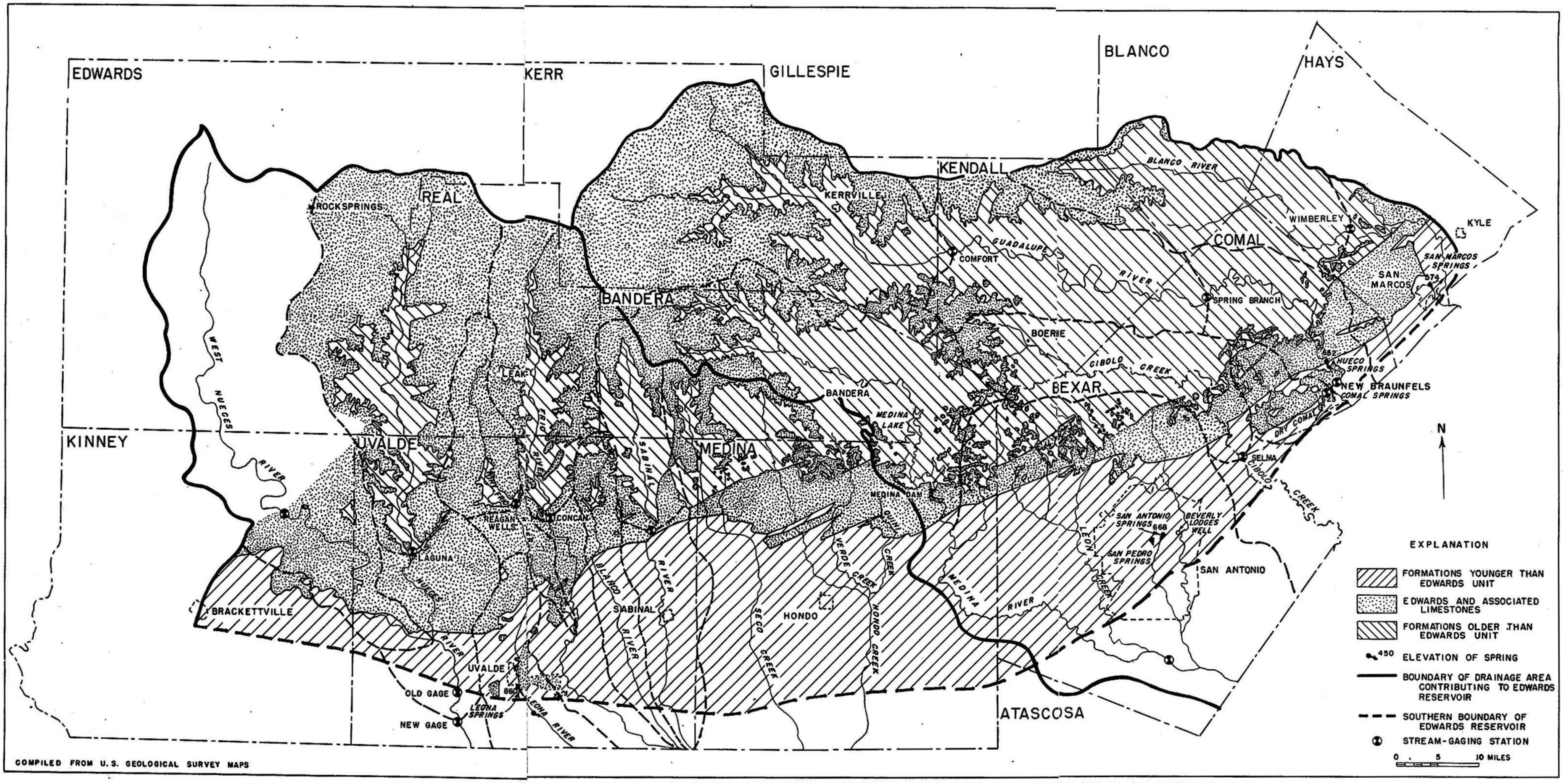

FIGURE 1.-GEOLOGIC MAP SHOWING EXTENT OF EDWARDS RESERVOIR AND AREA CONTRIBUTING RECHARGE.

Results of the Analyses

The analytical results of the initial exploratory samples are given in Table 1. Figure 2 serves as a general index map, indicating the locations of six Texas counties with respect to the city of San Antonio, the major water consumer. Also, the general trend of the water table, and the relative contributions of springs and wells to the total discharge are indicated. Table 2 lists all the water samples received for analysis, together with pertinent information and data. Table 3 contains a division of sample into river and reservoir samples, spring samples, and well waters, considering only well samples with measurable tritium levels. For the exact location of all the wells, springs and water bodies, reference may be made to Plate 12, Bulletin 5608, which is not included in this report. According to the Corps of Engineers, the stream samples were taken upstream from the fault zone.

To minimize the analytical costs, none of the samples were subjected to tritium enrichment before analysis. An arbitrary lower limit of 100 T.U. might be assumed for the detectability of tritium in these unenriched samples, under the conditions of analysis. Some of the counting data, however, indicated activities as low as < 30 T.U., and these results are listed in Table 2. However, any activities of less than 100 T.U. are only tentative and should be checked by further analyses. All of the river samples were found to be measurable. A total of 15 river and reservoir samples exhibited tritium activities between 118 T.U. and 441 T.U.

Of the spring samples six had tritium activities ranging from < 50 T.U. to 275 T.U., with three below 100 T.U. Of 75 well samples, only 10 had measureable tritium activities. Three well samples from Medina County had activity levels above 100 T.U. The activities of seven other well samples were determined tentatively to be between 50 and 100 T.U. The remaining 65 well samples had activities too low to be measured without tritium enrichment by a factor of 10 to 100.

The 94 samples which are reported in Table 2 were collected in two series. The first series was collected from August 6 to August 9, 1963. The second series was collected from October 30 to October 31, 1963.

Table 1

Preliminary Water Samples for Tritium Analysis

From the Edwards Underground Reservoir, Texas

Spring 1963

Sample	Tritium Activity (T.U.)
Comal Springs	< 100
Nueces River	500
Medina River	1190

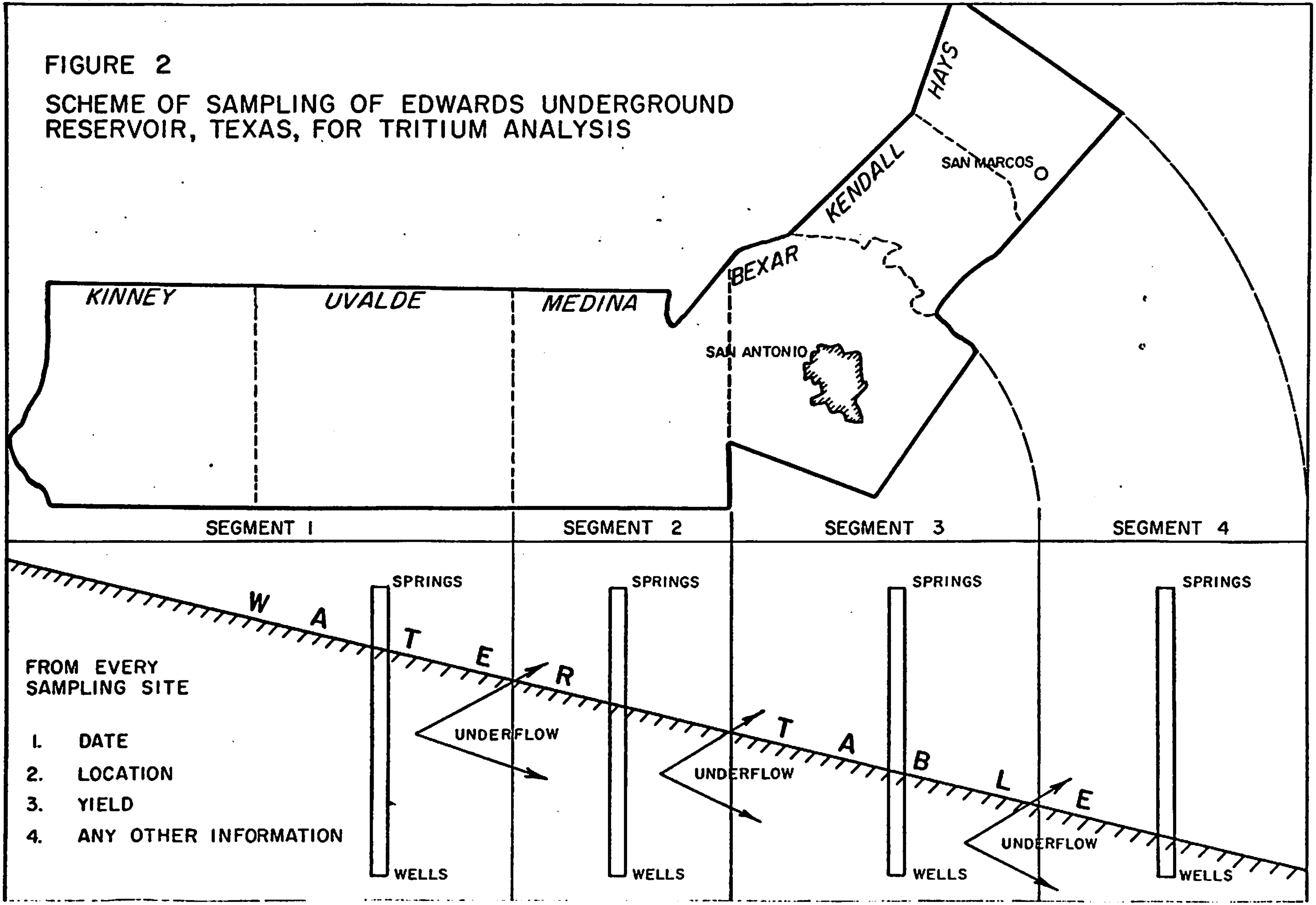
FIGURE 2
SCHEME OF SAMPLING OF EDWARDS UNDERGROUND RESERVOIR, TEXAS, FOR TRITIUM ANALYSIS
HAYS
KENDALL
SAN MARCOS
BEXAR
KINNEY
UVALDE
MEDINA
SAN ANTONIO
SEGMENT 1
SEGMENT 2
SEGMENT 3
SEGMENT 4
SPRINGS
WELLS
WATER TABLE
UNDERFLOW
FROM EVERY SAMPLING SITE
1. DATE
2. LOCATION
3. YIELD
4. ANY OTHER INFORMATION

Table 2. Water Samples for Tritium Analysis from the Edwards Underground Reservoir, Texas, August and October 1963

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (±10%)
<u>Kinney County</u>							
V-7	Las Moras Springs at Brackettville	-	-	5,000	75	Aug 63	150
X-5	drilled 1938	514	n.d.	2	81	Aug 63	< 100
Y-3	drilled 1925, Bulletin 6216	435	n.d.	n.d.	n.d.	Aug 63	< 100
<u>Uvalde County</u>							
-	Nueces River near Laguna	-	-	12,000	88	Aug 63	186
-	Nueces River at Laguna	-	-	5,000	n.d.	Oct 63	237
-	Frio River near Concan	-	-	7,500	88	Aug 63	289
-	Frio River at Concan	-	-	3,000	n.d.	Oct 63	260
-	Sabinal River near Utopia. Uvalde Lake. No water running in Sabinal River. Water standing several months.					Aug 63	162
-	Sabinal River - only few gpm flow above fault zone.	-	-	20	n.d.	Oct 63	147
-	Leona Springs near Uvalde	-	-	10,000	87	Aug 63	275
G-6-10	N.W. of Uvalde , Bulletin 6212	100	n.d.	2	77	Aug 63	< 100
H-4-64	W. Nueces River, Bulletin 6212	842	n.d.	2	78	Aug 63	< 100
H-5-135*	drilled 1941, Bulletin 6212 (Cased 100)	440	n.d.	850	74	Aug 63	< 100
H-6-22	drilled 1953 drawdown 5' after 5 hr. pumping at 1300 gpm (Cased 890)	1,300	n.d.	900	84	Aug 63	< 100
I-4-37	Sabinal City Well, 1919 Stat.1-230'(Cased 930)	1,493	n.d.	500	74	Aug 63	< 30
I-4-37	drilled 1923, static level 232'	1,493	n.d.	350	n.d.	Oct 63	< 30
H-2-4	drilled 1894, pumped all day	190	n.d.	1	n.d.	Oct 63	< 30

* listed as I-5-132 on sample tag

Table 2. (Continued)

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (±10%)
Medina County							
-	Seco Creek	-	-	2,500	n.d.	Oct 63	386
-	Hondo Creek	-	-	1,000	n.d.	Oct 63	441
-	Medina River below Medina Dam	-	-	-	62	Aug 63	189
-	Medina Division Dam Lake	-	-	-	n.d.	Oct 63	262
I-1-2*	drilled 1944, Bulletin 5608	-	n.d.	10	72	Aug 63	50
I-1-2*	drilled 1932	411	n.d.	5	n.d.	Oct 63	< 50
I-4-12	drilled 1944, Bulletin 5608	1,303	n.d.	-	85	Aug 63	103
I-5-80	static level - 204'	1,289	920-1,289	260	76	Aug 63	< 100
I-5-55	drilled 1926, Bulletin 5608	2,000	-	7	74	Aug 63	< 100
I-5-74	drilled 1958, max. yield 2,000 gpm	2,260	n.d.	900	75	Aug 63	< 100
I-2-16	drilled 1918, Bulletin 5601	400	n.d.	10	72	Aug 63	< 100
I-2-16	drilled 1918	400	n.d.	10	n.d.	Oct 63	< 100
I-3-43	drilled 1914, Bulletin 5608	237	140-237	10	73	Aug 63	< 100
I-3-117	drilled 1942, Bulletin 5601 (Cased 1285)	1,510	n.d.	1,100	75	Aug 63	< 30
I-3-117	Hondo City Well, 1942	1,510	-	800	n.d.	Oct 63	< 30
I-3-128a	drilled 1957, stat.level-174 (Cased 1,320)	1,654	n.d.	800	78	Aug 63	101
J-1-3	drilled 1957, Bulletin 5608	260	n.d.	10	n.d.	Aug 63	< 50
J-1-44	-	195	n.d.	3	n.d.	Aug 63	< 50
J-1-41	drilled 1929, stat.level-167	641	58-641	n.d.	n.d.	Aug 63	< 50
J-1-83	drilled 1948, Bulletin 5608	715	700-715	500	75	Aug 63	101
J-4-143	drilled 1955, stat. level-92	2,765	2,256-2,765	500	94	Aug 63	< 50

*as listed on sample tag and on transmittal sheet

Table 2 (Continued)

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (± 10%)
Atascosa County							
-	City of Lytle, stat. level-50', drilled 1955	2,379	2,100-2,379	650	101	Aug 63	< 100
Bexar County							
D-1	static level-238'	1,000	n.d.	5	n.d.	Aug 63	< 100
D-12	-	360	n.d.	10	n.d.	Aug 63	< 50
D-12	-	360	280-360	5	71	Oct 63	74
E-26	drilled 1908, deepened in 1954 to 387 ft.	387	n.d.	10	75	Aug 63	< 100
F-169	drilled 1945	460	10-460	175	73	Aug 63	< 50
G-63	drilled 1953, stat. level-115	576	n.d.	25	78	Aug 63	< 50
H-113	-	n.d.	n.d.	1,000	76	Aug 63	< 50
I-2	drilled 1946, stat. level-165	235	200-235	10	71	Aug 63	< 50
I-238	drilled 1957	1,199	886-1,199	400	74	Aug 63	< 30
J-125	drilled 1949	1,376	1,182-1,376	1,200	80	Aug 63	< 30
284	City of San Antonio	1,582	n.d.	2,000	82	Aug 63	< 50
284	City of San Antonio, drilled 1951	1,582	n.d.	2,000	82	Oct 63	< 30
J-87	drilled 1954	1,150	n.d.	1,100	80	Aug 63	< 50
J-90	drilled 1956, stat. level +23'(1958)	2,179	1,750-2,179	700	110	Aug 63	< 50
K-2	old well stat. level +53'	854	810-854	20	89	Aug 63	< 50
M-44	drilled 1955	2,226	1,980-2,220	10	105	Aug 63	< 60

Table 2 (Continued)

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (± 10%)
Guadalupe County							
D-67	drilled 1896	565	n.d.	10	75	Aug 63	< 80
D-18	drilled 1955, stat. level-136	370	300-370	15	76	Aug 63	67
D-56	drilled 1950	602	436-602	500	79	Aug 63	< 40
Comal County							
F-50	drilled 1934	375	n.d.	5	74	Aug 63	56
F-26	-	251	n.d.	3	73	Aug 63	< 50
F-75	drilled 1953 (cased 185')	210	n.d.	200	73	Aug 63	60
G-84	drilled 1956	272	n.d.	3	78	Aug 63	< 50
G-95	-	400	n.d.	3	82	Aug 63	< 50
G-34	drilled 1901	140	n.d.	n.d.	78	Aug 63	< 30
G-32	drilled 1906	190	n.d.	2	73	Aug 63	< 30
G-32	drilled 1906	190	n.d.	3	71	Oct 63	< 70
G-50	Comal Springs	-	-	67,500	75	Aug 63	60
G-50	Comal Springs	-	-	67,500	75	Oct 63	88
G-67	-	502	n.d.	1.5	74	Aug 63	< 30
H-20	-	300	n.d.	0.5	74	Aug 63	< 30
H-50	old	290	n.d.	2	74	Aug 63	86
-	Guadalupe River, 1st Crossing	-	-	n.d.	88	Aug 63	259
-	Guadalupe River, 1st Crossing	n.d.	n.d.	12,000	68	Oct 63	351

Table 2 (Continued)

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (± 10%)
Hays County							
E-20	drilled 1945, Bulletin 6004	320	n.d.	5	73	Aug 63	< 50
E-76	drilled 1954, Bulletin 6004, City of Buda	390	222-390	-	-	Aug 63	71
E-76	City of Buda	n.d.	n.d.	800	n.d.	Oct 63	< 50
E-48	drilled 1943, Bulletin 6004	400	n.d.	1	73	Aug 63	<100
E-59	drilled 1943, Bulletin 6004	500	n.d.	4	73	Aug 63	< 50
E-59	drilled 1937	500	n.d.	10	n.d.	Oct 63	< 50
-	Onion Creek near State 150	-	-	< 10	88	Aug 63	243
E-80	drilled 1950, stat. level-200	492	n.d.	15	74	Aug 63	< 50
G-44	drilled 1946, Bulletin 6004	450	n.d.	-	76	Aug 63	< 50
-	Blanco River near Wimberley	-	-	1,000	89	Aug 63	118
-	Blanco River near Wimberley	-	-	~ 1,000	n.d.	Oct 63	124
H-19	drilled 1949, Bulletin 6004	765	300-765	n.d.	76	Aug 63	< 50
H-19	City of Kyle (1949)	765	n.d.	700	n.d.	Oct 63	< 50
H-25	drilled 1934, Bulletin 6004, sulphur smell	372	100-372	n.d.	78	Aug 63	< 50
H-48	old, Bulletin 6004	158	n.d.	3	74	Aug 63	< 50
H-76	drilled 1941	204	n.d.	3	71	Aug 63	< 50
H-59	Goforth Springs, 1600 gpd for 12 years	-	-	25	87	Aug 63	177
H-66	San Marcos Springs	-	-	n.d.	71	Aug 63	<100
H-66	San Marcos Springs	-	-	3,000	n.d.	Oct 63	< 50
K-5	drilled 1913, Bulletin 6004	200	n.d.	3	73	Aug 63	<100
H-84	drilled 1941, Bulletin 6004	250	n.d.	3	74	Aug 63	< 50

Table 3

Summary of Water Samples Containing Measurable Activity

Well Number	County	Description	Tritium Activity (T.U.) Aug. 63	Oct 63
1. River and Reservoir Samples:				
-	Uvalde	Nueces River	186	237
-	"	Frio River	289	260
-	"	Sabinal River	162	147
-	Medina	Medina River	189	262
-	"	Seco Creek	-	386
-	"	Hondo Creek	-	441
-	Comal	Guadalupe River	259	351
-	Hays	Onion Creek	243	-
-	"	Blanco River	118	124
2. Spring Samples:				
V-7	Kinney	Las Moras Springs	150	-
-	Uvalde	Leona Springs	275	-
G-50	Comal	Comal Springs	60	88
H-59	Hays	Goforth Springs	177	-
H-66	"	San Marcos Springs	< 100	< 50
3. Well Samples with Identifiable Activity:				
I-1-2	Medina	411 feet deep	50	< 50
I-4-12	"	1303 feet deep	103	-
I-3-128a	"	1654 feet deep, cased 1320 feet	101	-
J-1-83	"	715 feet deep	101	-
D-12	Bexar	360 feet deep	< 50	74
D-18	Guadalupe	370 feet deep	67	-
F-50	Comal	375 feet deep	56	-
F-75	"	210 feet deep, cased 185 feet	60	-
H-50	"	290 feet deep	86	-
E-76	Hays	390 feet deep	71	< 50
H-84	"	250 feet deep	< 50	-

Discussion of the Analytical Results

Even though only one third of the water samples had tritium activities high enough to be measured without enrichment, the results of the analyses do exhibit some significant variations in activity with both location and time of sample collection.

1. River Water Samples

The data for river and reservoir samples in Table 3 show a considerable range in tritium activity. Blanco River contained the lowest concentrations of tritium, followed by Sabinal, Nueces, Medina, Onion, Frio, Guadalupe, Seco, and Hondo rivers and creeks, in order of increasing tritium concentrations.

The spread of activities from 118 to 441 T.U. in rivers is somewhat hard to understand upon first glance, if it is considered that rivers are in general supported by rains, and that rivers in any one area, such as the Edwards Plateau area, are in general supported by the same rains. Then large variations of tritium levels in streams of any one area might not be expected. However, in the present case it must be remembered that the water samples were taken following a long period of rather low rainfall, when only minor surface runoff contributed to the streams, so that base flows were approached. The stream flow data in Table 4 demonstrate the low rate of total runoff from the Edwards Plateau in the fall of 1963, including surface runoff and base flow. The total runoff of all rivers listed in Table 4 amounts to about 36,000 gpm in August 1963

Table 4

River Flow Rates and Tritium Levels

		River Flow Rates (gpm)*		Tritium Activities (T.U.)	
County	River	Aug 63	Oct 63	Aug 63	Oct 63
Hays	Blanco	1,000	~ 1,000	118	124
Uvalde	Sabinal	0	20	162	147
Uvalde	Nueces	12,000	5,000	186	237
Medina	Medina	62	~ 62(?)	189	262
Hays	Onion	< 10	< 10(?)	243	-
Uvalde	Frio	7,500	3,000	289.	260
Comal	Guadalupe	~ 12,000(?)	12,000	259	351
Medina	Seco	~ 2,500(?)	2,500	-	386
Medina	Hondo	~ 1,000(?)	1,000	-	441

*Flow rates were compiled from information transmitted on sampling tags.

and 25,000 gpm in October 1963. It is safe to say that only 1/10 to 1/20 of the normal surface runoff was in the streams when most of the samples were collected. This low runoff rate suggests that a significant portion of the river water during August and October 1963 may have passed from subsurface storage. This would have diluted the tritium levels of the recent rain water to a significant extent.

2. Well Water Samples

As was mentioned above, only three well water samples possessed tritium activities above 100 T.U., the lowest activity measureable with good precision in this study. The following are those three wells:

I-4-12,	1,303 feet deep,	103 T.U.
I-3-128a,	1,654 feet deep,	101 T.U.
J-1-83,	715 feet deep,	101 T.U.

All three wells are located in Medina County. They are located roughly along a 30-mile stretch of U.S. Highway 90. Well I-3-128a is cased to a depth of 1,320'. Well J-1-83 is known to produce from an aquifer at 700 to 715 feet depth. Then, the three wells bear out the fact that runoff water in that portion of the Edwards Underground Reservoir does proceed to considerable depth with little dilution. It is also interesting to recall at this point that Hondo Creek and Seco Creek pass within three miles of wells I-3-128a and I-4-12, respectively, and that both streams exhibited high tritium levels. The three deep wells in Medina County stand in a significant contrast to the other 72 wells sampled, which gave lower tritium activities. Since the beginning of 1957, a large amount of recharge has occurred in the Edwards reservoir, and it is surprising that more evidence of that (tritium-active) recharge was not encountered.

The average discharge of ground water in Medina County by pumpage (no springs) amounts only to 7.2×10^6 gpd (1962), which is 1.4% of the total discharge of 525×10^6 gpd for the six counties(1). On the other hand, the average recharge of the Edwards Reservoir portion located in Medina County, as described roughly as the area between the Sabinal and Medina Rivers, and a 50% portion of the Medina Lake recharge, amounts to about 20% of the total Edwards reservoir recharge(2). Clearly, almost all the water recharged in Medina County migrates as underflow elsewhere, making room for more recharge.

The remaining well water samples with measurable activity, but with less than 100 T.U., are mostly from shallow wells in Comal and Hays Counties. They have depths between 190 and 375 feet and are of secondary significance.

Conclusions and Recommendations

The work done during this study has demonstrated that natural tritium tracer can be usefully employed to investigate recharge and discharge problems of underground water storage and to provide data on rates and directions of water movement. In the present case only the least expensive means of analysis of unenriched water samples were employed, but it was possible to determine the natural concentrations of the tritium in the Edwards Reservoir and the degree of refinement necessary for more sensitive work. A calculation of the average tritium level in the Edwards Underground Reservoir assuming complete mixing, as shown in the Appendix, yields a value of about 30 or 80 T.U., based on an average depth of the reservoir of 600 or 1,750 feet, respectively. Some of the well water samples did contain tritium activities this high or even higher.

This work was intended to be preliminary and exploratory. A more detailed study is suggested, employing higher degrees of sensitivity of analysis. The laboratory techniques and apparatus now in use at Isotopes, Inc. permit analysis of unenriched samples for levels down to 15 T.U. and enriched samples down to 0.1 T.U. It is recommended that the water samples of low activity (< 100 T.U.) from this study be reanalyzed with the new apparatus. More evidence such as was obtained from the three Medina County deep well samples is expected.

It is suggested that further sampling of areas of special interest be performed while recharge of the reservoir by the spring rains (with high tritium activities) is occurring. This would make possible sensitive analyses without using artificially injected tritium. Artificial tracer injections, consisting of both observation well experiments and dissipation studies (point source studies), could be performed where natural tritium studies fail.

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Appendix

The Expected Tritium Level in Ground Waters

and Surface Waters of the U.S., 1963-1964

A Guide for the Proper Appraisal of Projects Involving Tritium Measurements

July 1, 1963

ISOTOPES, INCORPORATED
123 Woodland Avenue
Westwood, New Jersey

Table of Contents

Introduction

The abundance of tritium in nature has fluctuated greatly since the Castle series of tests of thermo-nuclear devices in 1954. Before 1954, the total amount of tritium on this planet was about 12 kg. At that time, the concentration in ocean surface waters was about 1 tritium unit (T.U.). By the end of the Castle series of nuclear tests, the total amount of tritium on the earth had doubled. Since then, as the result of further tests, we have experienced rains carrying thousands of T.U. and major streams carrying hundreds of T.U. The tritium activity found in water samples has varied, therefore, over a range of three orders of magnitude or more, depending on the origin and age of the sample.

Sensitive counting instruments can measure tritium without enrichment if it is present in a sample in excess of about 100 T.U. If the sample contains lower concentrations of tritium, it can be enriched by an electrolytical process, but this costs time and money.

It is the purpose of this paper to examine the past and present tritium levels in natural waters in the light of the published literature. In particular, it will be attempted to estimate the tritium content of West Texas water in underground storage, and to predict changes in these tritium levels during the next few years.

Models for the Expression of Tritium Fallout

An examination of the literature reveals that four or five different mechanisms have been proposed by which an idea of the total tritium fallout or of specific fallout in any time period might be gained. The most straightforward approach is the fusion equivalent bomb tritium plot (Libby).

In addition, we may propose a rain - groundwater tritium balance computation for 1953 - 1964 based on worldwide analyses.

It may be worthwhile to examine these mechanisms briefly, with reference to the original work, and apply them to our specific tritium problems.

a) The fusion equivalent bomb tritium plot (Libby)

W.F. Libby (1961, p.3373) published a diagram which shows a linear correlation between post-early fallout tritium in rain and in a number of water bodies and the fusion equivalent of previous thermonuclear blasts, as shown in Figure 3. It can be concluded that linearity between the tritium content of fresh surface waters and equivalent fusion energy (MT) may persist for several years after testing, if allowance for decay of tritium is made. At least Libby used data which cover a period of up to 3 years and achieved a reasonably good correlation. It will be attempted now to extend his diagram up to 1963-1964 and apply it to our test areas.

If we extend the abscissa of the diagram (Figure 3) to 318 MT and extend the straight lines through the tritium plots for the various

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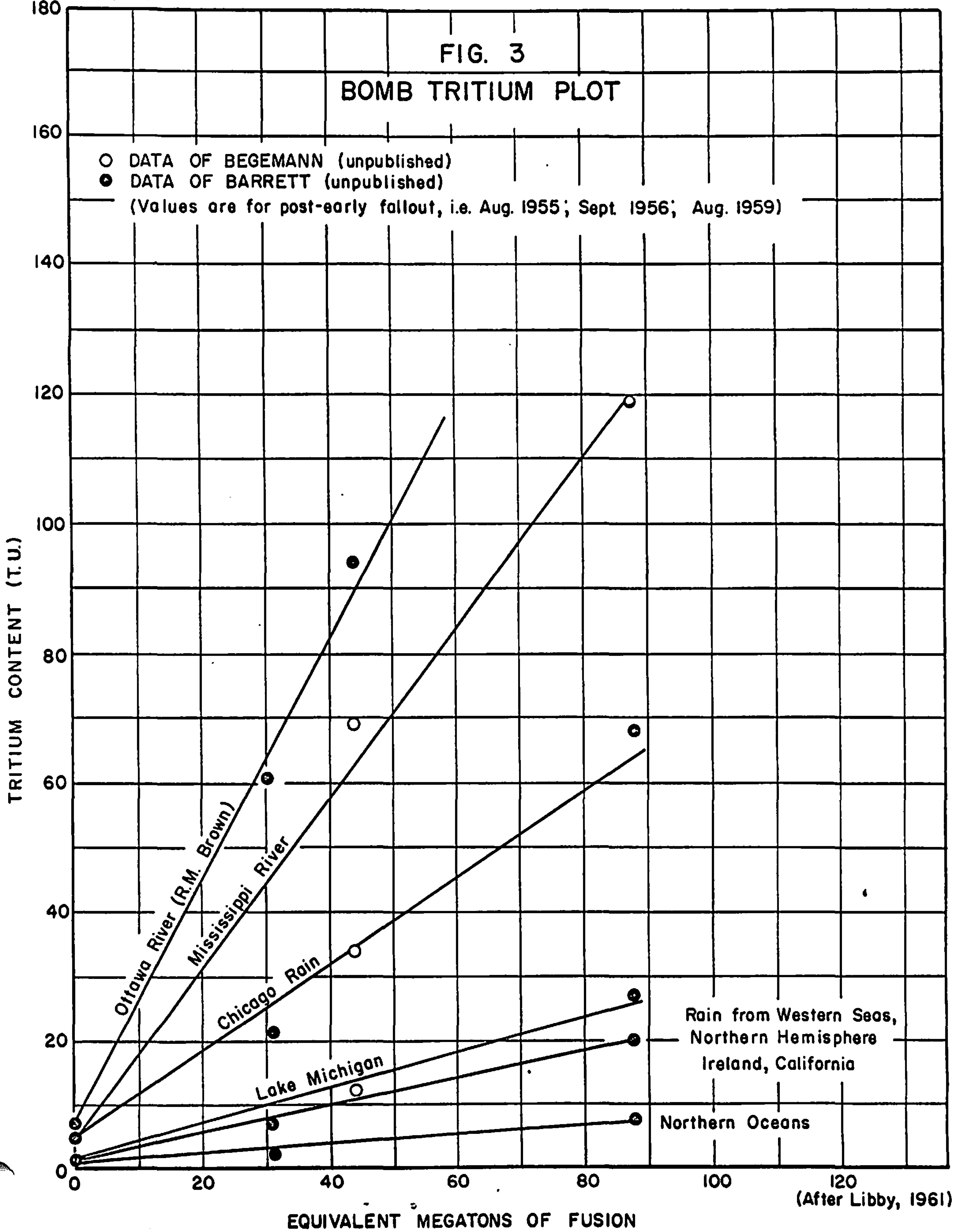

(After Libby, 1961)

localities, we get the following (maximum) projection for post-1962 rains:

California	65 T.U.
Lake Michigan	82 T.U.
Chicago rain	250 T.U.
Mississippi River	500 T.U.
Ottawa River	700 T.U.

This projection appears to be quite within reason. Libby (1963) himself published a diagram of "California tropospheric moisture" collected, in part, on the roof of the UCLA chemistry building. The 1962 average, up to September (last analysis), appears to have been about 70 T.U. On the other hand, the average 1962-1963 (weighted) rain analyses in Westwood will probably be about 700 T.U. The data of Brown (1961) for Ottawa rain up to 1959 suggest an extrapolation to a similar level. The tritium activity for rains over other areas on the North-American continent should be somewhere between 70 and 700 T.U.

b) Tritium levels in 1959-1963, according to reported data

For times up to 1954, we can safely assume a tritium level in surface ocean water of 1 T.U. (Giletti et al. 1958). The pre-bomb tritium level of the central U.S. was about 8 T.U. (Thatcher 1962), based on measurements of samples collected in 1952-1953. Underground reservoirs, if in contact with meteoric water supplies, must have had a tritium level lower than this, depending on the rate of turnover of the reservoir. Reservoirs which were out of contact with meteoric water for more than 50 years or which had rates of turnover of hundreds of years must be essentially "dead" with respect to tritium activity. Such waters are definitely in existence today.

Some deep wells near Artesia, N.M. were found in 1957 to have 1.5 T.U. (von Buttlar, 1959). Libby (1961) analyzed some San Fernando, California well water in 1960 which contained no detectable tritium. Then, deep underground reservoirs of no or low rate of turnover may be completely lacking in tritium activity or have activities of about 1 T.U. Some knowledge of the rate of turnover of reservoirs would be helpful in assessing their tritium activity prior to analysis.

One of the best records of tritium activities in rain and storage water was compiled by Brown (1961) for the Ottawa valley, Canada. For the pre-test level of Ottawa rains, a value of 15.3 T.U. is given. Tritium from the October 1958 tests of the USSR continued to appear in Ottawa rains at close to maximum concentrations to the end of the report period in late 1959. Brown believes that the observed summer peak in tritium concentration in rain is due to tritium evaporation from vegetation and reabsorption in the rain. Thus, he distinguishes T_R, tritium in rain, T_V, tritium in storage water, and T_N, the new tritium in rain, corrected for evaporative tritium. Brown gives the following figures for the average tritium deposition in Ottawa:

Date	Ave. T_R	Ave. T_V	Ave. T_N	Rainfall m/year	T Deposit 10^7 Atoms/cm^2yr
pre 1953	15.3	14.0	8.4	0.74	4.2
1953	21.1	14.4	12.6	0.746	6.3
1954	277	51	194	1.11	145.
1955	43	72	17	0.719	8.2
1956	145	78	89	0.800	48.
1957	122	92	70	0.734	34.
1958	537	132	362	0.855	208.
1959	541	270	343	0.893	205.

According to Libby (1963), more recent Ottawa rain data are:

1960 ~ 200
1961 ~ 300   as gleaned from Figure 1, p. 4490

For the calculation of storage water tritium, Brown used a fractional turnover rate of 0.27 per annum for the Ottawa valley, which put the mean residence time at 3.7 years. Brown calculated the fractional turnover per year for several streams, including the following:

Stream	Date Sampled	T.U. Observed	Fractional Turnover/yr
Lake Erie(exit)	14 August 1958	96.1	0.14
St. Lawrence R. (at Brockville)	13 September 1958	67.8	0.085
Deep River	30 June 1958	122	0.30
Deep River	30 September 1958	167	0.30

Thatcher (1962) made a comprehensive study of the distribution of tritium in rain over North America. His Table 1 gives the tritium concentrations during 1958 at various locations in the U. S. :

Location	Average, Adjusted Tritium Activity (T.U.)	Precipitation (cm) Sampled	Total
Key West	81	23.4	23.4
New Orleans	107	51.5	51.5
Memphis	260	61.5	63.9
Milwaukee	588	12.8	14.0
Omaha	443	40.2	41.9
Salt Lake City	255	5.0	5.3

Thatcher also gives a table from a study by Kaufman and Libby, listing tritium levels in ground water at various depths in a porous sandstone formation. The data are for November 1958, and are averages from 8 wells:

Depth (m)	Tritium Activity (T.U.)
0.6	120
7.5	35
15	15
30	1

The greater part of the spring 1958 fallout is believed to be deposited above 0.6 m. The tritium activity in the soil zone on top is believed to be about 300 T.U. This is the zone that provides water for direct evaporation from the surface of the soil. The data stress the importance of knowing the level from which water samples come.

Von Buttlar and Wendt made hydrological studies in New Mexico (1959) using tritium as a tracer. For 1959 they list tritium concentrations varying from 1160 T.U. in Los Alamos rains (June 25) to 6.6 T.U. in Rio Grande water (Feb. 6). They attempted to identify in well waters the sharp tritium peaks of the summer rains in 1954 and 1956. In 1956, two years after the rains with tritium activities in excess of 1000 T.U., they observed well water peaks with an average height of 50 T.U. The average tritium concentration in rain was about 500 T.U. during the summer of 1954. This means that a ten-fold dilution, on the average, had taken place.

Von Buttlar (1959) gives 1957 and 1958 tritium analyses for New Mexico river waters. The average tritium level in the river for 1957 and 1958 was 68 T.U., maintaining a fairly even level from Feb. 1957 to March 5, 1958. The maximum deviation was in June with 116 T.U. In a final analysis of the field experiment by von Buttlar and Wendt (1958), the senior author concluded in 1959 that the ground water tritium peak observed in 1956 was indeed caused by 1954 fallout. It is interesting to note that there was a two-year lag involved in observing the peak, even though a linear distance of about 5 to 10 miles separated the supply area from the observation wells. With an appreciable gradient of 10% in the aquifer (0.1 mile per mile), which consisted of rather porous alluvium, migration rates considerably in excess of 50 ft/day would have been expected. Also, the low level of tritium activity in the peaks (50 T.U.) may be somewhat sobering.

In another study near Socorro, von Buttlar found that by March 1958 recharge to the ground water from the 1954 rains had not reached the spring which discharges this ground water. Therefore, the velocity of the ground water flow in the area west of the Socorro Mountains must be smaller than 10 miles in four years, or 35 ft/day.

Near Deming, New Mexico, the Mimbres River supplies the aquifers several miles north of the town. The water that travels underground to the city is pumped from the ground in large quantities for irrigation in Mimbres Valley. The depth of the water table has increased from 80 to 100 feet during the last 15 years. This information indicates that the ground water near Deming is engaged in considerable turnover. Therefore, recharge by tritiated, recent rain water should be expected. However, sampling of 7 wells along a line of length 8 miles, which follows the natural gradient of the water table within 3 miles of Deming, did not turn up any abnormally tritiated water by March 1958. The average tritium activities were 6 T.U. It was hoped by the author that further monitoring of the heavily pumped wells might supply some information on the tritium pattern in the aquifer. A similar result is reported from deep-well samples near Artesia, N.M., with tritium levels of 1 T.U. for deep samples (1,000 feet) and 5 T.U. for shallow samples (90 feet).

More recently, Libby (1963) reported a tritium level of 23 T.U. in Lake Michigan during the 1958-1961 moratorium on nuclear weapons tests. Begemann and Libby (1957) indicated that the post-Castle fallout of 2×10^9 T atoms/cm^2 raised this lake from 1.6 to 7.2 T.U. Therefore, Libby calculates the total tritium fallout up to the summer of 1961 in the 30°-50°N latitude band to average 7.6×10^9 T atoms/cm^2, allowing for 7 years of decay (mean radioactive life of about 18 years). The 7.6×10^9 atoms still remaining in the summer of 1961 would correspond to $7.6 \times 10^9 \times 30.75 \times 2 \times 10^9$, or 15 T.U. in the top ocean water for 1961. The 30°-50°N average fallout over the continents for 1961 was 76 T.U., and in locations north of 50°N averaged 132 T.U. For post-moratorium rains, Libby (1963) notes a general rise in tritium levels after September 1961 and the tendency to drop off again in the summer and fall of 1962 in a manner somewhat analogous to the 1959 spring peak.

Libby (1962) studied the problems of recharge of the Orange County, California underground reservoir with Colorado River water by tritium analysis. A spotty distribution of the recharge water was found, as if the Colorado water went into certain depleted areas and raised the level of the remaining old water in other areas - a result which was no surprise to hydrologists.

In work on the Montebello Forebay, which has been recharged with Colorado River water since 1954, the underground flow and distribution could be understood in detail by tritium studies, as would not have been possible by any other means.

c) Computation of tritium levels in 1963-1964 in West Texas

It appears to be most appropriate to compute the expected tritium levels in West Texas ground waters by determining first, as accurately as possible, the following data:

T_R = tritium concentration in rain water

R = annual rainfall

Ch = annual recharge to reservoir, and

W = fractional withdrawal by pumpage and springs.

In the following, the best available figures are compiled:

Year	T_R (T.U.)	R (inches)	Ch (10^3 acre-feet)	W (10^3 acre-feet)
1953	9	32	168	468
1954	300	24	161	424
1955	50	13	192	388
1956	150	8	44	392
1957	150	70	1143	456
1958	400	80	1711	618
1959	400	50	690	621
1960	200	30	825	655
1961	275	25	692	683
1962	400	25*	252	589
1963	400	20*	150*	600*
1964	250	28*	250*	650*

* estimated

The reservoir capacity will be calculated assuming an effective area of 31,000 acres and a mean depth of a) 600 feet (according to the Corps of Engineers and b) 1,750 feet (based on Figure 16, Bull. 6201 and interpretation of chemical analyses of the water). The calculation of tritium activities in the reservoir, given below, considers both assumptions a) and b).

Table 5

Calculation of Average Tritium Concentration in Underground Storage, West Texas

Assumption:
a) complete mixing
b) discharge of completely mixed water only
c) no decay of tritium during the interval 1953-1964
d) vertical extent of reservoir A) 600 and B) 1,750 feet

		A) 600 ft. Thickness			B) 1,750 ft. Thickness		
Year	Change in Stored Water	Reservoir Volume (10^3acre ft.)		Tritium Activity (T.U.)	Reservoir Volume (10^3acre ft.)		Tritium Activity (T.U.)
1953	Initial volume	18,600	at	1	54,000	at	1
	lost	468	at	1	468	at	1
	gained	168	at	9	168	at	9
		18,300	at	1.1	53,700	at	1
1954	lost	424	at	1.1	424	at	1
	gained	161	at	300	161	at	300
		18,037	at	3.7	53,737	at	1.9
1955	lost	388	at	3.7	388	at	1.9
	gained	192	at	50	192	at	50
		17,841	at	4.2	53,241	at	2.1
1956	lost	392	at	4.2	392	at	2.1
	gained	44	at	150	44	at	150
		17,493	at	4.6	52,893	at	2.2
1957	lost	456	at	4.6	456	at	2.2
	gained	1,143	at	150	1,143	at	150
		18,180	at	13.8	53,580	at	5.4
1958	lost	618	at	13.8	618	at	5.4
	gained	1,711	at	400	1,711	at	400
		19,273	at	48	54,673	at	17.7
1959	lost	621	at	48	621	at	17.7
	gained	690	at	400	690	at	400
		19,342	at	61	54,742	at	22.5
1960	lost	655	at	61	655	at	22.5
	gained	825	at	200	825	at	200
		19,512		66.5	54,912	at	25
1961	lost	683	at	66.5	683	at	25
	gained	692	at	275	692	at	275
		19,521	at	74	54,921	at	28
1962	lost	589	at	74	589	at	28
	gained	252	at	400	252	at	400
		19,184	at	78	54,584	at	30

Table 5 (continued)

Year	Change in Stored Water	A) 600 ft. Thickness: Reservoir Volume (10^3acre ft.)		A) Tritium Activity (T.U.)	B) 1,750 ft. Thickness: Reservoir Volume (10^3acre ft.)		B) Tritium Activity (T.U.)
1963	lost	600	at	78	600	at	30
	gained	150	at	400	150	at	400
		18,734	at	81	54,134	at	31
1964	lost	650	at	81	650	at	31
	gained	250	at	250	250	at	250
		18,334	at	83	53,734	at	32

It can hardly be expected that the assumptions which led to this result are all correct. The effect of tritium decay should be but minor, because most of the increase in tritium activity happened in the last seven years. Under conditions of complete mixing, and allowing for decay, a realistic value might be A) 70 T.U. or B) 27 T.U. for the total reservoir. Because mixing is, of course, not complete and a good portion of the most recent rain is being discharged through springs, one may expect an actual average tritium activity of about A) 50 T.U. or B) 20 T.U. for the Edwards reservoir.

Conclusions

Present and future tritium measurements in groundwater samples should yield a range in tritium activity between 1 and 50 T.U. Groundwater samples exceeding 50 T.U. should be exceptions. River and lake waters with a high rate of turnover should have activities between 50 and, perhaps, 300 T.U. Activities in excess of a few hundred T.U. should be expected only in rains.

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APPENDIX V

ECONOMIC BASE STUDY

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

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ECONOMIC BASE STUDY

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AND TRIBUTARIES, TEXAS

APPENDIX V - ECONOMIC BASE STUDY

INTRODUCTION

1. SCOPE.- This appendix identifies and measures, insofar as practicable, the factors relevant to economic development and growth. Basic trends in various factors of the overall economy are projected into the future to establish the economic framework within which proposed projects will operate. These projections are reasoned conclusions about economic activity, based upon objective analysis of the past and careful estimates of the effect of new forces and development that are expected to influence future trends. The report, of which this is a part, is concerned primarily with water problems and demands associated with 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 resource of the reservoir.

2. RELATIONSHIP OF THIS APPENDIX TO OTHER PARTS OF THIS REPORT.- The economic base study analyzes the industrial development of the study area, establishes a broad and comprehensive concept of the probable economic growth of the individual areas affected by specific project purposes. Population, economy, and resources vary from one place to another, and projections for the base study area are not used for individual projects. Economic indicator projections for the areas of influence of the individual projects are included in the following appendixes: Appendix I, Attachment 2, Report by Public Health Service; Appendix IV, Flood Control Economics; and Appendix VI, Recreation and Fish and Wildlife. Volume I, Main Report, contains a section, Regional Economic Development, which presents data relative to the economy of the study area and the water supply area.

3. THE STUDY.- The economic base study is presented in three major parts: the first, "The Edwards Underground Reservoir Economic Base," deals with the study area, its location, description, current economy, trends, and framework projections; the second, "National, State, and Local Projections," is largely comparison of historical and projected statistical data; and the third, "Supplementary Economic Data," is a discussion of the rationale and method of projection and contains additional economic data. A bibliography is included and numbered credit lines make reference to the pertinent publications.

4. THE BASE STUDY AREA.- The study area is the composite of the areas pertinent to the various project purposes. It comprises 60 counties in southern Texas and contains about 63,959 square miles, 24 percent of the state of Texas. The study area occupies two physiographic provinces, the Great Plains and the Coastal Plain, which are distinctly separated by the Balcones Escarpment.

5. The Edwards Plateau section of the Great Plains province is the site of the Edwards Underground Reservoir. This underground reservoir, an interconnected series of limestone caverns containing underground lakes which are recharged with surface water from surface drainage of the area, is the source of large volumes of well water and spring water used for all purposes throughout a large part of the study area.

6. The Coastal Plain comprises about two thirds of the study area. This area extends south and east from the Balcones Escarpment.

7. To assist in analysis, the study area has been divided into three subareas, the limits of which are shown on the map of the study area, figure 1.

8. CLIMATE.- Major climatic difference within the study area can best be described in terms of variation in the availability of moisture. The eastern portion is relatively humid and the western portion is typically dry, although neither is completely free of either extreme. The average annual rainfall ranges from 40 inches at the extreme eastern point to 30 inches at the western edge of subarea I, and to about 20 inches at the western extremity of the study area.

9. Rainfall in the study area generally comes from local thunderstorms and frontal storms. The interactions of the air masses generally cause sharp, extensive frontal showers when the air from the interior moves vigorously southward, forcing warm air aloft. Less intense rainfall of longer duration occurs when the gulf air moves inland and overrides a relatively cooler air mass. Rainfall also occurs along the Balcones Escarpment when the warm moist gulf air is forced to rise over it.

10. Mean annual temperatures range from 65 degrees Fahrenheit on the north, to 73 degrees on the south, and the average freeze-free period ranges from 220 days to 320 days. Snow is uncommon.

11. Occasional hurricanes in late summer and early fall bring high winds and tides and heavy rains. Since 1900, 12 hurricanes have penetrated the study area. Tornadoes can occur but are uncommon.

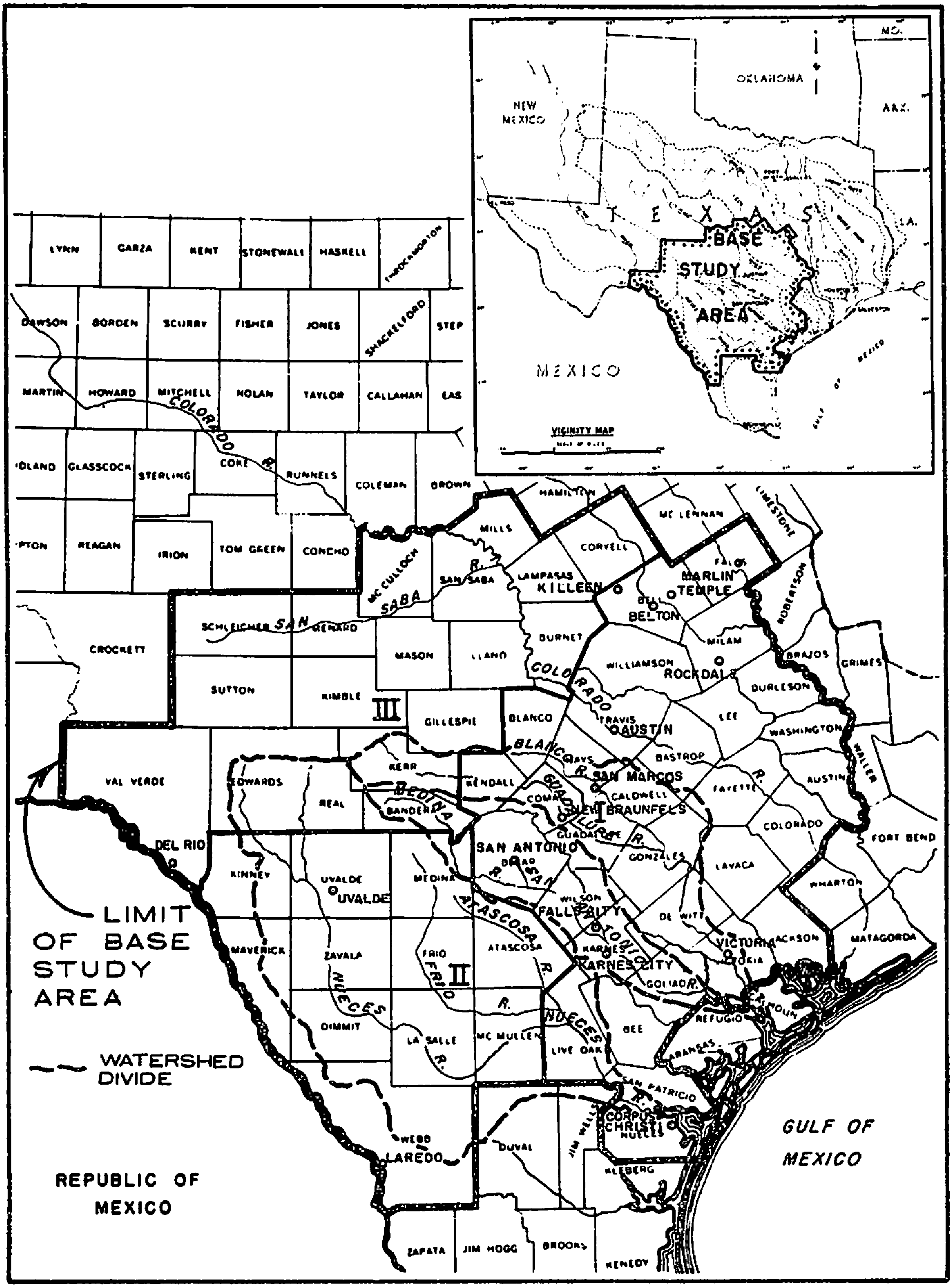

FIGURE I EDWARDS UNDERGROUND BASE STUDY AREA

12. EARLY DEVELOPMENT.- Early settlement of the study area was encouraged by the comparative mildness of the climate and an apparently constant supply of water for domestic and industrial use. Many Spanish missions were founded at or near flowing springs. The city of San Antonio, third largest in the state, was founded in 1718 on the spring-fed San Antonio River. 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 because of the constant spring-fed flow in the Guadalupe River.

13. POPULATION OF THE STUDY AREA.- The population of the study area in 1960 was 2,035,000, about 1.1 percent of the United States total. Since 1890, the total population of the area has increased at the rate of 1.73 percent per year as compared to the national average of 1.50 percent. Table 1 compares the population of the study area with that of the continental United States for the census years since 1890. Table 2 gives similar data for the three subareas.

14. Influenced by the transition from an economy based on commercialization of agriculture to one dominated by minerals exploitation and by technological advances in agricultural production, the population of the three subareas increased between 1890 and 1960 at widely differing rates. The population growth for the seventy year period is summarized below:

Year	Subarea I		Subarea II		Subarea III	
	Population (thousands)	Average annual percent of growth	Population (thousands)	Average annual percent of growth	Population (thousands)	Average annual percent of growth
1890	488.0		41.0		84.9	
		1.71		2.36		1.10
1940	1,138.8		131.8		147.7	
		2.12		0.89		-0.10
1960	1,733.1		157.4		144.6	

Source: United States Department of Commerce, Bureau of the Census.

15. The population of subarea I, the largest and most populous of the subareas, since 1940 has increased much more rapidly than the other subareas. Its rate of growth is over one and one-third times the average rate of growth of the nation.

16. Subarea II, rich in underground water and soils adapted to growing of fruits and vegetables, grew at the highest rate from 1890 to 1940. Webb County, the host county of Laredo, a port of entry at the Mexican border, increased in size from 15,000 to 46,000,

accounting for 46 percent of the total increase. In the twenty-year period 1940 to 1960 this subarea continued to grow, although four counties lost nine thousand inhabitants. The increase in Webb County amounted to 74 percent of the net increase for the subarea.

17. In subarea III, where the terrain is mostly rough and broken and composed of shallow, rocky soils, the economy is based almost exclusively on livestock raising on small ranches and livestock farms. The population of this area has increased at the slowest rate of any of the subareas. Between 1940 and 1950 it declined from 147,700 to 139,600, a loss of 5.5 percent. Part of this loss was regained in the ten years from 1950 to 1960 to achieve a net loss of 2.1 percent over the twenty years.

18. URBANIZATION OF THE STUDY AREA.- Since 1930, the increase in population has been almost exclusively urban in nature. The urban population of the area, which in 1930 was 39 percent of the total, increased from 509 thousand in 1930 to 1,494 thousand in 1960, 73 percent of the total.

19. The 15 principal cities of the study area, listed in table 3, contained 59 percent of the total population of the area in 1960, as compared to 32 percent in 1930. The four largest cities in 1960, Austin, Corpus Christi, Laredo, and San Antonio, contained one million inhabitants, 49 percent of the total for the area.

20. RURAL EXODUS.- The urban industrial expansion and decreasing agricultural employment opportunities have resulted in migration of rural inhabitants to the expanding urban centers. In the period 1930-1960, the urban population of the individual counties increased in every instance. At the same time, the rural population of all counties and the total population of 33 of the 60 counties decreased. Table 4 shows the urban, rural, and total population of the study area and the three subareas, and the rural population as a percent of the total for the census years 1930 to 1960. It is significant that subarea I, which comprises about 43 percent of the land area, contains 85 percent of the total population.

21. TEXAS AND THE STUDY AREA.- Comparison is made of the growth of population for Texas and the study area in the urban and rural components and increasing and decreasing counties. During the period from 1940 to 1960, the total population of Texas increased at the average rate of 2.02 percent per year. During this same period, the urban population increased from 45 percent to 75 percent of the total. The average rate of increase is 4.37 percent per year after discounting the effect of the change in definition in 1950. Rural population changed at the average rate of minus 1.38 percent per year. In 1960, 63 percent of the total population of Texas resided

TABLE 1

POPULATION GROWTH OF THE EDWARDS UNDERGROUND RESERVOIR STUDY AREA AND UNITED STATES

Year	Population (thousands) U. S.*	Population (thousands) Study area	Average annual percent of growth per period U. S.*	Average annual percent of growth per period Study area	Study area as percent of U. S.
1890	62,948	614			0.98
			1.90	2.94	
1900	75,995	820			1.08
			1.92	1.55	
1910	91,972	955			1.04
			1.40	1.24	
1920	105,711	1,080			1.02
			1.51	1.96	
1930	122,775	1,311			1.07
			0.70	0.79	
1940	131,669	1,418			1.08
			1.36	1.82	
1950	150,697	1,699			1.13
			1.71	1.82	
1960	178,464	2,035			1.14

Source: United States Department of Commerce, Bureau of the Census.
*Exclusive of Alaska and Hawaii.

TABLE 2

POPULATION GROWTH OF THE THREE SUBAREAS

Year	Subarea I Population (thousands)	Subarea I Average annual percent of growth	Subarea II Population (thousands)	Subarea II Average annual percent of growth	Subarea III Population (thousands)	Subarea III Average annual percent of growth
1890	488.0		41.0		84.9	
		3.13		1.91		2.28
1900	664.4		49.6		106.4	
		1.26		3.85		2.04
1910	752.7		72.4		130.2	
		1.43		1.89		-0.36
1920	867.3		87.3		125.7	
		1.93		3.15		1.22
1930	1,050.5		119.0		141.9	
		1.03		1.03		0.40
1940	1,138.8		131.8		147.7	
		2.17		1.17		-0.56
1950	1,411.7		148.0		139.6	
		2.07		0.62		0.35
1960	1,733.0		157.4		144.6	

Source: United States Department of Commerce, Bureau of the Census.

TABLE 3

POPULATION OF MAJOR CITIES IN THE STUDY AREA

City	1930	1940	1950	1960
Subarea I				
Austin	53,120	87,930	132,459	186,545
Beeville	4,806	6,789	9,348	13,811
Corpus Christi	27,741	57,301	108,287	167,690
Killeen	1,260	1,263	7,045	23,377
New Braunfels	6,242	6,976	12,210	15,631
Robstown	4,183	6,780	7,287	10,266
San Antonio	231,542	253,854	408,442	587,718
San Marcos	5,134	6,006	9,980	12,713
Seguin	5,225	7,006	9,733	14,299
Temple	15,345	15,344	25,467	30,419
Victoria	7,421	11,566	16,126	33,047
Total Subarea I	362,019	460,815	746,384	1,095,516
Subarea II				
Eagle Pass	5,059	6,459	7,276	12,094
Laredo	32,618	39,274	51,910	60,678
Uvalde	5,286	6,679	8,674	10,293
Total Subarea II	42,963	52,412	67,860	83,065
Subarea III				
Del Rio	11,693	13,343	14,211	18,612
Total Subarea III	11,693	13,343	14,211	18,612
Total 15 cities	416,675	526,570	828,455	1,197,193

Source: United States Department of Commerce, Bureau of the Census.

TABLE 4

POPULATION OF THE STUDY AREA
TOTAL-URBAN-RURAL BY SUBAREAS 1930-1960

	1930	1940	1950	1960
Study Area				
Total population	1,311,370	1,418,325	1,699,327	2,035,022
Urban	509,288	654,799	1,081,581	1,493,816
Rural	802,082	763,526	617,746	541,206
Rural as percent of total	61	54	36	26
Subarea I				
Total population	1,050,468	1,138,841	1,411,656	1,733,077
Urban	428,473	544,231	938,298	1,321,019
Rural	621,995	594,610	473,358	412,058
Rural as percent of total	59	52	34	24
Subarea II				
Total population	118,994	131,770	148,048	157,385
Urban	55,283	68,391	91,186	113,060
Rural	63,711	63,379	56,862	44,325
Rural as percent of total	54	48	38	28
Subarea III				
Total population	141,908	147,714	139,623	144,560
Urban	25,532	42,177	52,097	59,737
Rural	116,376	105,537	87,526	84,823
Rural as percent of total	82	71	63	59

Source: United States Department of Commerce, Bureau of the Census.

in the 29 Texas counties which are included within the state's 21 standard metropolitan statistical areas. The total population of the study area increased at the average rate of 1.82 percent per year between the census of 1940 and 1960. Meanwhile, urban population of the area increased from 46 percent to 73 percent of the total at the average rate of 3.76 percent per year, and rural population changed at the average rate of minus 1.05 percent per year. In 1960, 58 percent of the population of the study area resided in the four counties which compose the standard metropolitan statistical areas of Austin, Corpus Christi, Laredo, and San Antonio.

22. The growth pattern of individual counties is more diverse. Of the 254 counties in Texas, 138 counties experienced a loss in total population from 1940 to 1960 and decreased from 35.1 percent to 17.0 percent of the total, at the average rate of minus 1.62 percent per year. The 118 counties which gained in population during the 20 years increased from 64.9 percent to 83.0 percent of the total at the average rate of 3.28 percent per year. Of the 60 counties within the study area, 33 experienced a loss of inhabitants from 1940 to 1960 and decreased from 34.3 percent to 7.7 percent of the total at the average rate of minus 1.58 percent per year. The 27 counties which gained in population during the 20 years increased from 65.7 percent to 82.2 percent of the total at the average rate of 2.97 percent per year.

23. ESTIMATES OF FUTURE POPULATION.- Estimates of the future population of the United States have been constructed by many organizations. However, for the purpose of this study, it was considered necessary to adopt a single projection for purposes of comparison. The adopted projection is the medium of three which were made for the Economic Task Group of the Ad Hoc Water Resources Council Staff.1/ This projection was made to 1980, 2000, and 2020. The amounts used in this study for 1975 and 2025 were derived by interpolation and extrapolation and are as follows:

	Population as of July 1st in thousands	Average annual percent of change
1960	180,676	
		1.72
1975	233,310	
		1.73
2000	358,300	
		1.70
2025	546,156	

24. It has been estimated that the population of the state of Texas will be about 6 percent of the total population of the United States at the year 2025. The population for the state which is used in this study is 32.1 million. This estimate is about 6 percent greater than the value used in prior studies, i.e., the economic base study on Trinity River and Tributaries, Texas.2/ The higher estimate results from the change in the national guidelines.

25. Population projections have been made for each of the 254 counties of Texas as an aid in maintaining a rational relationship between regional studies within the state and the total for the state. The projections have been derived from a number of sources, e.g., Report of the United States Study Commission for Texas;3/ Water for the Future;4/ Water Requirements Survey - A West Texas Area;5/ Water Requirements Survey - Texas High Plains;6/ Water Requirements Survey - Red River Basin, Texas;7/ Projections for the Dallas, Fort Worth, and Houston Trading Areas;8/ Texas Board of Water Engineers Water Requirements Survey for Texas, Bulletin 5910;9/ and studies of individual areas by the United States Army Engineer District, Fort Worth, Corps of Engineers. Except for the studies by the Fort Worth District, the terminal year was never further in the future than 2010 and extension and modification were required to achieve an estimate for 2025.

26. About 90 percent of the Edwards Underground base study area was included within the study area of the United States Study Commission for Texas.3/ The Commission's demographic projections to the year 2010 have been maintained to the greatest extent possible. As in the past, most of the future economic activities will be in subarea I, and population will increase to the year 2025 in this area at an average rate of about 2 percent per year as compared to 2.1 percent in the 20 years 1940 to 1960. Favored by more equal distribution of annual rainfall to partially satisfy water requirements, soil types capable of increased crop production, and access to deep water transportation, all industries in the eastern portion of the study area are expected to show greater increase than those in the western portion. Population in subareas II and III is expected to increase at more moderate rates, resulting in an average rate for the study area of about 1.9 percent per year.

27. The trend toward urbanization will continue and by 2025, 93 percent of the inhabitants will dwell in urban centers. The amount and distribution of population by subareas for 1960 and as projected for 1975, 2000, and 2025 are given in table 5. The average annual percent of increase for the 65 year period is also given.

TABLE 5

DISTRIBUTION OF POPULATION 1960-2025

Area	1960		1975		2000		2025	
	Number in thousands	Percent urban	Number in thousands	Percent urban	Number in thousands	Percent urban	Number in thousands	Percent urban
Subarea I	1,733.0	76	2,681.9	86	4,446.8	92	6,338.1	94
Subarea II	157.4	72	202.7	78	263.2	84	330.7	90
Subarea III	144.6	41	182.3	57	206.9	67	241.8	72
Total	2,035.0	74	3,066.9	84	4,916.9	90	6,910.6	93

AVERAGE ANNUAL PERCENT OF INCREASE 1960 TO 2025

	Total population	Urban population
Subarea I	2.02	2.35
Subarea II	1.14	1.50
Subarea III	0.79	1.65
Total	1.90	2.28

28. Table 6 is an exhibit of the population of Texas, the study area, and the subareas for the years 1940, 1960, and 2025, showing the population for the counties in each area which experienced increases in population from 1940 to 1960, the population of the counties which experienced decreases in population from 1940 to 1960, and the totals. Also, the population of the gaining and losing counties is shown as a percent of the total population for each area. Table 7 shows the average annual rate of change for the population categories and areas which are listed in table 6.

29. The principal reason for loss of population by the various counties has been the decrease in employment opportunities due to changes in agriculture. Even small urban places have continued to gain residents though total population of the host county has decreased. Industrial diversification in most losing counties has resulted in a greater rate of increase in employment in most nonagricultural industries than at the national level. In many instances, the downward trend has been stayed. Estimates of population as of 1 April 1963 by the Population Research Center, Department of Sociology, the University of Texas, and published in the March 1964 issue of Texas Business Review 10/ indicate that 15 of the study area counties which lost population between 1940 and 1960 have gained in population since 1960. The average annual rate of increase since 1960 for the study area is as follows:

	Average annual percent change in population, 1960 to 1963
Total study area	1.98
Subarea I	1.88
Subarea II	1.25
Subarea III	3.97

Although some of the counties which decreased in population between 1940 and 1960 are projected to increase in the future, in all instances the population of the counties in this category is a smaller ratio of the total population of the including area at the terminal year than at 1960.

30. EMPLOYMENT IN THE STUDY AREA.- Changes in industry, which are the dominant factors in the economic growth of an area, may be measured in terms of changes in employment. Usually, population varies directly with total employment as changes in employment opportunities result in outmigration or inmigration of persons. Furthermore, the income of persons engaged in production is the principal component of the personal income of an area. So it may be said that these important measures of growth, population and income, are in great part determined by employment.

31. EMPLOYMENT SHIFT.- The shift technique as explained in the publication, Regions, Resources, and Economic Growth, 11/ is used in the analysis. This technique involves comparison of the changes in the area's growth with the changes which would have occurred in the study area at the rates of change for the nation as a whole. As an example, from 1940 to 1960 the population of the study area increased 616,697, or 43.5 percent. The population of the United States increased 35.7 percent during this same period. If the study area had grown at the same average rate of the United States, it would have shown an increase of 506,058, which is 110,639 less than the actual increase. This excess of the actual over the expected is termed the net upward shift; if the expected increase at the national rate had been greater than the actual, there would have been a net downward shift. The shift technique may be applied to any variable such as population, employment, or income.

32. The actual growth of employment in an area is the result of three separate factors. The first element of change is the result of the basic overall national rate of growth and is the value found by applying the national rate of increase to the local value at the base year (1940). For the study area, the expected growth from 1940 to 1960 at the national rate is 192.0 thousand, which is less than the actual growth by 29.4 thousand. This is the net upward shift in total employment.

33. The second element is related to the industry mix of the area and is based on the fact that when an industry is growing nationally because of increased demand for its products, areas in which the nationally growing industry is located will grow because of this advantage. Conversely, areas containing slow growth or declining industries will suffer as a consequence. This element is termed the industry mix or net composition shift in total employment.

34. The third element in the employment change is determined by the growth rate of the area in its particular industries and is termed the competitive effect or net local factor shift in total employment. This is the algebraic sum of the net shifts by industry and is the result of change in employment due to competition with other areas. It indicates whether the experience of the area is more or less favorable (in employment terms) than the experience of the economy as a whole. Between 1940 and 1960, the Edwards Underground study area had a favorable competitive experience which increased its employment by 133.9 thousand. The shift computation for the study area is given in table 8 and for the subareas in table 9.

TABLE 6

TEXAS AND THE STUDY AREA
COUNTIES WITH INCREASING AND DECREASING POPULATION

Area	1940		1960		2025	
	Number in thousands	Percent of total	Number in thousands	Percent of total	Number in thousands	Percent of total
Texas						
Total population	6,414.8	100.0	9,579.7	100.0	32,148.0	100.0
138 decreasing counties (1)	2,249.9	35.1	1,630.8	17.0	2,259.0	7.0
116 increasing counties (2)	4,164.9	64.9	7,948.9	83.0	29,889.0	93.0
Edwards Underground Base Study Area						
Total Study Area						
Total population	1,418.3	100.0	2,035.0	100.0	6,911.0	100.0
33 decreasing counties (1)	486.6	34.3	362.8	17.8	535.0	7.7
27 increasing counties (2)	931.7	65.7	1,672.2	82.2	6,376.0	92.3
Subarea I						
Total population	1,138.8	100.0	1,733.0	100.0	6,338.0	100.0
16 decreasing counties (1)	370.2	32.5	270.6	15.6	395.0	6.2
16 increasing counties (2)	768.6	67.5	1,462.4	84.4	5,943.0	93.8
Subarea II						
Total population	131.8	100.0	157.4	100.0	331.0	100.0
3 decreasing counties (1)	25.2	19.1	22.4	14.2	38.0	11.5
7 increasing counties (2)	106.6	80.9	135.0	85.8	293.0	88.5
Subarea III						
Total population	147.7	100.0	144.6	100.0	242.0	100.0
14 decreasing counties (1)	91.2	61.8	69.8	48.3	102.0	42.1
4 increasing counties (2)	56.5	38.2	74.8	51.7	140.0	57.9

Source: United States Department of Commerce, Bureau of the Census.
(1) Counties which lost population between 1940 and 1960.
(2) Counties which gained population between 1940 and 1960.

TABLE 7

AVERAGE ANNUAL PERCENT OF CHANGE IN POPULATION

Area	Average annual percent of change 1940 to 1960	1960 to 2025
Texas		
Total population	+2.02	+1.88
138 decreasing counties (1)	-1.62	+0.50
116 increasing counties (2)	+3.28	+2.06
Edwards Underground Base Study Area		
Total Study Area		
Total population	+1.82	+1.90
33 decreasing counties (1)	-1.48	+0.60
27 increasing counties (2)	+2.97	+2.08
Subarea I		
Total population	+2.12	+2.02
16 decreasing counties (1)	-1.58	+0.58
16 increasing counties (2)	+3.27	+2.18
Subarea II		
Total population	+0.89	+1.14
3 decreasing counties (1)	-0.58	+0.80
7 increasing counties (2)	+1.19	+1.20
Subarea III		
Total population	-0.10	+0.79
14 decreasing counties (1)	-1.36	+0.59
4 increasing counties (2)	+1.42	+0.96

See table 6, which shows absolute values upon which these average annual percent changes are based.
(1) Counties which lost population between 1940 and 1960.
(2) Counties which gained population between 1940 and 1960.

TABLE 8

EMPLOYMENT SHIFT
EDWARDS UNDERGROUND STUDY AREA, 1940 TO 1960

Major employment sector	Edwards Underground study area employment 1940	1960	Actual change	Expected change	Net shift
	(all values in thousands)				
Local factor net shift					
Agriculture, forestry, and fisheries	170.5	79.8	- 90.7	-80.6	- 10.1
Mining	8.3	12.0	+ 3.7	- 2.2	+ 5.9
Construction	25.8	52.7	+ 26.9	+23.5	+ 3.4
Manufacturing	26.5	63.9	+ 37.4	+18.6	+ 18.8
Wholesale & retail trade	78.7	142.3	+ 63.6	+47.8	+ 15.8
Finance, insurance, and real estate	10.3	25.1	+ 14.8	+ 9.2	+ 5.6
Transportation	13.7	22.0	+ 8.3	+ 4.0	+ 4.3
Communication and other public utilities	8.8	17.8	+ 9.0	+ 7.8	+ 1.2
Business and personal services	78.6	125.9	+ 47.3	+48.8	- 1.5
Government	72.2	173.3	+101.1	+10.7	+ 90.4
Totals	493.4	714.8	+221.4	+87.6	+133.9
Net composition (industry mix) shift					
Actual increase in total employment 1940 to 1960					221.4
Expected increase at average rate for U. S.					192.0
Net shift in total employment					29.4
Net local factor shift in total employment					133.9*
Net composition (industry mix) shift in total employment					-104.5

*Difference between -104,500 and -104,599 in table 9 due to rounding.

TABLE 9

EMPLOYMENT SHIFT FOR THE SUBAREAS 1940 TO 1960

	Net shift			
	Subarea I	Subarea II	Subarea III	Total
Local factor net shift				
Agriculture, forestry, and fisheries	-9,928	976	-1,152	-10,104
Mining	4,798	842	285	5,925
Construction	5,150	-348	-1,408	3,394
Manufacture	17,185	535	1,133	18,853
Trade	16,412	738	-1,354	15,796
Finance, insurance, and real estate	5,528	74	17	5,619
Transportation	4,804	-176	-304	4,324
Communications and other public utilities	851	376	-19	1,208
Business and personal services	+1,999	-2,080	-1,395	-1,476
Government	82,915	+152	+7,340	+90,407
Total local factor net shift	+129,714	+1,089	+3,143	133,946
Net composition shift				
Actual increase 1940 to 1960	211,885	3,974	5,532	221,391
Expected increase at U. S. rate	156,878	16,262	18,904	192,044
Net shift in total employment	55,007	-12,288	-13,372	29,347
Net local factor shift	129,714	1,089	3,143	133,946
Net composition shift	-74,707	-13,377	-16,515	-104,599

35. The effect of these elements is shown graphically in figure 2. The strong local factor shift in subarea I is sufficient to overcome the downward or negative net composition shift in all areas, resulting in a net upward shift for the study area. Fifty percent of the net local factor shift is in government.

36. It may be generalized that the rapid growth of the study area is associated with the relatively high rate of increase in employment in manufacturing, wholesale and retail trade, and government. Table 10 shows the labor force, unemployment, and number of persons engaged in the major industries in 1940 and 1960 by subareas and the percent of the total employed for each year. The table is based on data by counties contained in the publications of the Bureau of the Census for the respective years. In 1940, government includes persons engaged in public emergency work in addition to persons in the military and in public administration and government education. In 1960, the number of persons in government education was as follows: subarea I, 28,233; subarea II, 1,940; subarea III, 2,029; total study area, 32,202. The employed for whom industry is not reported have been distributed proportionally along all industries. Table 11 shows the average annual percent change in labor force and employment between 1940 and 1960.

37. It is paradoxical that subarea III, which experienced a decline of 2.14 percent in population between 1940 and 1960, experienced the greatest rate of increase in employment in mining, manufacturing, and government. This is the result of the losses from the decline of employment opportunities in agriculture and the gains from the diversifications of industry and due to two new military installations, Laughlin Air Force Base in Val Verde County and Fort Hood, a part of which is in Coryell County. The decline in agricultural employment of 12,266 was accompanied by a gain in non-agricultural employment of 17,798, for a net gain of 5,532. Ninety percent of the gain occurred in three counties: Kerr County, a health and recreational center, and Val Verde and Coryell Counties, where the increase is chiefly in military and its support. All counties except two minor stock raising counties showed increases in nonagricultural employment. However, in large part, except for the counties cited above, the principal increases were in industries oriented toward farming, either manufacture and supply of the equipment and material used in agricultural production, or process and distribution of the agricultural product.

38. EMPLOYMENT CHANGE IN THE STUDY AREA.- For the study area as a whole, employment in agriculture decreased 91 thousand, and employment in nonagricultural industries increased 312 thousand. Eighty percent of the increase in nonagricultural employment occurred in manufacture, wholesale and retail trade, business and personal services, and government (including the military). Unemployment declined in all portions of the study area but remains exceptionally high in subarea II, 8.8 percent of the labor force.

39. FUTURE EMPLOYMENT IN THE STUDY AREA.- Estimates of the future labor force for the study area include about 4 percent for unemployment with a labor force participation rate of 39.6 persons per hundred inhabitants. Estimates of future employment for the subareas and the study area by major industry are given in table 12. Also shown is the employment in 1960 and 2025 as a percent of the total employed and the average annual percent of change from 1960 to 2025.

40. AGRICULTURE.- Agriculture in the study area is highly important, contributing substantially to the income in the area. In 1960, about 7.5 percent of the income for the study area originated in this industry. Crop and livestock production provides income for the owners and operators of about 58,000 farm and ranch units. The marketing, processing, and distribution of agricultural products and the manufacture, distribution and sale of supplies needed by agriculture constitute an important segment of the urban economy. Of the total land, 87 percent of subarea I, 82 percent of subarea II, and 98 percent of subarea III are in farms and ranches.

41. Technological advances in agriculture have allowed constantly increasing production with decreased use of manpower. Between 1940 and 1960, the number of persons engaged in this industry in the study area declined 53 percent, from 169,700 to 79,225. In the same period, it is estimated that agricultural production increased 43 percent and that production per employee increased 206 percent.

42. Accompanying the decrease in manpower has been an increase in the size of farms. In the five-year period between the agricultural censuses of 1954 and 1959, the number and average size of farms in the study area and the three subareas changed as follows:

	1954		1959	
	Number of farms	Average size in acres	Number of farms	Average size in acres
Subarea I	55,500	264	44,900	329
Subarea II	4,300	2,047	3,500	2,337
Subarea III	13,800	965	9,800	1,376
Total	73,600	500	58,200	625

Source: United States Department of Commerce, Bureau of the Census.

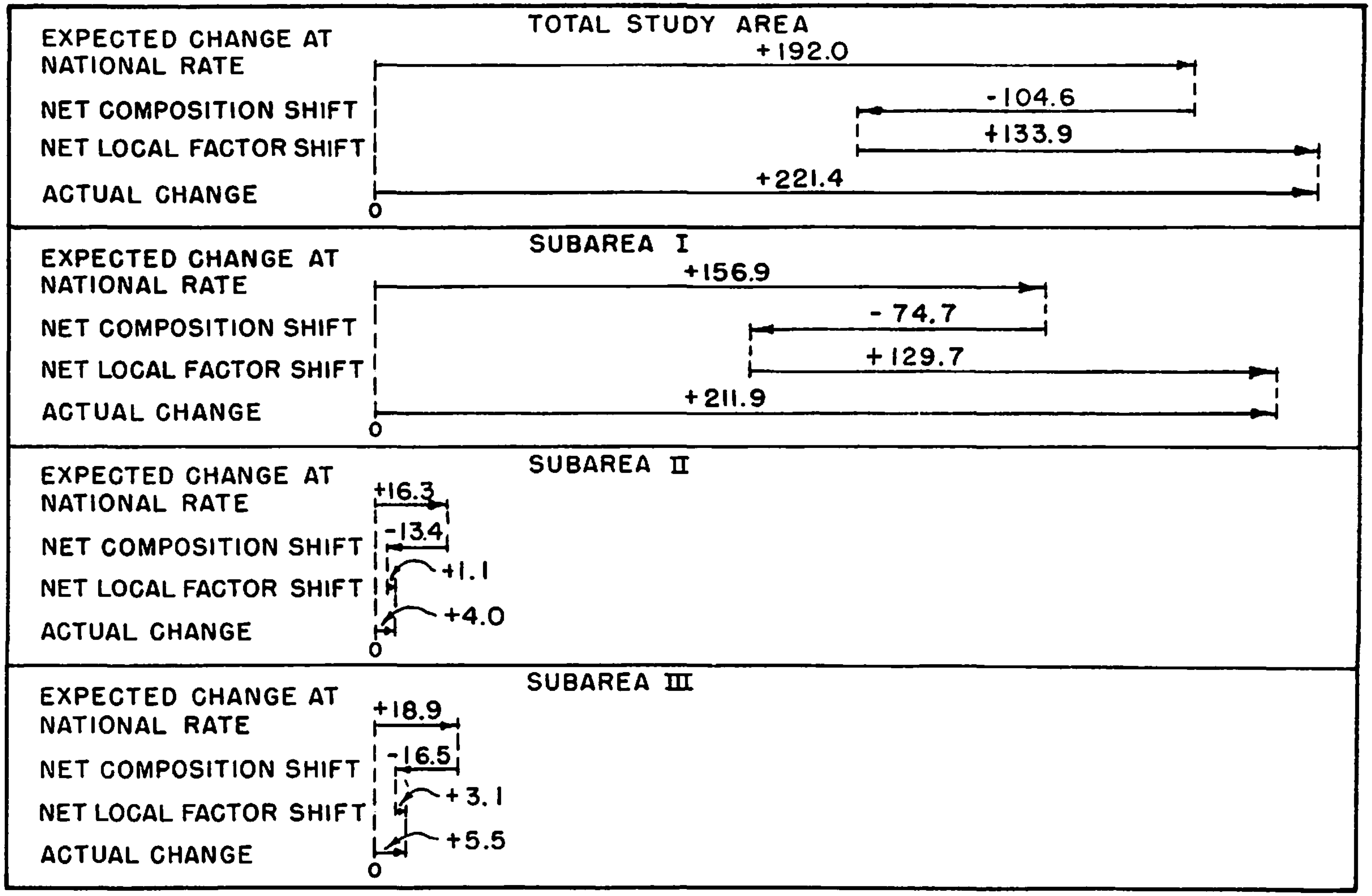

FIGURE 2. EMPLOYMENT SHIFT IN EDWARDS UNDERGROUND RESERVOIR BASE STUDY AREA 1940 TO 1960. VALUES FROM TABLE 9 (ROUNDED) IN THOUSANDS. SCALE: 1"=40,000.

TABLE 10

LABOR FORCE AND EMPLOYMENT 1940 AND 1960
EDWARDS UNDERGROUND RESERVOIR STUDY AREA

	Subarea 1				Subarea 2				Subarea 3				Total Base Study Area			
	1940		1960		1940		1960		1940		1960		1940		1960	
	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total	Number	Percent of total
Total employment	403,079	100.00	614,964	100.00	41,784	100.00	45,758	100.00	48,571	100.00	54,103	100.00	493,434	100.00	714,825	100.00
Agriculture, forestry and fisheries	128,743	31.94	57,945	9.42	18,238	43.65	10,592	23.15	23,508	48.40	11,242	20.78	170,489	34.55	79,779	11.16
Nonagricultural	274,336	68.06	557,019	90.58	23,546	56.35	35,166	76.85	25,063	51.60	42,861	79.22	322,945	65.45	635,046	88.84
Mining	7,438	1.84	10,268	1.67	688	1.65	1,348	2.95	199	0.41	431	0.80	8,325	1.69	12,047	1.69
Construction	21,165	5.25	45,490	7.39	1,830	4.38	3,140	6.86	2,818	5.80	4,053	7.49	25,813	5.23	52,683	7.37
Manufacture	24,119	5.98	58,216	9.47	1,175	2.81	2,534	5.54	1,165	2.40	3,114	5.76	26,459	5.36	63,864	8.93
Other private nonagricultural	160,947	39.93	290,427	47.22	13,931	33.33	21,188	46.30	15,284	31.46	21,492	39.72	190,162	38.54	333,107	46.60
Wholesale and retail trade	66,221	16.43	122,796	19.97	5,851	14.00	10,138	22.16	6,656	13.70	9,339	17.26	78,728	15.96	142,273	19.90
Finance, insurance and real estate	9,304	2.31	23,073	3.75	490	1.17	998	2.18	525	1.08	1,007	1.86	10,319	2.09	25,078	3.51
Transportation	10,813	2.68	18,778	3.05	1,534	3.67	1,806	3.95	1,318	2.71	1,399	2.58	13,665	2.77	21,983	3.07
Communications and other public utilities	7,677	1.90	15,324	2.49	515	1.23	1,347	2.94	632	1.30	1,172	2.17	8,824	1.79	17,843	2.50
Business and personal services	66,932	16.61	110,456	17.96	5,541	13.26	6,899	15.07	6.153	12.67	8.575	15.85	78,626	15.93	125,930	17.62
Government	60,667	15.06	152,618	24.83	5,922	14.18	6,956	15.20	5,597	11.53	13,771	25.45	72,186	14.63	173,345	24.25
Unemployment	38,239		26,942		4,080		4,389		3,298		1.477		45,617		32,808	
Total labor force	441,318		641,906		45,864		50,147		51,869		55,580		539,051		747,633	
Labor force participation rate	38.75		37.04		34.81		31.86		35.11		58.45		38.01		36.74	

Source: U. S. Bureau of the Census data adjusted as stipulated in the text.

TABLE 11

AVERAGE ANNUAL PERCENT OF CHANGE
IN LABOR FORCE AND EMPLOYMENT 1940 TO 1960
EDWARDS UNDERGROUND RESERVOIR STUDY AREA

	Average annual percent of change			
	Subarea I	Subarea II	Subarea III	Total Base Study Area
Total employment	2.13	0.46	0.54	1.87
Agricultural, forestry and fisheries	-4.01	2.68	-3.62	-3.73
Nonagricultural	3.60	2.03	2.72	3.44
Mining	1.62	3.42	3.94	1.86
Construction	3.91	2.74	1.83	3.63
Manufacture	4.50	3.92	5.04	4.50
Other private nonagricultural	3.00	2.12	1.72	2.84
Wholesale and retail trade	3.13	2.79	1.71	3.00
Finance, insurance and real estate	4.65	3.62	3.31	4.54
Transportation	2.80	0.82	0.30	2.41
Communications and other private utilities	3.52	4.93	3.13	3.58
Business and personal services	2.54	1.10	1.67	2.38
Government	4.72	0.81	4.60	4.48
Unemployment	-1.80	0.37	-3.94	-1.63
Total labor force	1.89	0.45	0.35	1.65

Source: Table 8.

TABLE 12

PROJECTION OF LABOR FORCE AND EMPLOYMENT IN THE
EDWARDS UNDERGROUND RESERVOIR STUDY AREA

Values in thousands

Year	Subarea	Employment: Total	Employment: Agriculture, forestry and fisheries	Employment: Total non-agricultural	Employment: Mining	Employment: Construction	Employment: Manufacture	Employment: Other private nonagricultural	Employment: Government	Unemployment	Total labor force
1960	I	615.0	57.9	557.0	10.3	45.5	58.2	290.4	152.6	26.9	641.9
	II	45.8	10.6	35.2	1.3	3.1	2.5	21.2	7.0	4.4	50.1
	III	54.1	11.2	42.9	0.4	4.1	3.1	21.5	13.8	1.5	55.6
	Total	714.8	79.8	635.0	12.0	52.7	63.9	333.1	173.3	32.8	747.6
1975	I	1,020.8	42.9	977.9	10.8	77.9	111.5	533.1	244.6	42.4	1,063.2
	II	77.1	5.0	72.1	1.4	6.2	5.7	46.2	12.6	3.3	80.4
	III	69.4	6.5	62.9	0.4	5.9	4.8	33.1	18.7	2.9	72.3
	Total	1,167.3	54.4	1,112.9	12.6	90.0	122.0	612.4	275.9	48.6	1,215.9
2000	I	1,692.5	38.6	1,653.9	12.3	126.6	191.9	918.1	405.0	70.6	1,763.1
	II	100.2	4.2	96.0	1.6	8.0	7.7	62.1	16.6	4.0	104.2
	III	78.7	4.5	74.2	0.5	6.8	5.7	39.4	21.8	3.3	82.0
	Total	1,871.4	47.3	1,824.1	14.4	141.4	205.3	1,019.6	443.4	77.9	1,949.3
2025	I	2,412.3	31.6	2,380.7	13.8	181.3	285.1	1,320.0	580.5	100.5	2,512.8
	II	125.9	3.8	122.1	1.8	10.1	10.0	79.1	21.1	5.2	131.1
	III	92.0	4.0	88.0	0.6	8.0	6.9	46.7	25.8	3.9	95.9
	Total	2,630.2	39.4	2,590.8	16.2	199.4	302.0	1,445.8	627.4	109.6	2,739.8
						Employment as a percent of the total					
1960	I	100.00	9.42	90.58	1.67	7.39	9.47	47.22	24.81		
	II	100.00	23.15	76.85	2.95	6.86	5.54	46.29	15.28		
	III	100.00	20.78	79.22	0.80	7.49	5.76	39.74	25.51		
	Total	100.00	11.16	88.84	1.69	7.37	8.93	46.32	24.24		
2025	I	100.00	1.31	98.69	0.57	7.52	11.82	54.72	24.06		
	II	100.00	3.02	96.98	1.43	8.02	7.94	62.83	16.76		
	III	100.00	4.35	95.65	0.65	8.70	7.50	50.76	28.04		
	Total	100.00	1.50	98.50	0.62	7.58	11.48	54.97	23.85		
						Average annual percent of change - 1960 to 2025					
	I	2.13	- 0.93	2.26	0.45	2.15	2.48	2.36	2.08	2.05	2.12
	II	1.57	- 1.57	1.93	0.50	1.83	2.16	2.03	1.78	0.29	1.49
	III	0.82	- 1.57	1.11	0.62	1.03	1.24	1.20	0.98	1.48	0.84
	Total	2.02	- 1.09	2.19	0.46	2.07	2.42	2.28	2.00	1.87	2.02

Note: Minor discrepancies are due to rounding.

43. VALUE OF FARM PRODUCTS SOLD.- As a measure of activity in this segment of the economy, the value of farm products sold has the essential qualities of being a measure of total production without consequential duplication and of availability at the local level in the form of statistics by counties. However, the difficulties encountered in the use and interpretation of any statistical series for small areas are compounded in estimating the effect of extremes in weather on agricultural production.

44. The prolonged Texas drought from 1951 to 1957 adversely affected agricultural production in dry farming, stimulated production in the localities where irrigation water is available, i.e., the High Plains of West Texas, depleted range and pastures, and resulted in a decrease in the dry farming acreage. The drought was broken in 1957, a year of abnormally heavy rainfall, which also adversely affected production.

45. For the study area, the effects of the drought are apparent in the results of the agricultural censuses. Between 1949 and 1954, agricultural production decreased in the semi-arid western half of the study area by about 10 percent and showed only a slight increase in the eastern portion where the drought was not quite so severe. As a result of the various factors which have influenced the study area, the rate of increase since 1939 should not be considered a normal trend.

46. Table 13 shows the value of farm products sold for the census years beginning with 1939. The values have been converted by use of the index of prices received by Texas farmers and are shown in 1960 prices. Since 1939, the quantity of production as measured by these values has increased 59 percent for subarea I, 52 percent for subarea II, and 4 percent for subarea III. In 1959, 63 percent of the value for the study area was obtained from the sale of livestock and livestock products and 37 percent from crops. Comparable percentages for the subareas for 1959 are as follows:

Subarea	Livestock and livestock products	Crops
I	52.81	47.19
II	71.08	28.92
III	89.85	10.15
Total	62.76	37.24

47. FARM PRODUCTS BY TYPE.- The principal crops raised for sale in the area are cotton, feed crops and vegetables. About 70 percent of the vegetables come from the Winter Garden Area in subarea II. Table 14 shows the distribution of value of farm products sold in 1959 for the subareas.

TABLE 14

DISTRIBUTION OF THE VALUE OF FARM PRODUCTS SOLD BY SUBAREA, 1959

	Total of Study area	Subarea I	Subarea II	Subarea III
Total	100.00	100.00	100.00	100.00
Livestock and livestock products	62.76	52.81	71.08	89.85
Meat animals	44.99	35.99	62.01	62.11
Dairy products	5.26	6.70	4.03	1.36
Poultry and eggs	6.89	8.76	1.25	4.93
Other	5.62	1.36	3.79	21.45
All crops	37.24	47.19	28.92	10.15
Food grains	2.93	4.16	*	1.04
Feed crops	7.22	9.04	5.18	2.64
Cotton	18.04	24.94	5.81	4.25
Oil crops	1.26	0.93	4.33	*
Fruits and nuts	0.36	0.27	0.20	0.84
Vegetables	2.52	1.15	11.51	0.16
Other	4.91	6.70	1.89	1.22

*Less than .01 percent.
Source: Based on data extracted from the Census of Agriculture, 1959, United States Department of Commerce, Bureau of the Census.

TABLE 13

EDWARDS UNDERGROUND STUDY AREA
VALUE OF FARM PRODUCTS SOLD
1939 TO 1959

	Subarea I		Subarea II		Subarea III		Total study area	
Year	Value	Average annual percent change	Value	Average annual percent change	Value	Average annual percent change	Value	Average annual percent change
	Values in thousands of 1960 constant dollars							
1939	161,338		38,563		71,943		271,844	
		2.29		0.89		-1.05		1.25
1944	180,703		40,301		68,241		289,245	
		4.14		3.64		-1.41		2.89
1949	221,311		48,644		63,553		333,508	
		0.05		-2.28		-2.00		-0.61
1954	222,380		43,342		57,789		323,511	
		2.92		6.02		5.20		3.80
1959	256,831		58,491		74,471		389,793	

Source: United States Department of Commerce, Bureau of the Census.

48. IRRIGATED LAND.- Data on irrigated cropland in the 1959 Census of Agriculture show that for the study area, the irrigated cropland harvested was 6.5 percent of the total cropland harvested, while the value of the produce sold from the irrigated land was 16.6 percent of the total. Comparable amounts for the three subareas are as follows:

	Irrigated cropland harvested as percent of total harvested	Value of crops sold from irrigated land as percent of total
Subarea I	4.3	12.0
Subarea II	33.9	54.0
Subarea III	3.2	5.4
Total study area	6.5	16.6

49. Data on irrigated land in 1958 prepared for the United States Study Commission for Texas 3/ by the United States Department of Agriculture, Soil Conservation Service and published in the Study Commission report were compared with data from the census of 1959.

	Census irrigated land-1959	USSC-T irrigated land-1958
Subarea I	152,046 acres	179,000 acres
Subarea II	143,382 acres	185,400 acres
Subarea III	18,494 acres	21,500 acres
Total	313,922 acres	385,900 acres

The USSC-T values are about 25 percent greater than the values from the census and irrigation is probably of greater importance than is indicated by the census values.

50. THE FUTURE OF AGRICULTURE.- It has been estimated by the Department of Agriculture that requirements for agricultural products to the year 1980 can be met using less land than is now in production. In Land and Water Resources 12/ it is estimated for the United States as a whole that between 1959 and 1980 cropland will decrease about 51 million acres, or 12 percent, while total crop production will increase about 46 percent, and that land in pasture and range will increase about 22 million acres, or about 2 percent. Crop production per acre will increase about 56 percent and pasture production per acre will increase about 35 percent. As in the past, a part of the increased production per acre will be achieved by shifts between uses. It is stated in Land and Water Resources 12/ that cropland has been concentrated on fertile and more nearly level areas. Hilly and eroded land has been put in grass and trees.

This shift of field crops to the better soil conditions has increased average yields. This trend will continue and areas containing the greatest proportion of land capable of supporting continued high production will profit the most from improved technology, i.e., hybridization, machinization, fertilization, improved stock strains, soil improvement, etc., as well as terracing, drainage, and flood control. Therefore, future production in the base study area has been estimated with consideration of the current production and the capacity of the individual area for additional production.

51. Subarea I has the greatest capacity for increase of the three subareas. It is estimated that the 179,000 acres of irrigated land presently irrigated will increase to 366,000 acres by the year 2025. Of the total land in the inventory acreage, 63 percent may be permanently used for production of field crops. It is estimated that agricultural production in this subarea will increase about 390 percent, as compared to about 200 percent for the nation.

52. Subarea II is semiarid and production of field crops is practically limited to irrigated crops or to feed crops adaptable to the area. Irrigation by ground water will continue at a slightly lower rate as aquifers are depleted. It is estimated from data in the Study Commission report 3/ that surface-water irrigation will increase in such volume as to maintain the total irrigation at about its present level. The increase in agricultural production will be about 204 percent for subarea II.

53. Subarea III, also semiarid of climate, is almost exclusively devoted to ranching. Production of meat animals will increase at a greater rate than most other agricultural commodities. Irrigation in this area, while relatively unimportant, will increase from about 21.5 thousand acres to about 50,000 acres. The increase in agricultural production for subarea III will be about 283 percent.

54. Table 15 shows the estimate of the value of farm products sold for the projection years, and the average annual rate of increase - 1960 to 2025.

TABLE 15

EDWARDS UNDERGROUND STUDY AREA
PROJECTION OF VALUE OF FARM PRODUCTS SOLD
1960 TO 2025

Area	1960	1975	2000	2025
	Values in millions of 1960 constant dollars			
Subarea I	269.9	440.3	867.7	1,321.4
Subarea II	62.5	76.2	131.7	190.1
Subarea III	77.5	98.0	201.2	296.7
Total study area	409.9	614.5	1,200.6	1,808.2

Average annual percent of increase 1960 to 2025:

Subarea I	2.47
Subarea II	1.73
Subarea III	2.08
Study area	2.31

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 of Texas a tremendous boost in the chemical field. The state's income originating in manufacturing is about 16 percent of the total, as compared to about 9 percent which was derived from manufacturing in 1940.

57. For the study area, manufacturing is not of such relative importance. In 1960, about 8.5 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. Within the study area, 96 percent of the manufacturing is found in subarea I and 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 nondurable 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. 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. 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 for the study area is contributed by these refineries. 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 alumina 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 processes imported bauxite and reduces alumina at its plant in San Patricio County.

62. MANUFACTURING EMPLOYMENT.- Manufacturing employment, which in 1960 accounted for 9 percent of the total employment in the study area, was principally engaged in production of nondurable goods. Employment in industries processing agricultural products was about 37 percent of the total. Table 16 shows the 1960 employment in manufacturing for the subareas by major category and each category as a percent of the total for the area. No breakdown of <u>other nondurable products</u> is available, but it is estimated that about 50 percent of this category were employed in petroleum refining.

TABLE 16

MANUFACTURING EMPLOYMENT IN THE
EDWARDS UNDERGROUND RESERVOIR STUDY AREA
1960

Industry	SUBAREA I: Number of employees	SUBAREA I: Percent of total	SUBAREA II: Number of employees	SUBAREA II: Percent of total	SUBAREA III: Number of employees	SUBAREA III: Percent of total	TOTAL STUDY AREA: Number of employees	TOTAL STUDY AREA: Percent of total
Furniture, lumber and wood products	3,895	6.69	83	3.27	473	15.19	4,451	6.97
Primary metal industries	4,548	7.81	78	3.08	8	0.26	4,634	7.26
Fabricated metal industries	2,851	4.90	34	1.34	26	0.83	2,911	4.56
Machinery except electrical	2,665	4.58	115	4.54	300	9.63	3,080	4.82
Electrical machinery	835	1.43	4	0.16	54	1.73	893	1.40
Motor vehicles and motor vehicle equipment	356	0.61	15	0.59	17	0.55	388	0.61
Transportation equipment except motor vehicle equipment	1,141	1.96	20	0.79	327	10.50	1,488	2.33
Other durable goods	5,332	9.16	88	3.47	228	7.32	5,648	8.83
Total durable goods	21,623	37.14	437	17.25	1,433	46.02	23,493	36.78
Food and kindred products	14,220	24.43	926	36.54	668	21.46	15,814	24.77
Textile mill products	2,923	5.02	8	0.32	134	4.30	3,065	4.80
Apparel and other fabricated textiles	3,622	6.22	643	25.37	360	11.56	4,625	7.24
Printing, publishing and allied products	7,020	12.06	260	10.26	370	11.88	7,650	11.98
Chemical and allied products	3,940	6.77	37	1.46	35	1.12	4,012	6.28
Other nondurable products	4,868	8.36	223	8.80	114	3.66	5,205	8.15
Total nondurable products	36,593	62.86	2,097	82.75	1,681	53.98	40,371	63.22
Total manufacturing	58,216	100.00	2,534	100.00	3,114	100.00	63,864	100.00

Source: United States Department of Commerce, Bureau of the Census.

63. THE OUTLOOK FOR MANUFACTURING IN THE STUDY AREA.- Manufacturing will continue to be a major source of income in the study area. Food and fiber products, construction materials, chemicals and allied products, primary metals, and the products of petroleum refining will continue to constitute the major part of manufacture. Increases in agricultural production will support increased output of the first two categories. The favorable position of the area with relation to availability of crude petroleum and natural gas, i.e., large local production supplemented by imports by deep water transportation, encourages further advances in the chemical and refining industries. Importation of ores in support of the primary metals industry will increase.

64. For the study area, the rate of increase in manufacturing, which was at its greatest during the war years, was more moderate from 1954 to 1958. The average annual rate of increase from 1939 to 1954 was 8 percent per year and from 1954 to 1958 was 6.1 percent per year. Employment in manufacture increased between 1940 and 1960 at the average rate of 4.5 percent per year. The average annual percent of increase in manufacturing employment from 1960 to 2025 is estimated at about 2.4 percent per year. The projection of the value added by manufacture, as well as the historical data for the census years since 1939, is contained in table 17.

TABLE 17

VALUE ADDED BY MANUFACTURE
HISTORICAL AND PROJECTED

Year	Subarea I	Subarea II	Subarea III	Total study area
	(Values in millions of 1960 constant dollars)			
1939	105.7	3.0	1.7	110.4
1947	208.1	6.2	3.5	217.8
1954	378.7	7.3	6.7	392.7
1958	475.7	11.8	9.5	497.0
1960	539.5	13.4	10.7	563.6
1975	1,532.8	33.4	26.1	1,592.3
2000	4,684.9	80.8	54.2	4,819.9
2025	12,169.8	187.0	113.6	12,470.4
	Average annual percent change			
1939 to 1958	8.24	7.48	9.48	8.24
1958 to 2025	4.96	4.21	3.77	4.93

Source: United States Department of Commerce, Bureau of the Census.

65. MINING.- The mineral industry supplies about 2 percent of the employment and an estimated 3 percent of the income in the study area. In addition, the industry supplies part of the materials for the expanding manufacturing industry, as well as large quantities of construction materials.

66. 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 sand and gravel, stone, uranium, high calcium limestone, shell, clays, and lignite production in the study area makes 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 stockpiled 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 alumina 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; and 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. Shell dredged from shallow bays along the Gulf coast was used in cement and lime manufacture, concrete aggregate and chemicals. High calcium limestone for cement is important. Three of the 17 cement plants of the state are located in the study area; two in San Antonio; one in Corpus Christi. Bexar County led the state in the value of stone (shell excluded) produced in 1960.

67. Several minerals are imported in significant quantity for processing in Texas, such as bauxite at the Aluminum Company of America plants at Point Comfort and Rockdale, and Reynolds Metals Company near Corpus Christi where alumina is extracted and reduced. Copper and zinc are imported at Corpus Christi and processed at the American Smelting and Refining Company smelter.

68. THE VALUE OF MINERALS PRODUCED IN THE STUDY AREA.- In recent years, the value of mineral production for the study area has averaged about 9.5 percent of the value of all minerals produced in Texas. A large proportion of the study area's production is exported for final consumption. All of the native asphalt produced in Texas, about 20 percent of the cement, and all the uranium ore is produced in the study area.

69. For the study area, production in this industry to a great degree is dictated by demands of the state and nation and is estimated to increase at the same rate as the production for the state. Table 18 contains historical data for the state of Texas and the study area and the estimated values for 1975, 2000, and 2025.

TABLE 18

VALUE OF MINERAL PRODUCTION
HISTORICAL AND PROJECTED

Year or Period	Texas	Study area			
		Total	Subarea I	Subarea II	Subarea III
	(Values in millions of 1960 constant dollars)				
1940	1,582	NA	NA	NA	NA
1952	2,972	281	252	23	6
1960	4,135	405	347	42	15
1975	6,307	617	530	64	23
2000	12,577	1,230	1,056	128	46
2025	24,759	2,423	2,082	251	90
	Average annual percent change				
1952 to 1960	4.21	4.65	4.08	7.82	12.13
1960 to 2025	2.79	2.79	2.79	2.79	2.79

Source: United States Department of the Interior, Bureau of Mines (Historical data only).
NA - Not available.

70. BUILDING PERMITS IN THE STUDY AREA.- Since 1951, the value of building permits issued by municipalities in the study area has ranged from 14 to 19 percent of the total of building permits for the state of Texas. Table 19 shows the value of building permits for the subareas from 1951 to 1962 and the average annual percent of increase for the same period. The data have been converted to 1960

values by means of the Engineering News Record Building Cost Index. In 1962, 93 percent of the building permits issued in the study area were issued in subarea I.

TABLE 19

BUILDING PERMITS IN THE STUDY AREA

Year	Subarea I	Subarea II	Subarea III	Total study area
	(Values in millions of 1960 constant dollars)			
1951	144.0	3.0	6.0	153.0
1956	186.0	3.9	5.5	195.4
1958	178.9	3.1	6.6	188.6
1960	153.9	5.3	9.0	168.2
1962	197.0	4.8	9.9	211.7
	Average annual percent of change			
1951 to 1962	2.89	4.37	4.66	3.00

Source: Construction in Texas, published monthly by the Bureau of Business Research, College of Business Administration, University of Texas.

71. NEW CONSTRUCTION.- Major components of new construction not included in the value of building permits are federal construction, both military and civil; state highway construction; and construction of residential, industrial, municipal, and other facilities in areas not requiring building permits. Since the value of construction of these categories is not available for the counties of the study area, an estimate was prepared of the value of all new construction for the years 1940, 1950, 1960, using the relationship of employment and income in comparison with the data for the state of Texas. It is estimated that the value of new construction for the study area in 1940 was about 135 million dollars, and in 1960, about 542 million dollars, an increase of 7.20 percent per year. The estimated 1960 value is about 1.8 times the reported building permits for the year.

72. PROJECTION OF NEW CONSTRUCTION.- Future demands for new construction in support of the increasing populations and expanding industry will increase this industry at the average annual rate of 4.25 percent. The total value of new construction put in place in the year 2025 is estimated to be $5.7 billion, nearly 15 times the estimated 1960 value.

73. OTHER PRIVATE NONAGRICULTURAL INDUSTRIES.- The industries in this category are the service industries: wholesale and retail trade; finance, insurance, and real estate; transportation; communications and other public utilities; and the various business and personal services such as business repair and household services; entertainment and recreation; medical; private education; welfare; religious; and other professional and related services. Between 1940 and 1960, employment in these industries increased about 78 percent for the study area, with the highest rate of growth in communications and other public utilities, and in finance, insurance, and real estate. Employment in these two most rapidly growing industries was relatively low in the study area prior to 1940. The demands for these services increased rapidly as population increased and became more highly concentrated in urban centers. The proportionate number of persons in these categories is now approaching the national level.

74. GOVERNMENT.- For the study area, the most important single segment of the economic structure is government. In 1960, employment in government, including public administration, military, and employment in public education, was 173,345, or 25 percent of the total employment. It is estimated that income in government amounted to about 25 percent of the total income for the area.

75. EMPLOYMENT IN GOVERNMENT.- Table 20 shows 1960 employment in government for the study area and the subareas by the principal categories, public administration, military, and public education, in absolute numbers and in percent of the total employment in each area.

76. In addition to the direct contribution of government to the economy, there is also the indirect contribution of dependent employment. A complete analysis of this factor is not possible from available data, but it is estimated that employment dependent upon public administration, government education, military, and civilian employees with the military, is about 200 thousand.

77. MILITARY INSTALLATIONS.- Large permanent military installations are maintained at various points within the study area. These include:

a. <u>San Antonio</u>.

(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 VIII U. S. Army Corps.

c. Killeen.

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.

Laredo Air Force Base.

e. Del Rio.

Laughlin Air Force Base.

f. Corpus Christi.

Corpus Christi Naval Air Station.

Numerous small military installations and reserve components are located throughout the study area.

78. DISPOSABLE INCOME.- Estimates of disposable income, i.e., the income remaining to persons after deduction of personal tax and nontax payments to general government, for the area and subareas are contained in table 21. This comprehensive measure of output is a most satisfactory alternate to the gross national product and at the national level, exhibits the same average annual growth rate that has characterized the trend of gross national product. It is an excellent measure of regional development, showing the income flow to individuals from all sources, minus of course, the tax allowance.

79. The estimate of income in 1940 was prepared from estimates of total personal income by counties in Survey of Buying Power. 13/ The estimates for 1950 and 1960 were prepared from data on income by

TABLE 20

EMPLOYMENT IN GOVERNMENT - 1960

Subarea	Category	Number employees	Percent of total employment
I	Public administration	54,363	8.84
	Military	70,022	11.39
	Public education	28,233	4.59
	Total	152,618	24.82
II	Public administration	2,982	6.52
	Military	2,034	4.44
	Public education	1,940	4.24
	Total	6,956	15.20
III	Public administration	2,786	5.15
	Military	8,956	16.55
	Public education	2,029	3.75
	Total	13,771	25.45
Study area			
	Public administration	60,131	8.42
	Military	81,012	11.33
	Public education	32,202	4.50
	Total	173,345	24.25

Source: United States Department of Commerce, Bureau of the Census.

counties in the United States census for the respective years. Estimates of tax and nontax payments were deducted to achieve the disposable income amounts. The estimates have been deflated by use of the implicit price deflator for total personal consumption expenditures to derive values in 1960 constant dollars.

80. Rates of increase in personal income for the nation on a whole, comparable to those contained in table 21 are as follows: 1940 to 1950, 4.07 percent per year; 1950 to 1960, 3.39 percent per year. Between 1940 and 1960, reflecting the industrial stimulus of the war effort, income in the study area and in subarea I increased at a greater rate than the average for the nation. In subareas II and III, principally agricultural in nature, the rate of increase was less than 90 percent, the rate of increase for the nation.

81. PER CAPITA DISPOSABLE INCOME.- Just as the total of real disposable income is the measurement of economic activity, so is per capita disposable income the measurement of material welfare. Per capita disposable income, expressed in 1960 constant dollars, increased more rapidly in each of three subareas than in the nation as a whole. Per capita income for the nation increased 52 percent from 1940 to 1960. Corresponding rates of increase for the area are: study area, 78 percent; subarea I, 76 percent; subarea II, 66 percent; and subarea III, 87 percent. Only in subarea III has the absolute value of the increase per person exceeded the absolute value of the increase per person for the nation. The absolute values of the increase per person are: United States, $663; study area, $643; subarea I, $655; subarea II, $406; subarea III, $682. Per capita income for 1940, 1950 and 1960 for the study area and the subareas is given in table 22.

82. The per capita income for the study area was 76 percent of the national average in 1960, as compared to 65 percent in 1940. This comparison by subareas is as follows:

	Per capita income as a percent of the national average	
Subarea	1940	1960
I	67	78
II	48	53
III	61	76
Study area	65	76

83. Table 23 makes comparison of the growth rates of population and disposable income. The factor for total income is the product of the factors for population and per capita income (minor discrepancies are due to rounding). Subarea III shows the greatest rate of increase

in per capita income and a decrease in total population. The decrease in population is traceable to out-migration of farm workers. The large increase in per capita income is due principally to the disproportionate increase in the greater than average earning industries, mining, manufacture, and government, Most of the change in the latter category occurred in Webb County where Laughlin Air Force Base was initiated in the early 1940's and in Coryell County, which contains a part of Fort Hood.

TABLE 23

COMPARISON OF GROWTH OF POPULATION AND INCOME
1940 TO 1960

	United States	Study area Total	Subarea I	Subarea II	Subarea III
	Factors of growth - 1960 values divided by 1940 values				
Population	1.36	1.43	1.52	1.19	0.98
Disposable income					
Per capita	1.52	1.78	1.76	1.66	1.87
Total	2.08	2.55	2.68	1.96	1.83

84. FUTURE INCOME IN THE AREA.- Continued increase in per capita and total income is intrinsic to the population and individual growth projected in the foregoing paragraphs. The favorable position of subarea I in comparison with the position of the other subareas will result in even greater disparity of future growth than past. Continued increase in the high income manufacturing industries, petrochemistry and primary metals, will be the major force causing the per capita income for this subarea to increase faster than the other subareas. The different industrial composition of each subarea results in varying degrees of increase. Table 24 makes comparison of population growth and income growth for the period 1960 to 2025. Subarea I continues to lead in growth of population and total income.

85. The absolute values of the per capita and total disposable income for 1960, 1975, 2000, and 2025 are shown in table 25. The average annual rates of increase from 1960 to 2025 are contained in table 26.

TABLE 21

DISPOSABLE INCOME FOR THE SUBAREAS

Year	Study area Value	Study area Average annual percent increase	Subarea I Value	Subarea I Average annual percent increase	Subarea II Value	Subarea II Average annual percent increase	Subarea III Value	Subarea III Average annual percent increase
	Values in millions of 1960 constant dollars							
1940	1,177		980		82		116	
		6.42		6.80		5.03		3.71
1950	2,193		1,892		134		167	
		3.18		3.33		1.85		2.41
1960	2,998		2,625		161		212	

Source: 1940 based on estimates of income by county in Survey of Buying Power;13/ 1950 and 1960 based on income data in the 1950 and 1960 censuses, United States Department of Commerce, Bureau of the Census.

TABLE 22

PER CAPITA DISPOSABLE INCOME FOR THE SUBAREAS

Year	Study area Value	Study area Average annual percent increase	Subarea I Value	Subarea I Average annual percent increase	Subarea II Value	Subarea II Average annual percent increase	Subarea III Value	Subarea III Average annual percent increase
	Values in 1960 constant dollars							
1940	830		860		619		783	
		4.52		4.54		3.84		4.34
1950	1,291		1,341		902		1,198	
		1.33		1.23		1.29		2.03
1960	1,473		1,515		1,025		1,465	

Source: Computed from table 21 (population in table 4).

TABLE 24

COMPARISON OF GROWTH OF POPULATION AND INCOME 1960 TO 2025

	United States	Study area Subarea I	Subarea II	Subarea III	Total
	Factors of growth, 2025 values ÷ 1960 values				
Population	3.023	3.657	2.101	1.672	3.396
Disposable income					
Per capita	3.458	3.841	3.483	3.501	3.861
Total	10.457	14.047	7.320	5.854	13.107

TABLE 25

EDWARDS UNDERGROUND RESERVOIR STUDY AREA
DISPOSABLE INCOME 1960, 1975, 2000 AND 2025

	1960	1975	2000	2025
Total disposable income in millions of 1960 constant dollars				
Subarea I	2,625.4	6,149.8	15,568.8	36,879.1
Subarea II	161.3	305.9	575.6	1,180.7
Subarea III	211.7	383.0	642.8	1,239.4
Total study area	2,998.4	6,838.7	16,787.2	39,299.2
Per capita disposable income in 1960 constant dollars				
Subarea I	1,515	2,293	3,501	5,819
Subarea II	1,025	1,509	2,187	3,570
Subarea III	1,464	2,101	3,107	5,126
Total study area	1,473	2,230	3,414	5,687

TABLE 26

EDWARDS UNDERGROUND RESERVOIR BASE STUDY AREA
RATES OF INCREASE IN INCOME 1960 TO 2025

	Disposable income Per capita	Total
Average annual percent of increase 1960 to 2025		
Subarea I	2.09	4.15
Subarea II	1.94	3.11
Subarea III	1.95	2.76
Total study area	2.10	4.04

86. THE GROWTH RATES OF THE SUBAREAS.- The comparison of rates of growth is made by means of the average annual percent of change during the period, thus allowing comparison of growth rates during time periods of different length. Table 27 is a summary of the growth rates of the indicators used in this study for the three subareas and the total of the study area. Examination of the table reveals that the future rates of increase in population for subareas II and III and value of farm products sold for subareas I and III are greater than the historical rates.

87. For each of the subareas, it is apparent that loss of population has been confined to rural areas where decline in employment opportunities in agriculture has been greatest. There is evidence that the Texas drought of 1951 to 1957 accelerated the decline of employment opportunities in agriculture. The counter forces of industrial dispersion and enlarged scope of service activities have resulted in increases in urban population, even in counties where the total population has declined. For subarea III, population loss occurred only in the period from 1940 to 1950. Sixty one percent of the loss was regained in the ensuing 10 years. Urban population increased in each decennium and accounted for all gains in the totals. In fact, table 4 shows that urban population has increased throughout the study area since 1930 and has accounted for the population increase in all areas, while rural population has declined. Further increase in urban population is projected, accompanied by a lessening rate of rural population loss, to achieve the net increase in total population.

88. Subarea I is favored by large areas of land capable of supporting continued agricultural production, potential large increase in irrigation, average rainfall sufficient to the requirements of most crops, and proximity to large urban areas. These factors were considered in projecting agricultural production to increase at about 1.4 times the rate for the United States as a whole.

89. Subarea III, although semiarid, has more than average capacity for additional agricultural production. Irrigation is expected to more than double. The demand for meat animals, the principal product of subarea III, is expected to increase more rapidly than the requirements for crops. Production in this subarea is projected at about 1.2 times the rate for the nation as a whole.

TABLE 27

EDWARDS UNDERGROUND RESERVOIR BASE STUDY AREA
SUMMARY OF GROWTH RATES
AVERAGE ANNUAL PERCENT OF CHANGE

Economic indicator	Study area 1940 to 1960 except as noted	Study area 1960 to 2025	Subarea I 1940 to 1960 except as noted	Subarea I 1960 to 2025	Subarea II 1940 to 1960 except as noted	Subarea II 1960 to 2025	Subarea III 1940 to 1960 except as noted	Subarea III 1960 to 2025
Population	1.82	1.90	2.12	2.02	0.89	1.14	-0.10	0.79
Urban population	4.21	2.28	4.53	2.35	2.55	1.50	1.76	1.65
Disposable income	4.79	4.04	5.05	4.15	3.43	3.11	3.06	2.76
Per capita disposable income	2.91	2.10	2.87	2.09	2.56	1.94	3.18	1.95
Value of farm products sold	1.82 (1)	2.31	2.35 (1)	2.47	2.11 (1)	1.73	0.18 (1)	2.08
Value added by manufacture	8.24 (2)	4.88	8.24 (2)	4.91	7.48 (2)	4.14	9.48 (2)	3.70
Value of mineral production	4.65 (3)	2.79	4.08 (3)	2.79	7.82 (3)	2.79	12.13 (3)	2.79
Value of new construction	7.20	4.25	(4)	(4)	(4)	(4)	(4)	(4)

(1) 1939 to 1959.
(2) 1939 to 1958.
(3) 1952 to 1960
(4) Value of new construction has not been estimated for the subareas.

NATIONAL, STATE AND STUDY AREA PROJECTIONS

90. POPULATION PROJECTIONS.- The population projection for the United States is the medium projection of three which were made for the Economic Task Group of the Ad Hoc Water Resources Council Staff. 1/ Population was projected to 1980, 2000, and 2020. The amounts used in this study for 1975 and 2025 were found by interpolation and extrapolation.

91. In the period 1890-1960, the population of Texas increased at the average annual rate of 2.1 percent. This is about one and one-half times the average annual rate of increase of the United States for the same period. Texas population is estimated to be about 6 percent of the United States population at the year 2025. After comparing various trends and resulting population figures, the estimated populations of 13.0 million for 1975 and 32.1 million for 2025 were adopted. For the period 1960 to 2025, average annual rate of increase is 1.88 percent.

92. The study area is expected to increase in population at a rate practically the same as the state of Texas. Most of this increase will occur in subarea I. All industries, including agriculture, are expected to show more rapid growth in this subarea than in the others.

93. Table 28 contains historical data pertaining to population which have been extracted from publications of the U. S. Department of Commerce, Bureau of the Census, and the computed average annual rates of change for each decennial period. United States includes Alaska and Hawaii, beginning with 1940. Table 29 shows the projection of population and comparisons of future growth rates. Population of the three subareas and their rates of growth from 1960 to 2025 are as follows:

	Total Study area	Subarea I	Subarea II	Subarea III
	(population in thousands)			
1960	2,035.0	1,733.0	157.4	144.6
2025	6,910.6	6,338.1	330.7	241.8
Average annual percent of change 1960-2025	1.90	2.02	1.14	.80

94. URBAN POPULATION.- The concentration of population in cities and towns is particularly significant to the water resource planner. Since 1940, the intercensal rate of increase of urban population of the United States has exceeded the rate of increase of the total population by an average of about 40 percent. This is true even after discounting the effect of the change in the

urban-rural definition in 1950. A continued high rate of urbanization is recognized in all available projections for United States urban population. The projection of the urban population of the United States in this study assumes the urban population will increase from about 70 percent of the total in 1960 to about 92 percent of the total in 2025. At the adopted rates of increase, the census amount of 125,268,750 in 1960 will increase to 181,210,000 in 1975 and to 500,156,000 in 2025. Using the 1960 population as the base of 1.00, the resultant factors are 1.45 for 1975 and 3.99 for 2025. The average annual rate of increase, 1960 to 2025, is 2.15 percent.

95. The urbanization of the state of Texas has been progressing at an even faster rate than the United States. During the period 1940 to 1960, the urban population of the state increased from 45 percent to 75 percent of the total at the average annual rate of 4.37 percent. By the year 2025, about 95 persons in 100 will dwell in urban centers.

96. The rapid movement to cities is also apparent in the base study area. In 1960, 73 percent of the people were urbanites. Table 30 gives the urban population of the United States, Texas, and the base study area for the years 1930, 1940, 1950, and 1960, with the intercensal rates of change. Table 31 presents projection data.

97. RURAL POPULATION.- The rapid increase in urban population has been accompanied by a decrease in rural population. The change in definition of urban in the 1950 census has complicated the process of computing trends in this area. Table 32 is a comparison of the rates of change in rural inhabitants in the United States, Texas, and the base study area. It is apparent from table 32 that a large portion of the increase in urban population in Texas has resulted from migration of rural inhabitants to cities and towns within the study area itself.

98. POPULATION BY PLACE OF RESIDENCE.- Set forth in table 33 is the 1960 population of the United States, Texas, and the base study area by place of residence, urban, rural nonfarm and rural farm.

99. No attempt has been made to divide future rural population into its component parts. Place of residence is becoming more and more a matter of choice than necessity. High speed highways from farm gate to urban centers lend impetus to the concentration of persons into centers of population where the services of modern living are readily available. In 1960 in the Edwards Underground Reservoir base study area, 43 percent of the persons engaged in agricultural pursuits resided in urban or rural nonfarm areas. The future rural population is shown in table 34.

TABLE 28

POPULATION 1890-1960

Year	United States Population	United States Average annual percent change	Texas Population	Texas Average annual percent change	Study area Population	Study area Average annual percent change
1890	62,947,714		2,235,527		613,905	
		1.90		3.15		2.94
1900	75,994,575		3,048,710		820,314	
		1.92		2.49		1.55
1910	91,972,266		3,896,542		955,275	
		1.40		1.81		1.24
1920	105,710,620		4,663,228		1,080,231	
		1.51		2.25		1.96
1930	122,775,046		5,824,715		1,311,370	
		0.74		0.97		0.79
1940	132,164,569		6,414,824		1,418,325	
		1.36		1.86		1.82
1950	151,325,798		7,711,194		1,699,327	
		1.71		2.19		1.82
1960	179,323,175		9,579,677		2,035,022	

Source: United States Department of Commerce, Bureau of the Census, Decennial census.

TABLE 29

PROJECTION OF POPULATION

Year	United States (1)	Texas (2)	Study area
	Amounts in thousands		
1960	180,676	9,579.7	2,035.0
1975	233,310	12,957.2	3,066.9
2000	358,300	20,630.2	4,916.9
2025	546,156	32,147.9	6,910.6
	Factors of growth		
1975 ÷ 1960	1.29	1.35	1.51
2000 ÷ 1960	1.98	2.15	2.42
2025 ÷ 1960	3.02	3.36	3.40
	Average annual percent change		
1960 to 2025	1.72	1.88	1.90

(1) July 1st, based on projections for the Economic Task Group of the Ad Hoc Water Resources Council Staff. 1/

(2) April 1st.

TABLE 30

URBAN POPULATION 1930-1960

	United States (1)		Texas		Study area	
Year	Population	Average annual percent change	Population	Average annual percent change	Population	Average annual percent change
1930	68,954,823		2,389,348		509,288	
		0.80		2.00		2.54
1940	74,705,338		2,911,389		654,799	
		2.63		5.21 (2)		5.15(2)
1950	96,846,817		4,838,060		1,081,581	
		2.62		4.04		3.28
1960	125,268,750		7,187,470		1,493,816	

Source: United States Department of Commerce, Bureau of the Census.

(1) Beginning in 1940, U. S. data includes Alaska and Hawaii.

(2) The rates of increase for the decade from 1940 to 1950 when the population figures for the old definition are compared are: United States, 1.70%; Texas, 4.71%; study area, 4.24%.

TABLE 31

PROJECTION OF URBAN POPULATION

Year	United States	Texas	Study area
	Amount in thousands		
1960	125,269	7,187	1,494
1975	181,210	10,743	2,567
2000	309,400	18,710	4,442
2025	500,156	30,528	6,461
	Factors of growth		
1975 ÷ 1960	1.45	1.49	1.71
2000 ÷ 1960	2.47	2.60	2.97
2025 ÷ 1960	3.99	4.25	4.32
	Average annual percent change		
1960 to 2025	2.15	2.25	2.28

TABLE 32

RURAL POPULATION - 1940, 1950, AND 1960

Year	Population	Change during period	Proportion of urban increase	Average annual percent change
		United States		
1940	57,459,231			
		3,738,373		
1950 (old definition)	61,197,604		-	+0.32
1950 (new definition)	54,478,981			
		-424,556	.0149	-0.08
1960	54,054,425			
		Texas		
1940	3,503,435			
		-404,907	.2380	-1.24
1950 (old definition)	3,098,528			
1950 (new definition)	2,873,134			
		-480,927	.2047	-1.52
1960	2,392,207			
		Study area		
1940	763,526			
		-55,942	.1660	-0.76
1950 (old definition)	707,584			
1950 (new definition)	617,746			
		-76,540	.1857	-1.33
1960	541,206			

Source: United States Department of Commerce, Bureau of the Census.

TABLE 33

POPULATION BY PLACE OF RESIDENCE - 1960

	Total	Urban	Rural nonfarm	Rural farm
U. S.	179,323,175	125,268,750	40,609,527	13,444,898
Percent	100.00	69.85	22.65	7.50
Texas	9,579,677	7,187,470	1,697,725	694,482
Percent	100.00	75.03	17.72	7.25
Study area	2,035,022	1,493,816	361,098	180,108
Percent	100.00	73.41	17.74	8.85

Source: United States Department of Commerce, Bureau of the Census.

TABLE 34

FUTURE RURAL POPULATION

Year	United States	Texas	Study area
	Amounts in thousands		
1960	54,054	2,392	541
1975	52,100	2,214	500
2000	48,900	1,920	475
2025	46,000	1,620	450
	Factors of growth		
1975 ÷ 1960	0.96	0.92	0.92
2000 ÷ 1960	0.90	0.80	0.88
2025 ÷ 1960	0.85	0.68	0.83
	Average annual percent change		
1960 to 2025	-0.25	-0.61	-0.28

100. DISPOSABLE INCOME 1960 AND PRIOR YEARS.- Table 35 presents the estimates of real disposable income for selected years. The estimates of disposable income have been deflated by the implicit price deflator for total personal consumption expenditures and are shown in 1960 constant dollars.

TABLE 35

DISPOSABLE INCOME FOR SELECTED YEARS

Year	United States Values	United States Average annual percent change	Texas Values	Texas Average annual percent change	Study area Values	Study area Average annual percent change
	Values in millions of 1960 constant dollars					
1929	148,523		4,828		NA	
		1.14		2.00		
1940	168,324		6,006		1,177	
		4.07		6.79		6.42
1950	250,793		11,587		2,193	
		3.39		3.64		3.18
1960	349,889		16,563		2,998	

Source: United States: United States Department of Commerce, Office of Business Economics; Texas: 1929, 1940, and 1950, ibid; 1960, estimated from data on total personal income by United States Department of Commerce, Office of Business Economics; Study area: 1940, estimated from data on total personal income in Survey of Buying Power; 13/ 1950 and 1960 estimated from data on total income in U. S. census, United States Department of Commerce, Bureau of the Census.

NA - not available.

NOTE: In 1960, United States includes Alaska and Hawaii.

101. Real per capita disposable income, the amount of personal income remaining to the individual after taxes, expressed in 1960 constant dollars in the period 1940 to 1960 increased at a greater rate for Texas and the study area than for the nation as a whole. Not only has the rate of increase been greater, but the absolute quantity of the increase, $793 for Texas, has exceeded the increase of $663 for the nation. The increase for the study area is $643, 97 percent of the increase for the nation.

TABLE 36

PER CAPITA DISPOSABLE INCOME

Year	United States Values	United States Average annual percent change	Texas Values	Texas Average annual percent change	Study area Values	Study area Average annual percent change
			Values in 1960 constant dollars			
1940	1,274		936		830	
		2.66		4.85		4.52
1950	1,657		1,503		1,291	
		1.58		1.40		1.33
1960	1,937		1,729		1,473	
			Percent of the national average			
1940	100		73		65	
1950	100		91		78	
1960	100		89		76	

Source: Values in table 35 divided by number of inhabitants in table 28.

102. PROJECTION OF DISPOSABLE INCOME.- For the United States, the projection of disposable income uses the rate of increase of the medium projection of gross national product from the Economic Task Group.1/ This is done because it is the principal component of gross national product and exhibits the same average annual growth rate that characterizes the trend of the gross national product.

103. For Texas and the study area, the projection of personal income was derived from estimates of income and employment by industry. The per capita income for Texas and the study area continues to gain on the per capita income for the nation. Texas per capita value, which in 1960 was 89/100 of the United States per capita value, is 99/100 by 2025. Corresponding proportions for the study area are 76/100 in 1960 and 85/100 in 2025. The projection data for total disposable income and per capita disposable income are shown in tables 37 and 38, respectively.

TABLE 37

PROJECTION OF DISPOSABLE INCOME

	1960	1975	2000	2025
Values in millions of 1960 constant dollars				
United States	349,889	616,008	1,509,982	3,658,821
Texas	16,563	32,338	84,471	212,900
Study area	2,998	6,839	16,778	39,299
Average annual percent of increase 1960 to 2025				
United States	3.68			
Texas	4.01			
Study area	4.04			

TABLE 38

PROJECTION OF PER CAPITA DISPOSABLE INCOME

	1960	1975	2000	2025
Values in 1960 constant dollars				
United States	1,937	2,640	4,214	6,699
Texas	1,729	2,496	4,095	6,622
Study area	1,473	2,230	3,414	5,687
Average annual percent of increase 1960 to 2025				
United States	1.93			
Texas	2.09			
Study area	2.10			

TABLE 37

PROJECTION OF DISPOSABLE INCOME

	1960	1975	2000	2025
	Values in millions of 1960 constant dollars			
United States	349,889	616,008	1,509,982	3,658,821
Texas	16,563	32,338	84,471	212,900
Study area	2,998	6,839	16,778	39,299
	Average annual percent of increase 1960 to 2025			
United States	3.68			
Texas	4.01			
Study area	4.04			

TABLE 38

PROJECTION OF PER CAPITA DISPOSABLE INCOME

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	Values in 1960 constant dollars			
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Texas	1,729	2,496	4,095	6,622
Study area	1,473	2,230	3,414	5,687
	Average annual percent of increase 1960 to 2025			
United States	1.93			
Texas	2.09			
Study area	2.10			

104. VALUE OF FARM PRODUCTS SOLD.- As a measure of activity in this segment of the economy, the value of farm products sold has the essential qualities of being a measure of total production without consequential duplication and of availability at the local level in the form of statistics by counties. Table 39 presents the value of farm products sold for the United States, Texas, and the base study area.

TABLE 39

VALUE OF FARM PRODUCTS SOLD

	United States		Texas		Study area	
Year	Value	Average annual percent change	Value	Average annual percent change	Value	Average annual percent change
	Values in thousands of 1960 constant dollars					
1939	16,703,950		1,219,620		271,844	
		3.20		1.80		1.25
1944	19,554,970		1,333,680		289,245	
		1.43		4.20		2.89
1949	21,000,950		1,638,360		333,508	
		2.64		-0.74		-0.61
1954	23,926,920		1,578,910		323,511	
		4.67		4.53		3.80
1959	30,071,080		1,970,920		389,793	

Source: United States Department of Commerce, Bureau of the Census.

105. The principal crops raised for sale in the study area are cotton, feed crops, and vegetables. Sale of livestock and livestock products accounts for 63 percent of the total sales of farm products.

106. Table 40 shows the distribution of the value of sales for the United States, Texas, and the study area, by subareas. Other livestock products includes horses, mules, mohair, wool, and the statistical discrepancy which exists due to inability to identify the amount sold of minor commodities. Other crops includes the statistical discrepancy due to inability to identify the value of certain crops sold.

107. PROJECTION OF THE VALUE OF FARM PRODUCTS SOLD.- Recent trends and detailed analyses for agriculture indicate that the domestic market for farm products rises at about the same rate as population.1/ Extension of this relationship seems the most logical

assumption for long range projections. Total farm output, which in this study is considered synonymous with value of farm products sold, is projected to increase in direct proportion to demand. This implies that future imports and exports will also increase in the same proportion.

108. A portion of the projected national increase in output was allocated to the state of Texas and to the study area with due consideration of the current production and the potential for increased production. The study area, especially the eastern one half, has large capacity for increase due to soil types and potential increase in irrigation. Farm production for the study area is projected to increase faster than for the State or the Nation. The projection of the value of farm products sold is given in table 41.

109. VALUE ADDED BY MANUFACTURE.- The historical data on manufacture have been extracted from the reports of the U. S. Census of Manufacture by the United States Department of Commerce, Bureau of the Census. Table 42 presents the data for the census years beginning with 1929. Values have been deflated by the Bureau of Labor Statistics index of all commodities other than farm products and food to achieve values in 1960 constant dollars.

110. PROJECTION OF THE VALUE ADDED BY MANUFACTURE.- The projection of value added by manufacture for the Nation was constructed by use of data in Resources in America's Future,14/ which is a very detailed analysis of the future economy of the United States to the year 2000. The value added by manufacture to the year 2000 was estimated by applying the medium projection of the Federal Reserve Board index of manufacturing production, as shown in Resources in America's Future,14/ to the value added in 1960 and extrapolating to the year 2025.

111. Texas' and the study area's share in manufacturing is expected to increase. The advantage of climate, resources, and location are supplemented by aggressive leadership. In 1963, over 300 new industries located in Texas, a volume of increase exceeded only by New York. The contribution to the total of value added for the nation between 1929 and 1958 increased from 1.5 percent to 3.5 percent for Texas and from 0.15 percent to 0.34 percent for the study area. By the year 2025, Texas' and the study area's shares of the national total will increase to about 5.0 percent for Texas and 0.5 percent for the study area. The projections of the value added by manufacture are shown in table 43.

112. MINERAL PRODUCTION.- Historical data on mineral production were extracted from reports by the United States Department of the Interior, Bureau of Mines. Table 44 presents the total value of production for selected years since 1940. Mineral fuels supplied 93

TABLE 40

DISTRIBUTION OF THE VALUE OF FARM PRODUCTS SOLD IN 1959
COMMODITY CLASSES AS A PERCENT OF THE TOTAL

	United States	Texas	Total of Study Area	Subarea I	Subarea II	Subarea III
Total	100.00	100.00	100.00	100.00	100.00	100.00
Livestock and Livestock Products	55.60	44.54	62.76	52.81	71.08	89.85
Meat Animals	31.12	31.28	44.99	35.99	62.01	62.11
Dairy Products	13.94	5.71	5.26	6.70	4.03	1.36
Poultry and Eggs	9.65	5.60	6.89	8.76	1.25	4.93
Other	0.89	1.95	5.62	1.36	3.79	21.45
All Crops	44.40	55.46	37.24	47.19	28.92	10.15
Food Grains	7.23	7.59	2.93	4.16	*	1.04
Feed Crops	8.88	10.65	7.22	9.04	5.18	2.64
Cotton	6.87	31.74	18.04	24.94	5.81	4.25
Oil Crops	4.01	0.93	1.26	0.93	4.33	*
Tobacco	3.39	0.00	0.00	0.00	0.00	0.00
Fruits and Nuts	4.63	0.97	0.36	0.27	0.20	0.84
Vegetables	5.45	2.12	2.52	1.15	11.51	0.16
Other	3.94	1.46	4.91	6.70	1.89	1.22

Source: Estimates prepared from the 1959 Census of Agriculture, United States Department of Commerce, Bureau of the Census.

* Less than .01 percent

TABLE 41

PROJECTION OF VALUE OF FARM PRODUCTS SOLD

Year	United States	Texas	Study area
	Values in millions of 1960 constant dollars		
1960	31,046	2,057	409.9
1975	40,096	3,164	614.5
2000	61,415	5,311	1,200.6
2025	94,064	8,148	1,808.2
	Factors of growth		
1975 ÷ 1960	1.29	1.54	1.50
2000 ÷ 1960	1.98	2.58	2.93
2025 ÷ 1960	3.03	3.96	4.41
	Average annual percent change		
1960 to 2025	1.72	2.14	2.31

TABLE 42

VALUE ADDED BY MANUFACTURE

	United States		Texas		Study area	
Year	Value	Average annual percent change	Value	Average annual percent change	Value	Average annual percent change
	Values in millions of 1960 constant dollars					
1929	59,982		902.5		87.9	
		-1.02		0.95		2.31
1939	54,175		992.3		110.4	
		7.98		11.25		8.86
1947	100,121		2,328.2		217.8	
		3.92		7.75		8.79
1954	131,068		3,926.0		392.7	
		2.51		6.92		6.06
1958	144,698		5,129.3		497.0	

Source: United States Department of Commerce, Bureau of the Census.

TABLE 43

PROJECTION OF VALUE ADDED BY MANUFACTURE

Year	United States	Texas	Study area
	Values in millions of 1960 constant dollars		
1960	163,571	5,817	563.6
1975	305,874	13,445	1,592.3
2000	870,862	41,357	4,819.9
2025	2,461,033	122,380	12,470.4
	Factors of growth		
1975 ÷ 1960	1.87	2.31	2.82
2000 ÷ 1960	5.32	7.11	8.55
2025 ÷ 1960	15.05	21.04	22.13
	Average annual percent change		
1960 to 2025	4.26	4.80	4.88

Note: 1960 value, for the United States and Texas, are from the United States Department of Commerce, Bureau of the Census. 1960 value for the study area estimated at same proportion of State as existed in 1958.

TABLE 44

VALUE OF MINERAL PRODUCTION

	United States		Texas		Study area	
Year	Value	Average annual percent change	Value	Average annual percent change	Value	Average annual percent change
	Values in millions of 1960 constant dollars					
1940	9,288		1,582		NA	
		-2.20		-5.42		
1942	8,883		1,415		NA	
		-0.12		15.23		
1944	8,862		1,879		NA	
		-3.00		-1.99		
1946	8,338		1,805		NA	
		13.48		16.80		
1948	10,738		2,458		NA	
		1.28		0.51		
1950	11,014		2,483		NA	
		3.43		9.40		
1952	11,782		2,972		281.3	
		7.14		9.22		17.95
1954	13,526		3,545		382.3	
		13.02		9.12		13.79
1956	17,279		4,220		487.8	
		-4.65		-4.68		-8.17
1958	15,711		3,834		408.1	
		6.72		3.85		-0.43
1960	17,892		4,135		404.6	

Source: United States Department of the Interior, Bureau of Mines.
NA - not available.

percent of the value of mineral production in Texas in recent years, as compared to about 70 percent for the Nation. Based on values, about one-fourth of the mineral production of the Nation, including one-third of the mineral fuels, originates in Texas. Of the Texas volume, about 10 percent is produced in the study area.

113. PROJECTION OF THE VALUE OF MINERAL PRODUCTION.- The projection of the value of mineral production is influenced significantly by changes and substitutions, as well as by financial incentive. Changes and substitutions are more evident than ever before. Synthetic replaces natural material only to be itself displaced by yet another synthesis or by natural material in a different form or process. A change in use of the various mineral products will be brought about by the higher value which it may receive by being consumed at its "highest and best use." An example of this would be natural gas becoming increasingly more important and valuable as a raw product in the petrochemical industry - thus, in future years other forms of energy may replace at least in part the use of gas as an energy fuel. Financial incentive will also influence the future value of mineral production. Oil companies who can have the benefit of the more economically produced imported petroleum do not have the financial incentive to invest in domestic development and production of crude which will not net them as high a $/barrel return on investment as foreign crude oil. It is likely that the present crude oil import policies will be modified sometime in the future; however, the influence of such a revision cannot be evaluated at this time. The attractiveness of domestic development and production will certainly improve when the gap between domestic consumption and imports widens to such an extent that there is not an over abundance of crude oil as is the case at this time. Proration of oil production, which is a practice common in the states producing most of the crude in the United States, has had a great influence on the willingness of individuals to invest in domestic development and production. Since proved reserves are increased as a result of successful development, they too are a function of financial incentive. This can best be illustrated by recalling how rapidly the proved reserves increased during the "Suez" period.

114. In preparing the projection of the value of mineral production for the United States, it was assumed that the value of minerals other than fuels will increase about in proportion to the increase to the total economy. The value of fuels is estimated to increase directly as the estimated production of energy. This means that when substitution occurs, the value of the substitute fuel in terms of cents per B.t.u. at the consumption location will be about the same as the value of the original fuel. National consumption of energy at the beginning of this century was about 9,900 trillion B.t.u., or 130 million B.t.u. per person. Total

consumption of energy at the year 2025 is estimated at 246,900 trillion B.t.u., or about 450 million B.t.u. per person. This value is a reasonable extrapolation of the estimates contained in Resources in America's Future.14/

115. Although the long-term record of increasing consumption and the increasing shift to foreign sources for a number of our mineral supplies, indicates that we have not continued to maintain our capacity to meet needs competitively from domestic sources, a few commodities (such as crude oil) are in oversupply on the domestic or world market. These surpluses are believed to be temporary. The domestic and foreign needs for minerals will continue to increase because of continued growth in both population and per capita consumption of mineral products. These increased needs indicate an earlier shortage based on presently known reserves. As stated in Research and Development on Natural Resources prepared by the Committee on Natural Resources, Federal Council for Science and Technology - May 1963,15/ ". . . Known supplies of minerals minable at present costs will not support growing demands for many minerals for more than a few decades."

116. New resources have literally been created many times by developing new methods to discover concealed deposits, by finding ways to extract more remote and deeply buried mineral deposits and ways to process lower grade ores, by developing substitutes and replacements from abundant materials that were not usable previously, and by finding ways to synthesize vital but scarce materials. Development of the tar and oil shales of west central United States is an example of one such a change which is now underway. Only minor improvements in the economic positions of this energy source will result in making it competitive with other sources.

117. The national projection of the value of mineral production was made using the rates of increase which were outlined in Resources in America's Future 14/ as a guide. Projections for the United States, Texas, and the study area are contained in table 45. The projection for the base study area is at the same rate as the State in the belief that demand for minerals throughout the Nation will be the principal factor in determining production within the State and the study area.

118. NEW CONSTRUCTION.- Data on the value of new construction put in place during the year, as reported by the Department of Commerce, Bureau of the Census are used for historical data for the nation. Comparative data for Texas were prepared by taking a two-year moving average of the value of construction contracts awarded. The basic data are found in the publication of the United States Bureau of the Census, Statistical Abstract of the United States for 1948, 1954, and 1960, which contains the

TABLE 45

PROJECTION OF THE VALUE OF MINERAL PRODUCTION

Year	United States	Texas	Study area
	Values in millions of 1960 constant dollars		
1960	17,892	4,135	404.6
1975	26,819	6,307	617.2
2000	52,817	12,577	1,230.0
2025	103,251	24,759	2,422.8
	Factors of growth		
1975 ÷ 1960	1.50	1.52	1.52
2000 ÷ 1960	2.95	3.04	3.04
2025 ÷ 1960	5.77	5.99	5.99
	Average annual percent change		
1960 to 2025	2.73	2.79	2.79

historical figures published currently by the F. W. Dodge Corporation, New York, New York, in Statistical Research Service. Use was made of the two-year moving average as being a close approximation of value of construction put in place. In the initial stages of formulation, data from the University of Texas, Bureau of Business Research publication, Construction in Texas, on the value of building permits were used to establish trends for the study area. Comparison of the trends of building permits with the trends of other indicators showed that building permits, because of the limited coverage, could not be accepted as the basis for a projection of new construction. Studies were made of the relationship of new construction and other indicators.

119. For the nation as a whole, the relationship between total personal income and value of new construction was found to be very close. However, it is desirable to achieve estimates of future personal income from estimates of the income within the various industries rather than the reverse. Therefore, the value of new construction during the census years of 1940, 1950, and 1960 was arrived at using the relationship of employment and income in comparison with similar data for the state of Texas. Table 46 shows the historical data for the United States, Texas, and the study area as derived from various sources. Values have been converted to 1960 constant dollars by use of the index of construction from Engineering News Record.16/

120. PROJECTION OF NEW CONSTRUCTION.- The national projection of the value of new construction was made using the data contained in Resources in America's Future 14/ as a guide. The projections of the value of new construction in Texas and the study area were made with the plan of providing future amounts which will be sufficient to support the anticipated total economy of each of these areas. The projections of this indicator are contained in table 47.

121. The comparison of rates of growth is facilitated by the use of the average annual percent of change during the period. An advantage in the use of the average annual percent of change is the ability to compare rates of growth during time periods of different length. Table 48 is a summary of the growth rates of the indicators used in this study for the United States, Texas, and the study area.

122. Texas and the Edwards Underground base study area, spurred forward by the requirements of the second world war and rapid advances in petrochemistry, enjoyed accelerated growth during and following the war years.

123. Despite the effect of an economy oriented principally toward the slow growing industries of agriculture and mining, between 1940 and 1960, population, employment, and income increased at a greater rate for the study area than the average for the nation. The demand for synthetics readily produced from the hydrocarbons available in Texas will continue to lend impetus to the growth of Texas and its component parts.

124. The study area is projected at a more rapid rate than the state as a whole until the later part of the century, when growth will become more moderate as the average for the nation is approached. Within the study area growth will be more rapid in the eastern portion which includes the larger standard metropolitan areas of Austin, San Antonio, and Corpus Christi. The effect of waterborne commerce will continue to be felt in augmentation of natural resources with imported material. Greater than average capacity for increased agricultural production, a higher than average proportion of the area capable of sustaining continued cultivation, moderate climate, and greater rainfall to assist in satisfying increasing water requirements are further advantages of the eastern part of the study area.

TABLE 46

VALUE OF NEW CONSTRUCTION

Year	United States Value	United States Average annual percent change	Texas Value	Texas Average annual percent change	Study area Value	Study area Average annual percent change
	Value of construction put in place millions of 1960 constant dollars					
1940	24,117		609		135	
		6.22		8.09		10.67
1950	44,110		1,326		372	
		2.33		4.43		3.83
1960	55,556		2,048		542	

Source: United States: 1940 and 1950, U. S. Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1957; 1960, U. S. Bureau of the Census, Statistical Abstract of the United States (published annually). Texas: Estimated from data on contract awards from F. W. Dodge, New York, New York, Statistical Research Service, as contained in U. S. Bureau of the Census, Statistical Abstract of the United States (published annually). Study area: Estimated by the Fort Worth District from the state of Texas data, using indicator relationship. See text.

TABLE 47

PROJECTION OF VALUE OF NEW CONSTRUCTION

Year	United States	Texas	Study area
	Values in millions of 1960 constant dollars		
1960	55,556	2,048	383
1975	108,993	4,315	964
2000	274,608	11,246	2,476
2025	686,736	28,790	5,735
	Factors of growth		
1975 ÷ 1960	1.96	2.11	2.51
2000 ÷ 1960	4.94	5.49	6.46
2025 ÷ 1960	12.36	14.06	14.97
	Average annual percent change		
1960 to 2025	3.94	4.15	4.25

TABLE 48

UNITED STATES, TEXAS, AND THE STUDY AREA
SUMMARY OF GROWTH RATES
AVERAGE ANNUAL PERCENT OF CHANGE

Economic indicator	United States		Texas		Study area	
	1940 to 1960 except as noted	1960 to 2025	1940 to 1960 except as noted	1960 to 2025	1940 to 1960 except as noted	1960 to 2025
Population	1.54	1.72	2.03	1.88	1.82	1.90
Urban population	2.62	2.15	4.62	2.25	4.21	2.28
Disposable income	3.72	3.68	5.21	4.01	4.79	4.04
Per capita disposable income	2.12	1.93	3.12	2.09	2.91	2.10
Value of farm products sold	2.98 (1)	1.72	2.43 (1)	2.14	1.82 (1)	2.31
Value added by manufacture	5.21 (2)	4.26	9.03 (2)	4.80	8.24 (2)	4.88
Value of mineral production	3.33	2.73	4.92	2.79	4.65 (3)	2.79
Value of new construction	4.26	3.94	6.25	4.15	7.20	4.25

(1) 1939 to 1959.
(2) 1939 to 1958.
(3) 1952 to 1960.

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SUPPLEMENTARY ECONOMIC DATA

125. GENERAL.- The economic base study is designed to measure the recent economic growth of the area contributive to the water resource requirements of the Edwards Underground Reservoir and to estimate future growth in the area. Projections of industrial development, population, employment, and income are included to assist in measurement of the probable increase in water resource requirements.

126. All basic material used in the study has been extracted from published sources. There has been no attempt to accumulate original material through survey or interview. Original computations have been undertaken in estimating the industrial sources of income received by persons for participation in current production and in estimating the value of new construction for the base study area.

127. The pattern of national economic growth and the forces behind it provide the logical starting point for regional analysis. Historical and projected data are included for the United States, the state of Texas, and the base study area to provide for ready comparison. The economic base for the national projections was established by the Economic Task Group of the Ad Hoc Water Resources Council Staff, an interdepartmental group formed for the purpose of furnishing uniform guidelines for all river basins and other water and related land resource development studies.

128. General assumptions governing all projections in this study are as follows:

a. There will be no major wars, changes in international tensions, serious extended depression, or uncontrolled inflation during the projection period.

b. A high level of employment will be attained.

c. There will be sufficient water of acceptable quality and price to support the development.

129. Projections have been made with as much objectivity as possible. The estimates of future growth for Texas and the study area are believed reasonable and probable; provided the national growth implicit to the established guidelines is attained. The projections are not predictions but are reasoned estimates of the probable trend of future development.

130. Liberal use has been made of material and context in the publications of Resources for the Future, Inc., Washington, D. C. and of the report and unpublished supporting material of the United States Study Commission for Texas. The demographic projections by the Study Commission for the component parts of the study area have been maintained to the fullest extent possible.

131. ECONOMIC INDICATORS.- Certain factors, or economic indicators, are used in estimating future growth and needs. The indicators selected for this study were considered for each project purpose include:

Indicator	Project purposes: Flood control	Recreation: fish and wildlife	Water supply
Population	x	x	x
New construction	x		x
Value added by manufacture	x		x
Value of farm products sold	x		
Value of mineral production	x		
Personal income	x	x	x

132. The indicators were selected for the following reasons:

a. Population.- Population growth has been a major contributor to the expansion in domestic demand for food and other goods and services. Population is considered to be the basic economic indicator to which all other economic indicators are related in some degree.

b. New construction.- Construction activity sets the pace for activity in a large number of supply industries and was, therefore, selected as an economic indicator for use in this study.

c. Value added by manufacture.- This economic indicator was selected because it is a measure of industrial activity and because a major portion of the national income originates in this sector of the economy.

d. Mineral production.- Mining is one of the basic industries of modern society, and ready availability of mineral resources is a principal factor in the rapid development of the base study area. The indicator is included because of its influence in various sectors of the economy.

e. Real personal income.- The gross national product is considered the most comprehensive measure of economic activity. Although gross state and base study area product data are not available at present, data on personal income are available. Therefore, personal income has been selected as an economic indicator since it is the principal component of the gross product, and is the best indicator for which data are available for use in all of the areas considered in this study. For this study, real personal income has been converted to real disposable income, that portion of income remaining after deduction of a tax allowance.

f. Value of farm products sold.- Value of farm products sold is a measure of agricultural activity. This economic indicator is closely related to flood control and water supply.

g. Labor force and employment.- Labor force and employment is included as a useful guide in determining the need for raw materials, water, and basic services, such as power and transportation. Furthermore, projections of employment and income per employee are the tools by which estimates of total income are derived.

133. SELECTION OF THE STUDY AREA.- Relevant areas were selected for the various project purposes, in order to analyze the economic characteristics, development, and past trends, as well as to project future growth and needs. The study area is a composite of the areas selected. Guides used in selecting these areas are as follows:

a. Flood control.- Area in and adjacent to areas subject to flood damages.

b. Water supply.- Area that will affect the potential demand for water.

c. Fish and wildlife.- Area from which will be drawn recipients of fish and wildlife benefits resulting from the proposed improvements.

d. Recreation.- Area from which will be drawn recipients of recreation benefits resulting from the proposed improvements.

134. MEASURES OF GROWTH.- In estimating growth trends for the various economic indicators, data for the United States were projected to establish the general trend. Next, the applicable data for the state of Texas were projected in a manner comparable to that of the United States, with consideration being given to present and prospective future conditions in the state. Data were then prepared for the counties in the study area, summated, and projected within the general framework of the data for the state, consideration being given to present and prospective conditions in the study area. The projected amounts of the economic indicators at the end of various time periods were then divided by the corresponding amounts for 1960 to give factors of growth based on 1960. The 1960 amounts were assigned a value of 1.00. By this procedure, estimates of trends take the form of numerical measures of growth by which the estimates of needs for water resources and benefits under 1960 conditions of development are converted to estimates under conditions which are expected during the life of the projects considered.

135. NATIONAL PROJECTIONS.- The national projections were computed within the general guidelines established by the Economic Task Group of the Water Resources Council Staff.1/ These guidelines were developed by an interagency task group to establish uniform assumptions as a frame of reference for water resource planning. The summary of the medium of the projections are shown in table 49.

136. PROJECTION METHODOLOGY.- Using population, employment, income, and industrial development relationships, a model of economic development relationships, a model of economic development for the nation was constructed within the national guidelines of the Water Resources Council staff. The projections were extended to the year 2025 in a manner consistent with the established trends. This was done in order to encompass the first 50 years of the time period during which the water resources projects were to be studied.

137. STATE AND LOCAL PROJECTIONS.- State and local projections were derived by relating changes in each region to changes in the national total of the various components. The probable course of agricultural development was obtained by allocating the computed national production to the subareas of the nation in relation to current production and to the capability for expansion in the area under consideration. In a similar fashion, development in the other industries was allocated to the area under consideration in relation to current production, past trends, and resource limitations. Population projections which were prepared by the United States Study Commission for Texas have been adhered to except for minor adjustments. The rate of increase of national population in the guidelines is higher than was used in the Study Commission report and the population of Texas has been adjusted upward for consistency with the new national trend.

138. THE BASIC TOOLS OF PROJECTION.- The basic tools used in projections are employment and participation income. The first step was to estimate their values for the base year. 1960 was chosen as the base year because of the availability of material in the United States census for counties and other minor subdivisions.

139. LABOR FORCE AND EMPLOYMENT.- In order to obtain an insight to the current economy, the pattern of employment and unemployment was examined for the Nation, the State, and the study area. Table 50 presents the number of employees engaged in the major industries, the unemployment, and total labor force for 1940 and 1960 and the average annual percent of change for the period. The table was prepared from data contained in the United States Census reports for the reporting years. Government includes public administration, government education, and military in both reporting years and, in 1940, also includes persons engaged in public emergency work. The number of persons in the category, Industry not reported, have been distributed proportionately among the industries.

TABLE 49

NATIONAL ECONOMIC GROWTH PROJECTIONS TO 2020

			Projections					
			1980		2000		2020	
	Unit	Average 1959-61	Total	Change from 1959-61 (percent)	Total	Change from 1980 (percent)	Total	Change from 2000 (percent)
Population 1/	Mil.	180.8	254	41	358	41	502	40
Labor Force 2/	Mil.	73.1	103	41	147	43	206	40
Employment total	Mil.	68.9	100	45	141	41	197	40
Agriculture	Mil.	5.7	3.2	-47	2.4	-25	2.1	-12
Government	Mil.	10.1	14.7	46	20.7	41	29.0	40
Private nonfarm	Mil.	53.1	82.0	54	117.6	43	165.8	41
Gross national product 3/	Bil.Dol.	515	1,100	114	2,230	103	4,520	103
Gross national product per worker 3/	Dol.	7,475	11,000	47	15,800	44	22,900	45

1/ Population of the United States as of 1 July, including Alaska and Hawaii.
2/ Including military.
3/ In 1962 dollars.

TABLE [illegible]

LABOR FORCE AND EMPLOYMENT 1940 AND 1960

	United States					Texas					Study Area				
	1940		1960		Average annual percent change 1940-1960	1940		1960		Average annual percent change 1940-1960	1940		1960		Average annual percent change 1940-1960
	Number in Thousands	Percent of total	Number in thousands	Percent of total		Number in thousands	Percent of total	Number in thousands	Percent of total		Number in thousands	Percent of total	Number in thousands	Percent of total	
Total employment	[illegible]	100.00	[illegible]	100.00	[illegible]	[illegible]	100.00	[illegible]	100.00	2.19	493.4	100.00	714.8	100.00	1.87
Agriculture, forestry and fisheries	[illegible]	17.97	[illegible]	[illegible]	[illegible]	646.2	28.65	303.5	8.72	-3.71	170.5	34.55	79.8	11.16	-3.73
Nonagricultural	39,246	[illegible]	61,934	93.1[illegible]	[illegible]	1,609.5	71.35	3,177.4	91.28	3.46	322.9	65.45	635.0	88.84	3.44
Mining	92[illegible]	1.93	681	[illegible]	[illegible]	61.8	2.74	104.1	2.99	2.64	8.3	1.69	12.0	1.69	1.86
Construction	2,086	[illegible]	3,976	[illegible]	[illegible]	111.9	4.96	262.1	7.52	4.35	25.8	5.23	52.7	7.37	3.63
Manufacture	10,727	[illegible]	[illegible],249	27.47	[illegible]	213.8	9.48	562.2	16.15	4.95	26.5	5.36	63.9	8.93	4.50
Other private non-agricultural	19,770	41.32	31,204	46.94	2.31	959.0	42.51	1,762.5	50.63	3.09	190.1	38.54	333.1	46.60	2.84
Wholesale and retail trade	7,649	15.99	12,258	18.49	2.40	385.5	17.09	732.0	21.03	3.26	78.7	15.96	142.3	19.90	3.00
Finance, insurance and real estate	1,489	3.11	2,808	4.22	3.22	56.8	2.52	143.8	4.13	4.75	10.3	2.09	25.1	3.51	4.54
Transportation	2,209	4.62	2,855	4.30	1.29	103.3	4.58	152.1	4.37	1.96	13.7	2.77	22.0	3.07	2.41
Communications and other public utilities	950	[illegible]	1,791	2.69	3.22	38.6	1.72	103.4	2.97	5.05	8.8	1.79	17.8	2.50	3.58
Services	7,473	15.62	11,462	17.24	2.16	374.8	17.61	631.2	18.13	2.64	78.6	15.93	125.9	17.62	2.38
Government	5,737	11.99	7,824	11.77	1.56	263.0	11.66	486.5	13.98	3.12	72.2	14.63	173.3	24.25	4.48
Unemployment	5,590	-	3,505	-	-2.[illegible]	199.2	-	155.0	-	-1.25	45.6	-	32.8	-	-1.63
Total labor force	[illegible]	-	[illegible]	-	1.35	2,455.0	-	3,635.9	-	1.95	539.0	-	747.6	-	1.65
Labor force participation rate*	[illegible]		[illegible]			[illegible]		[illegible]			38.01		36.74		

*Labor force participation rate equals (amount of labor force shown above divided by amount of population in table 28) multiplied by 100.
Source: U. S. Bureau of the Census data adjusted as stipulated in the text.

140. EMPLOYMENT SHIFT.- The shift technique of regional analysis as explained in the publication, Regions, Resources and Economic Growth,11/ has been applied to the employment data in table 50. The computations for Texas are contained in table 51 and for the study area are contained in table 8.

141. The total net employment shifts resulting from the local-factor effect (the last column in tables 51 and 8) and the composition effect is as follows:

	Texas	Study area
	(all values in thousands)	
Actual increase in total employment 1940 to 1960	1,225.7	221.4
Expected increase at average rate for the U. S.	875.9	192.0
Net shift in total employment	+ 349.8	+ 29.4
Net local factor (competitive effect) shift in total employment	+ 652.4	+133.9
Net composition (industry mix) shift in total employment	- 302.6	-104.5

Texas and the study area experienced upward net shifts in total employment because strong upward local factor shifts were sufficient to offset significant downward composition shifts resulting from the relative specialization in mining and agriculture.

142. INDUSTRIAL DISTRIBUTION OF THE EMPLOYMENT SHIFT.- The component sector's share of the total differential shift for Texas and the study area is as follows:

Industry	Texas	Study area
Agriculture	5.10	6.43
Mining	8.08	3.76
Construction	6.72	2.17
Manufacturing	27.32	11.97
Wholesale and retail trade	15.62	10.06
Finance, insurance, and real estate	5.05	3.57
Transportation	2.56	2.74
Communication and other public utilities	4.21	0.76
Services	7.75	0.96
Government	17.59	57.58
Total	100.00	100.00

Of particular significance are increases in manufacturing, government, and wholesale and retail trade in Texas; and government, manufacturing, and wholesale and retail trade in the study area.

143. PARTICIPATION INCOME.- Estimates of participation income, i.e., Industrial Source of Civilian Income Received by Persons for Participation in Current Production, for the United States and for the individual states are prepared by the United States Department of Commerce, Office of Business Economics. These data were published in 1956 for selected years for the continental United States and the individual states in Personal Income by States since 1929. Data for current years are published in the August issue of Survey of Current Business, a monthly publication of the Office of Business Economics. Detailed examination of the change in income is possible by means of these statistics.

144. Early in the preparation of the Edwards Underground base study, it became apparent that the income of military personnel is a salient feature in Texas and the study area; therefore, estimates were made of the income of the military by use of the estimates of the wages and salaries of the armed forces plus an estimate of other labor income. These data, for the nation and the state, are available in the Office of Business Economics publications which contain the civilian income data. The estimated income of the armed forces was added to the civilian income to achieve the participation income of all employed persons.

145. Comparable data on participation income for counties are not available; therefore, the participation income for the state of Texas has been allocated to subareas through relationship with other indicators; i.e., value of farm products sold; value added by manufacture; wholesale and retail sales, and the employment in the various industries.

146. The participation income, by major industry, for the United States, Texas, and the study area are presented in table 52. The data for 1940 are presented in 1960 constant dollars.

147. CHANGE IN PARTICIPATION INCOME.- For Texas and the study area the rate of increase of participation income was about 30 percent and 18 percent greater than the rate of increase for the nation. However, the industrial distribution of the increase differed in all cases. The rate of participation income in government for the study area is 1.6 times the rate for the nation and about 1.1 times the rate for Texas. Table 53 shows the change in participation income by industry - 1940-1960.

TABLE 51

EMPLOYMENT SHIFT FOR TEXAS

1940 to 1960

Major Employment Sector	Texas Employment 1940	Texas Employment 1960	Actual change	Expected change	Net shift
	(all values in thousands)				
Agriculture	646.3	303.5	-342.8	-305.7	-37.1
Mining	61.8	104.1	+42.3	-16.4	+58.7
Construction	111.9	262.1	+150.2	+101.4	+48.8
Manufacturing	213.8	562.2	+348.4	+149.9	+198.5
Wholesale and retail trade	385.5	732.6	+347.1	+233.6	+113.5
Finance, insurance, and real estate	56.8	143.8	+87.0	+50.3	+36.7
Transportation	103.3	152.1	+48.8	+30.2	+18.6
Communication and public utilities	38.6	103.4	+64.8	+34.2	+30.6
Services	374.8	631.2	+256.4	+200.1	+56.3
Government	263.0	486.5	+223.5	+95.7	+127.8
Total	2,255.8	3,481.5	+1,225.7	+573.3	+652.4
Total competitive net shift in employment					+652.4

TABLE 52

PARTICIPATION INCOME 1940-1960
EDWARDS UNDERGROUND ECONOMIC BASE STUDY

	United States					Texas					Study area				
	1940		1960		Average annual percent change 1940-1960	1940		1960		Average annual percent change 1940-1960	1940		1960		Average annual percent change 1940-1960
	Value	Percent of the total	Value	Percent of the total		Value	Percent of the total	Value	Percent of the total		Value	Percent of the total	Value	Percent of the total	
	Values in millions of 1960 constant dollars														
Total	140,134	100.00	327,308	100.00	4.33	5,104	100.00	15,320	100.00	5.65	1,009.6	100.00	2,734.6	100.00	5.11
Agriculture, forestry, and fisheries	12,805	9.14	14,951	4.57	0.79	942	18.46	1,169	7.63	1.03	217.5	21.54	223.7	8.18	0.14
Nonagricultural	127,329	90.86	312,357	95.43	4.59	4,162	81.54	14,151	93.27	6.31	792.1	78.46	2,510.9	91.82	5.94
Mining	3,031	2.16	4,349	1.33	1.81	319	6.26	808	5.27	4.76	41.8	4.14	79.1	2.89	3.24
Construction	5,418	3.87	21,038	6.43	7.02	226	4.43	1,034	6.75	7.90	51.0	5.05	193.4	7.07	6.89
Manufacture	36,181	25.82	94,589	28.90	4.92	568	11.12	2,695	17.59	8.10	63.6	6.31	261.1	9.55	7.32
Other private nonagricultural	64,509	46.05	146,606	44.79	4.19	2,374	46.53	7,142	46.62	5.66	444.5	44.02	1,178.4	43.08	5.00
Wholesale and retail trade	28,644	20.44	63,011	19.25	4.00	1,097	21.51	3,200	20.89	5.50	220.0	21.78	520.7	19.04	4.40
Finance, insurance, and real estate	6,412	4.58	16,420	5.02	4.81	202	3.95	770	5.03	6.92	35.6	3.52	125.0	4.57	6.48
Transportation	8,806	6.28	16,068	4.91	3.05	375	7.34	875	5.71	4.33	48.6	4.82	117.6	4.30	4.52
Communications and other public utilities	[illegible]	2.54	9,031	2.76	4.76	126	2.46	458	2.99	6.67	28.4	2.82	73.7	2.69	4.88
Business and personal services	17,084	12.19	42,07[illegible]	12.86	4.61	574	11.25	1,839	12.00	6.00	111.9	11.08	341.4	12.48	5.74
Government	18,190	12.98	[illegible]	[illegible]	[illegible]	675	13.20	2,472	16.13	6.71	191.2	18.94	798.9	29.23	7.41

Source: See text.

TABLE 53

CHANGE IN PARTICIPATION INCOME BY INDUSTRY 1940 to 1960

	United States		Texas		Study area	
	Amount of change	Percent	Amount of change	Percent	Amount of change	Percent
	Values in millions of 1960 constant dollars					
Total	187,174	100.00	10,216	100.00	1,725.0	100.00
Agriculture, forestry and fisheries	2,146	1.15	227	2.22	6.2	0.36
Nonagriculture	185,028	98.85	9,989	97.78	1,718.8	99.64
Mining	1,318	0.70	489	4.79	37.3	2.16
Construction	15,620	8.34	808	7.91	142.4	8.26
Manufacture	58,408	31.21	2,127	20.82	197.5	11.45
Other private nonagricultural	82,097	43.86	4,768	46.67	733.9	42.54
Government	27,585	14.74	1,797	17.59	607.7	35.23

Source: Computed from table 49.

148. AGRICULTURAL PROJECTION.- Estimates of future income and employment in agriculture were obtained by relationship with the future value of farm marketings, or as used in this study, value of farm products sold.

149. METHOD OF PROJECTING THE VALUE OF FARM PRODUCTS SOLD.- In connection with the preparation of the United States Study Commission report,3/ the Department of Agriculture prepared estimates of production requirements of agricultural commodities for the nation for the year 2010. The economic base for these production studies was somewhat lower than the economic base in the guidelines of the Economic Task Group.1/ Comparison of major indicators is as follows:

	USSC-T	Task group (medium projection)
	Values at year 2010	
Population (millions)	379.0	424.2
Labor force (millions)	163.0	174.4
Gross national product (billions of 1960 dollars)	2,664.0	3,090.4

150. The Study Commission production requirements were adjusted to the level of the Task Group Economic base and projected to year 2025. The average annual rate of increase of the total from 1960 to 2025 is 1.72 percent, the same as the rate of increase of population. The projections were disaggregated to major commodity levels and rates of growth computed for each commodity group.

151. Estimates of future production requirements are also available in the United States Department of Agriculture publication, Land and Water Resources,12/ which contains projections to 1980. Comparison of the projections contained therein and the projections in this study is made by means of average annual percent of increase and is as follows:

	Average annual percent of increase in national projections	
	Land and water resources	As used in this study
Population	1.87	1.72
Disposable income	4.14	3.85
Per capita disposable income	2.21	2.09
Farm output	1.82	1.72 (1)
Total crop production	1.69	1.57 (2)
Product added by livestock	2.11	1.83 (3)

(1) Value of farm products sold.
(2) Value of all crops sold.
(3) Value of livestock and livestock products sold.

152. The comparison discloses that the principal reason for the differences in the rate of increase in agriculture is the difference in the other economic projections upon which the agricultural projection is based. Modification to the same economic base results in reasonable agreement.

153. Future production in Texas and the study area was estimated by allocating the national production to the individual areas with consideration of current production and the capacity of the individual areas for expansion. The production capacity was estimated by relationship of the capability of the acreage to support continued cultivation, as revealed by an inventory of the land by capability class. The increased future production will be derived from improved technology and from a continuation of the shift in land uses. Cropland will be concentrated on the more fertile level land. Areas containing the greatest proportion of land capable of supporting continued high production will profit the most.

154. LAND USE BY CAPABILITY CLASS.- The agricultural land in the United States has been inventoried and the results published by the U. S. Department of Agriculture, Soil Conservation Service. The publications list the land in each county by land use. Land in each land use is classified into eight standard land capability classes, thus dividing it along the lines of the physical conditions affecting its inherent capabilities. The risks of soil damage or limitations in use become progressively greater from class I to class VIII.

155. Under good management, soils in classes I, II, III, and IV are capable of producing the common cultivated field crops as well as adapted range, pasture, and forest vegetation. Class I soils have few limitations in their use and ordinarily need only good soil management measures for safe, sustained cropland use. Class II lands have some limitations that reduce the choice of crops and plants that should be grown on them, but good soil conservation measures can overcome them without great difficulty. Class III lands are severely limited in use opportunities, requiring relatively intensive application of soil conservation measures to permit safe, sustained cropland use. Class IV lands are safely adapted to but few uses, and generally should be tilled only periodically, if at all.

156. Soils in classes V, VI, and VII generally are not suited for safe, continued tillage. They are best used for range, pasture, and forest, although crops especially adapted to the conditions are grown. Class V lands are limited principally by excessive wetness, rather than by erosion or other hazards. They are restricted to noncrop uses or to special crops such as rice. Safe, continued noncrop use of class VI lands requires certain restrictive measures that can be relatively easily and successfully adopted. Class VII lands, on the other hand, require severe restrictions and very careful adjustment to be permanently successful. Class VIII lands ordinarily are not productive enough to offset the costs to the owners of development and management. No study area agricultural lands were classified as class VIII.

157. Table 54, Use of Inventory Acreage by Capability Class, was prepared from the Texas Soil and Water Needs Inventory.17/ Two-thirds of the inventory acreage in subarea I has characteristics which permit its safe, permanent use to grow field crops, provided it is treated with proper combination of conservation measures. In subarea II, 46 percent of the land and in subarea III, 19 percent of the land exhibit these same characteristics.

158. PROJECTION OF THE VALUE OF FARM PRODUCTS SOLD.- Table 54 shows that for the study area a large proportion of land is not in its highest order of use. There are about 18.7 million acres of land in capability classes I, II, and III of which 7.2 million, or 38 percent are in cropland. Table 5 in Land and Water Resources 12/ reveals that for the nation there are 638 million acres in capability classes I, II, and III of which 373 million acres or 58 percent are in cropland. This would indicate a greater proportionate capacity for increased production for the study area than for the nation as a whole. The study area's share of agricultural output is projected to increase from about 1.3 percent of the total for the nation in 1959 to about 1.9 percent of the total in 2025. Seventy-five percent of this increase will occur in subarea I where irrigated land will increase from about 179 thousand acres to about 366 thousand acres.

159. Table 55 presents the percent of increase between 1960 and 2025 for the commodity classes. The increase is expressed as a percent of the 1960 estimated production. Using the rates of increase and the value of each commodity in 1960, the corresponding value at 2025 was computed. Values for the intermediate years 1975 and 2000 were found in similar fashion.

160. PROJECTION OF INCOME AND EMPLOYMENT IN AGRICULTURE.- Income in agriculture was computed as a proportion of the value of farm products sold. Income per employee was projected and used with farm income in estimating agricultural employment.

161. THE NATIONAL MODEL.- Working within the limitations imposed by the National Projections of the Water Resources Council and the development in national industries presented in the prior section, NATIONAL, STATE, AND LOCAL PROJECTIONS, a national income model was prepared. Future participation income for Agriculture, Mining, Construction, and Manufacturing was estimated as a proportion of the value of the appropriate indicator. Income per employee in each industry was projected at rates consistent with past performance and the number of employees derived by division. The sum of Mining, Construction, and Manufacture was subtracted from other private nonagriculture and the difference has been called other private nonagricultural industries. The total of participation income was estimated as a proportion of Gross National Product and income in other private nonagriculture found by subtraction of the known values.

162. The Water Resources Council labor force and employment projections use the Bureau of Labor Statistics concept of employment in which dual job holding is a factor. Because the Bureau of Census data is available at all levels of this study the employment distribution was commuted to the Bureau of Census concept.

163. The employment and participation income projections for the United States are contained in table 56. The values of the industrial projection, population, and disposable income are repeated at the bottom of the table for ease of reference.

164. STATE AND AREA NONAGRICULTURAL EMPLOYMENT.- In order to account for the total of the economy with no more divisions than absolutely necessary, projections were made for only the major nonagricultural segments: mining, construction, manufacture, other private nonagricultural industries, and government. Proper relationship of employment and industrial development was maintained by means of participation income by industry.

TABLE 54

EDWARDS UNDERGROUND BASE STUDY AREA
USE OF INVENTORY ACREAGE BY CAPABILITY CLASS
FOR SUBAREAS

Capability class	Cropland	Pasture range	Forest woodland	Other	Total
	(thousands of acres)				
		Total study area			
I	468.8	208.2	163.2	4.6	844.8
II	4,585.7	5,562.4	722.4	103.5	10,974.0
III	2,150.4	3,143.6	1,554.9	45.5	6,894.4
IV	404.0	1,043.3	1,456.5	11.3	2,915.1
Total	7,608.9	9,957.5	3,897.0	164.9	21,628.3
V-VII	784.1	12,922.1	5,139.7	266.3	19,112.2
Total	8,393.0	22,879.6	9,036.7	431.2	40,740.5
		Subarea I			
I	268.6	177.9	117.6	3.8	567.9
II	3,626.5	2,136.0	615.9	50.4	6,428.8
III	1,623.0	1,475.3	1,350.1	26.1	4,474.5
IV	297.9	489.6	1,297.5	10.1	2,095.1
Total	5,816.0	4,278.8	3,381.1	90.4	13,566.3
V-VII	144.8	1,451.6	1,814.8	201.2	3,612.4
Total	5,960.8	5,730.4	5,195.9	291.6	17,178.7
		Subarea II			
I	109.3	-	-	-	109.3
II	461.0	2,779.8	-	50.5	3,291.3
III	243.3	887.8	44.2	15.6	1,190.9
IV	19.5	206.8	-	-	226.3
Total	833.1	3,874.4	44.2	66.1	4,817.8
V-VII	303.2	4,218.5	497.6	20.3	5,039.6
Total	1,136.3	8,092.9	541.8	86.4	9,857.4
		Subarea III			
I	90.9	30.3	45.6	0.8	167.6
II	498.2	646.6	106.5	2.6	1,253.9
III	284.1	780.5	160.6	3.8	1,229.0
IV	86.6	346.9	159.0	1.2	593.7
Total	959.8	1,804.3	471.7	8.4	3,244.2
V-VII	336.1	7,252.0	2,827.3	44.8	10,460.2
Total	1,295.9	9,056.3	3,299.0	53.2	13,704.4

Source: United States Department of Agriculture, Soil Conservation Service.

TABLE 55

PERCENT OF INCREASE IN AGRICULTURAL PRODUCTION BY COMMODITY CLASS FROM 1960 TO 1975, 2000, AND 2025

Area	1975	2000	2025
Increase as a percent of 1960 estimate of value of sales			
United States			
Livestock and livestock products	26	103	225
All crops	22	83	175
Total	24	94	203
Texas			
Livestock and livestock products	60	193	359
All crops	49	128	241
Total	54	158	296
Total study area			
Livestock and livestock products	52	206	378
All crops	46	171	279
Total	50	193	341
Subarea I			
Livestock and livestock products	73	254	467
All crops	52	186	303
Total	63	222	390
Subarea II			
Livestock and livestock products	24	120	227
All crops	16	86	149
Total	22	111	204
Subarea III			
Livestock and livestock products	27	162	290
All crops	24	138	216
Total	26	160	283

TABLE 56
ECONOMIC GROWTH PROJECTIONS
UNITED STATES

Year	Labor Force: Participation rate	Labor Force: Number in thousands	Unemployment in thousands	Industrial Category: Agriculture Forestry & Fisheries	Nonagricultural: Total	Nonagricultural: Mining	Nonagricultural: Construction	Nonagricultural: Manufacture	Nonagricultural: Other Private	Nonagricultural: Government	Total
				Number of employees in thousands							
1960	38.72	69,972	3,505	4,533	61,934	681	3,976	18,249	31,204	7,824	66,467
1975	39.66	92,532	4,280	2,786	85,466	702	5,298	23,014	46,215	10,237	88,252
2000	39.84	142,750	5,944	1,843	134,963	793	8,136	36,681	73,131	16,222	136,806
2025	40.00	218,754	8,750	1,619	208,385	889	12,401	57,301	113,384	24,410	210,004
Average annual percent change 1960 to 2025		1.77	1.42	-1.60	1.88	0.41	1.77	1.78	2.01	1.77	1.79
				Participation income in millions of 1960 constant dollars							
1960				$ 14,951	$ 312,357	$ 4,349	$ 21,038	$ 94,589	$ 146,606	$ 45,775	$ 327,308
1975				17,736	562,977	6,520	41,276	174,186	261,321	79,674	580,713
2000				24,268	1,399,196	12,840	103,994	445,273	640,559	196,530	1,423,464
2025				33,876	3,415,303	25,100	260,067	1,101,675	1,552,130	476,330	3,449,179
Average annual percent change 1960 to 2025				1.27	3.75	2.73	3.94	3.85	3.70	3.66	3.69

Projections of Income, Industry and Population

Year	Population in thousands	Value of farm products sold millions	Value of mineral production millions	Value of new construction millions	Value added by manufacture millions	Disposable Income: Total millions	Disposable Income: Per capita
			Value in 1960 constant dollars				
1960	180,676	$ 31,046	$ 17,892	$55,556	$163,571	$ 349,889	$ 1,937
1975	233,310	40,096	26,819	108,993	305,874	616,008	2,640
2000	358,300	61,415	52,817	274,608	870,862	1,509,982	4,214
2025	546,156	94,064	103,251	686,736	2,461,033	3,658,821	6,699
Average annual percent change 1960 to 2025	1.72	1.72	2.73	3.94	4.26	3.68	1.93

165. INCOME AND INDUSTRIAL DEVELOPMENT.- Participation income per employee for Texas and the study area was projected using the national rate of increase as a guide. For each industry, participation income was maintained at the same proportion as in 1960. Total personal income was derived by assuming the ratio of participation income to total income to remain the same as in 1960.

166. Table 57 presents the projections of Labor Force and Employment and Participation Income for Texas, and table 58 gives similar data for the study area. Projections of the individual indicators are reported for ready reference.

TABLE 57
ECONOMIC GROWTH PROJECTIONS
TEXAS

Year	Labor Force: Participation rate	Labor Force: Number in thousands	Unemployment in thousands	Industrial Category: Agriculture Forestry & Fisheries	Nonagricultural: Total	Nonagricultural: Mining	Nonagricultural: Construction	Nonagricultural: Manufacture	Nonagricultural: Other Private	Nonagricultural: Government	Total
				Number of employees in thousands							
1960	37.95	3,636	155	304	3,177	104	262	562	1,763	486	3,481
1975	39.11	5,067	203	216	4,648	109	376	876	2,624	663	4,864
2000	39.65	8,179	327	147	7,705	125	597	1,492	4,413	1,078	7,852
2025	39.65	12,746	510	124	12,112	141	931	2,448	6,905	1,687	12,236
Average annual percent change 1960 to 2025		1.95	1.85	-1.39	2.08	0.47	1.97	2.29	2.12	1.93	1.95
				Participation income in millions of 1960 constant dollars							
1960				$ 1,169	$ 14,151	$ 808	$ 1,034	$ 2,695	$ 7,142	$2,472	$ 15,320
1975				1,658	28,040	1,232	2,178	6,216	13,810	4,604	29,698
2000				2,513	75,232	2,458	5,678	19,041	36,238	11,817	77,745
2025				3,457	193,623	4,838	14,536	56,138	88,686	29,425	197,080
Average annual percent change 1960 to 2025				1.68	4.11	2.79	4.15	4.78	3.95	3.88	4.01

PROJECTIONS OF INCOME, INDUSTRY AND POPULATION

Year	Population in thousands	Value of farm products sold millions	Value of mineral production millions	Value of new construction millions	Value added by manufacture millions	Disposable Income: Total millions	Disposable Income: Per capita
			Value in 1960 constant dollars				
1960	9,580	$2,057	$4,135	$2,048	$5,817	$16,563	$ 1,729
1975	12,957	3,164	6,307	4,315	13,445	32,338	2,496
2000	20,630	5,311	12,577	11,246	41,357	84,471	4,095
2025	32,148	8,148	24,759	28,790	122,380	212,900	6,622
Average annual percent change 1960 to 2025	1.88	2.14	2.79	4.15	4.80	4.01	2.09

TABLE 58
ECONOMIC GROWTH PROJECTIONS
EDWARDS UNDERGROUND RESERVOIR STUDY AREA

Year	LABOR FORCE: Partic- ipation rate	LABOR FORCE: Number in thousands	Unemploy- ment in thousands	INDUSTRIAL CATEGORY: Agriculture, Forestry and Fisheries	Nonagricultural: Total	Nonagricultural: Mining	Nonagricultural: Construction	Nonagricultural: Manufacture	Nonagricultural: Other Private	Nonagricultural: Government	Total
				Number of employees in thousands							
1960	36.74	747.6	32.8	79.8	635.0	12.0	52.7	63.9	333.1	173.3	714.8
1975	39.65	1,215.9	48.6	54.4	1,112.9	12.6	90.0	122.0	612.4	275.9	1,167.3
2000	39.65	1,949.3	77.9	47.3	1,824.1	14.4	141.4	205.3	1,019.6	443.4	1,871.4
2025	39.65	2,739.8	109.6	39.4	2,590.8	16.2	199.4	302.0	1,445.8	627.4	2,630.2
Average annual per- cent change 1960 to 2025		2.02	1.87	-1.09	2.19	0.46	2.07	2.42	2.28	2.00	2.02
				Participation income in millions of 1960 constant dollars							
1960				$ 223.7	$ 2,510.9	$ 79.1	$ 193.4	$ 261.1	$ 1,178.4	$ 798.9	$ 2,734.6
1975				321.9	5,894.1	120.7	484.9	737.7	2,814.6	1,736.2	6,216.0
2000				568.0	14,759.5	240.2	1,250.1	2,233.0	6,713.0	4,323.2	15,327.5
2025				767.2	35,277.4	471.6	2,895.7	5,777.6	16,214.6	9,917.9	36,044.6
Average annual percent change - 1960 to 2025				1.92	4.15	2.79	4.25	4.88	4.11	3.95	4.05

PROJECTIONS OF INCOME, INDUSTRY AND POPULATION

	Population in thousands	Value of Farm Products sold millions	Value of mineral production millions	Value of new construction millions	Value added by manufacturing millions	DISPOSABLE INCOME: Total millions	DISPOSABLE INCOME: Per capita
		Value in 1960 constant dollars					
1960	2,035.0	$ 409.9	$ 404.6	$ 383.0	$ 563.6	$ 2,998.4	$ 1,473
1975	3,066.[illegible]	614.5	617.2	960.4	1,592.3	6,838.7	2,230
2000	4,916.[illegible]	1,200.6	1,230.0	2,476.0	4,319.9	16,787.2	3,414
2025	6,910.[illegible]	1,803.2	2,422.8	5,735.2	12,470.4	39,299.2	5,687
Average annual percent change - 1960 to 2025	1.[illegible]0	2.31	2.79	4.25	4.88	4.04	2.10

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167. The bibliography is divided into two parts, Reference and General. Footnote numbers refer to the reference bibliography. The general bibliography is presented under two headings, Sources of Historical Data and References for Techniques and Projection Patterns. Publications in the Reference Bibliography are repeated in the General Bibliography.

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APPENDIX VI

RECREATION AND FISH AND WILDLIFE

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

APPENDIX VI
RECREATION AND FISH AND WILDLIFE

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

APPENDIX VI
RECREATION AND FISH AND WILDLIFE

INTRODUCTION

1. SCOPE.- Described herein are the methods and techniques used in determining the needs for lands and facilities for recreation and fish and wildlife purposes in the Edwards Reservoir area within the Guadalupe, San Antonio, and Nueces River Basins. Investigations for this study include the use and projections of data compiled for existing Corps of Engineers projects and data obtained from reports prepared by other agencies, especially the Outdoor Recreation Resources Review Commission (ORRRC). Special studies were made to determine the effects, needs, and economics of the recreation and fish and wildlife aspects of this proposed plan of improvement. The studies were coordinated with the U. S. Fish and Wildlife Service and a report prepared by this agency is included as an attachment to this appendix.

2. The analysis contained in this appendix relative to the general recreation and fish and wildlife recreation needs of the area has been used in the formulation of the recommended plan of improvement.

EXISTING AND PROPOSED IMPROVEMENTS

3. GENERAL.- Improvements in the interest of water conservation and flood control have been constructed in the watershed of the Edwards Underground Reservoir by the Federal Government and local agencies. The proposed improvements include the construction of five reservoirs in the watershed of the Edwards Underground Reservoir as follows: two multiple-purpose and two flood-control and recharge reservoirs by the Corps of Engineers, and one water conservation reservoir by local interests. Locations of existing, authorized, and proposed improvements are shown in plate 1, Plan of Improvement. Existing and proposed projects in the area are as follows:

a. Corps of Engineers.

(1) Existing - Canyon Reservoir.

(2) Under construction - San Antonio Channel Improvement.

(3) Authorized - Blieders Creek Reservoir.

(4) Recommended in this report - Cloptin Crossing, Montell, Concan, and Sabinal Reservoirs.

b. Other agencies.

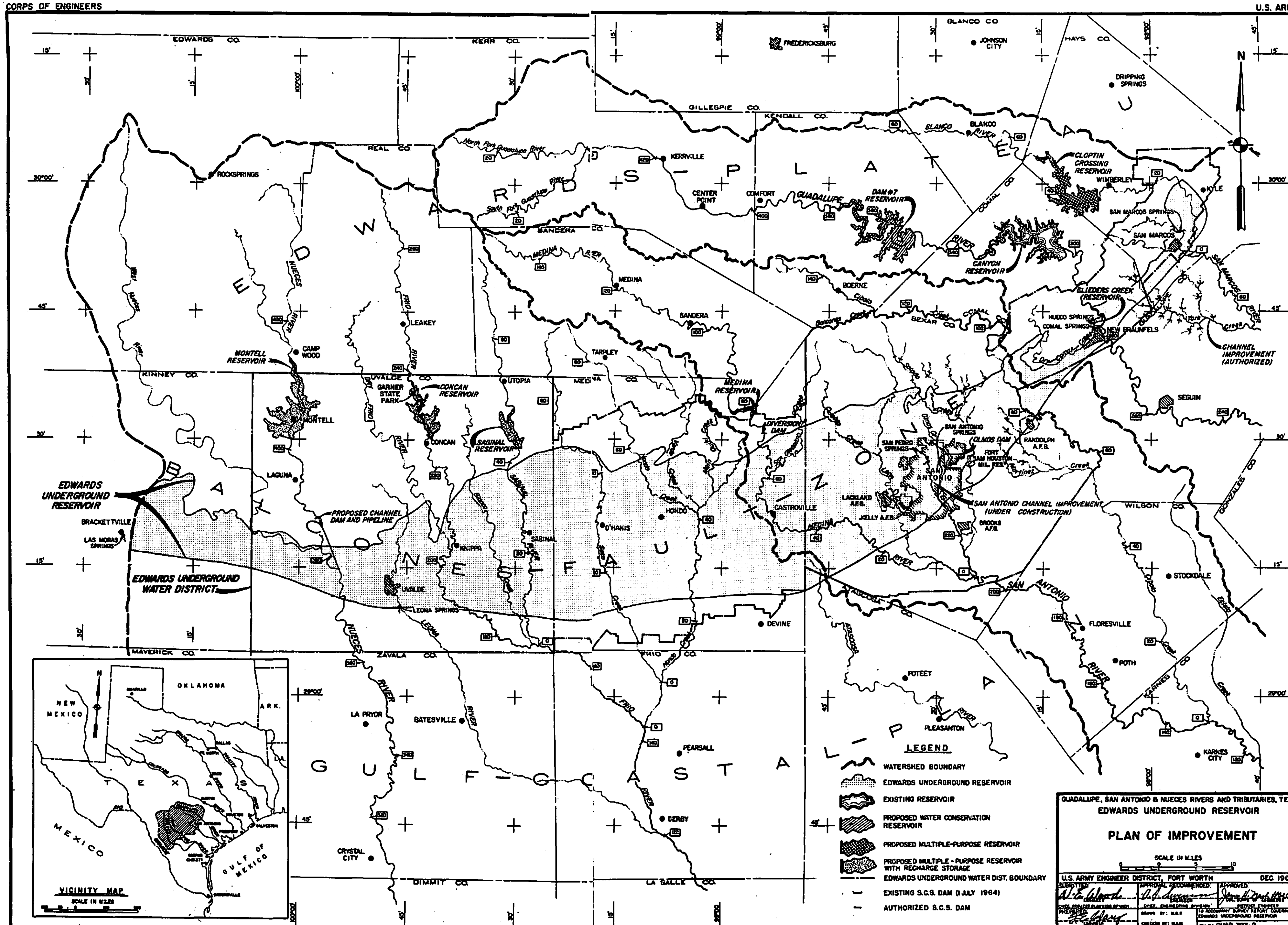
(1) Existing - Medina Reservoir, Olmos Reservoir, and 18 Soil Conservation Service detention reservoirs.

(2) Authorized - 20 additional Soil Conservation Service detention reservoirs.

(3) Recommended in this report - Dam No. 7 Reservoir.

4. EXISTING AND PROPOSED RECREATION AREAS.- Recreation areas and facilities are developed or proposed at all of the Corps' reservoir projects cited above except the Blieders Creek project, and they will be open to public use. No recreational development is proposed for the Blieders Creek Reservoir, since this is a local flood protection project and there will be no conservation storage. Medina Reservoir is owned and operated by an irrigation district and although there is some recreational development at the project, it is essentially operated for private interests. In April 1962, there were 16 flood-detention reservoirs authorized for construction in the Salado Creek watershed, a tributary of the San Antonio River. In August 1959, there were 6 flood-detention reservoirs authorized, 5 of which have been constructed, in the Martinez Creek watershed, a tributary of the San Antonio River. In February 1958, there were 16 flood-detention reservoirs authorized, 13 of which have been constructed, in the York Creek watershed, a tributary of the San Marcos River. The flood-detention projects are planned and constructed by the Soil Conservation Service in cooperation with Soil Conservation Districts. At the top of the flood-detention pool levels, the reservoirs range in size from about 11 to 140 surface acres. These reservoirs are not generally open to free public use, since they are located on privately owned land. However, the projects will afford some water-related recreation potentialities since some owners invite or permit relatives, friends, and associates to participate in the recreational activities available. In addition to the existing and proposed water development projects in the watershed area, the Texas Parks and Wildlife Commission owns and operates the Garner State Park, which is located in Uvalde County. While these developments meet some of the recreation needs of the area, the principal public outdoor recreation opportunities within the study area are, or will be, afforded by the existing and proposed Corps projects.

5. The Edwards Underground Reservoir lies diagonally across the south central portion of the state in the Balcones fault zone. It



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 UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
EDWARDS PLATEAU
BALCONES FAULT ZONE
GULF COASTAL PLAIN
VICINITY MAP

lies between the cities of Kyle on the eastern edge and Brackettville near the western edge within the Guadalupe, San Antonio, and Nueces River Basins. The study area includes the portions of the three river basins within the Balcones fault zone, the area to the north known as the Edwards Plateau, and the contiguous area along the southern boundary of the underground reservoir in the Gulf Coastal Plain. The Edwards Plateau is an area of rolling hills with limestone covering most of the surface. Soils are thin in this area but are sufficient to provide for the growth of small trees and ranges of grass and weeds. The plateau country has been largely devoted to ranching. The clear running streams of the plateau country, which are fed by springs, flow along the canyons cut through limestone formations. The streams and the rugged hill country of the area are known for their scenic beauty.

6. Proposed improvements would result in the construction of five reservoirs in the upper reaches of the Edwards Reservoir area. Cloptin Crossing Reservoir on the Blanco River and Dam No. 7 Reservoir on the Guadalupe River are proposed in the Guadalupe River Basin. In the Nueces River Basin, Montell, Concan, and Sabinal Reservoirs are proposed. The location of these reservoir projects is shown on plate 1, Plan of Improvement. Montell and Cloptin Crossing Reservoirs would be multiple-purpose projects (flood control, water conservation, and recreation). Concan and Sabinal Reservoirs would be flood-control and recharge projects and would have no permanent conservation storage. These four reservoirs would be constructed and operated by the Corps of Engineers. No water-oriented recreational development is proposed for Concan and Sabinal Reservoirs. Dam No. 7 would be a water conservation project and would be constructed and operated by local interests. For the purpose of this report, it is assumed that local interests will develop the recreation potential of this project. All estimates in this report concerning expected visitation, land requirements, recreation facilities, including costs and benefits, have been included only for those projects proposed for Federal construction. The proposed improvements included in this report would result in an increase in impounded water surface measured at the top of conservation pool levels, by approximately 6,320 acres. Reservoir waters would be relatively clear and of good quality.

7. Based on data compiled for the completed multi-purpose projects in the Fort Worth District, it is believed that the principal recreational use of projects in the proposed plan of improvement would fall in the day-use category. However, the projects are expected to attract some visitors from greater distances and for longer periods of use. Much of the area under investigation attracts visitors annually from all sections of the state. The area also attracts a considerable number of visitors from outside the state. The climate is warm and moderately humid in summer, and winter periods

are normally short and have comparatively mild temperatures. The area also has an abundant population of deer and small game, which attracts many hunters during the open hunting season.

8. POPULATION OF AREA OF INFLUENCE.- On the basis of the above analysis, it is considered that the principal area of influence would be comprised of 20 counties. Fourteen of these counties are wholly or partially within the Edwards Underground Reservoir area, and six counties are immediately downstream along the southern boundary of the underground reservoir. The actual and projected population for the 20 counties follows:

	1960	1975	2025	2075
Population	1,123,000	1,626,500	4,022,600	9,167,000

This projected population is also shown on figure 1.

9. DEMAND FOR OUTDOOR RECREATION.- Conclusions reached by the Outdoor Recreation Resources Review Commission and others interested in the field of recreation indicate that past actions taken to provide for outdoor recreation have not been adequate for present needs and will not be adequate for the foreseeable future. The population is increasing rapidly, and individually the people are seeking the outdoors at a growing rate. Therefore, outdoor recreation demands are expected to increase rapidly during the coming decades. The major factors which indicate this large and sustained increase in outdoor recreation demand are as follows:

a. Rapid and steady growth in population with a marked trend toward a more urbanized population;

b. Larger than average increase in numbers of older people, retired or otherwise, with time for outdoor recreation;

c. Larger than average increase in young people not yet in the labor force;

d. Steady growth in per capita real incomes;

e. Improved travel facilities which bring more distant recreation areas within usable range;

f. Increase in leisure time due to paid vacations and shortened work weeks.

Outdoor Recreation Resources Review Commission studies further indicate that the greatest need for recreational activities is generated by the

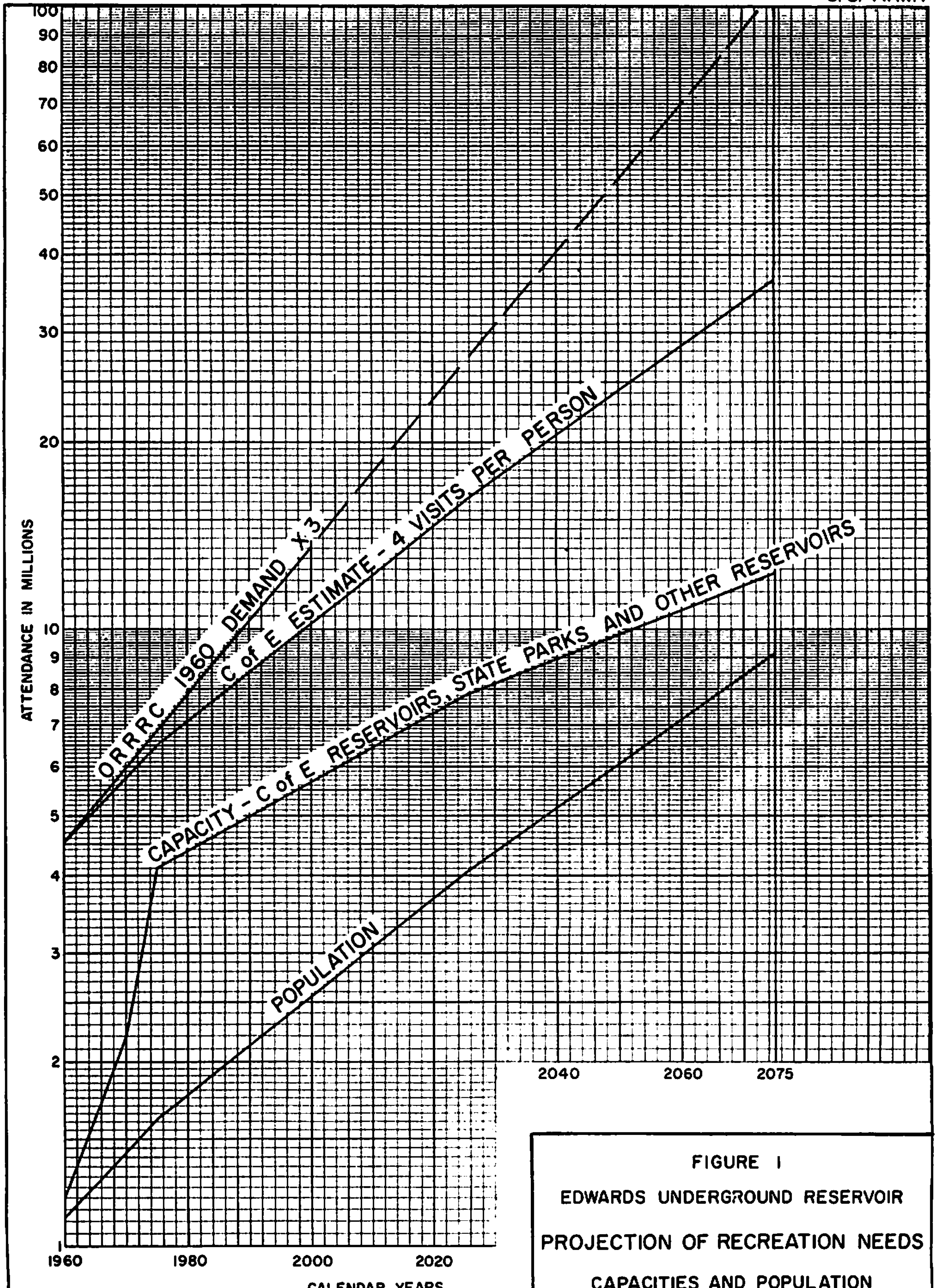


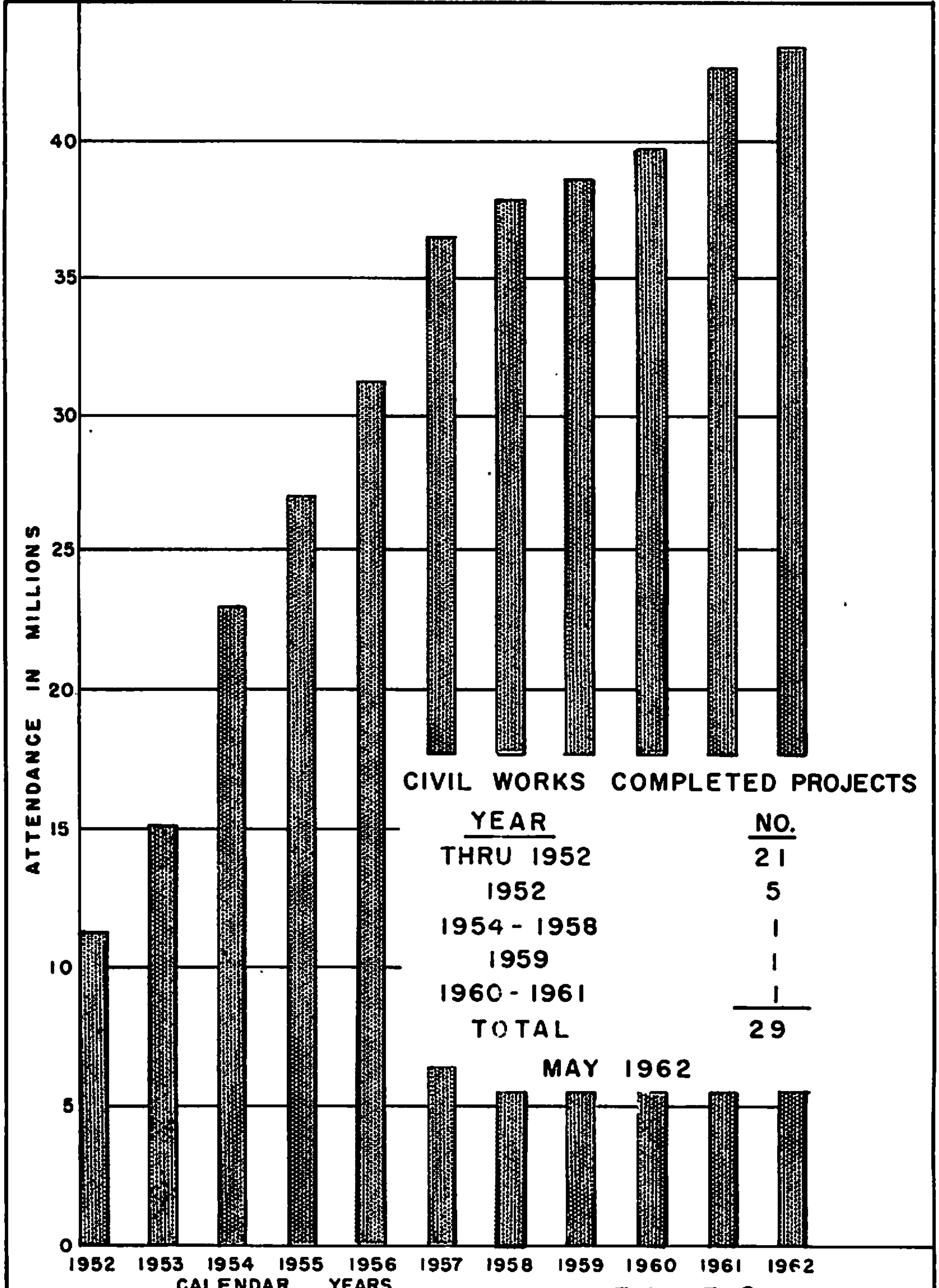
FIGURE 1
EDWARDS UNDERGROUND RESERVOIR
PROJECTION OF RECREATION NEEDS
CAPACITIES AND POPULATION

SCALES AS SHOWN

concentrated population in the metropolitan areas and to a slightly lesser degree by the adjacent urban areas. In addition, there is an apparent trend toward a higher percentage of participation in outdoor recreation activities than in past years. Based on ORRRC predictions that the demand for outdoor recreation will triple by the year 2000, a straight line projection, as shown on figure 1, indicates that the capacities of the existing and proposed projects will not satisfy the recreation demand for the study area.

10. DEMAND FOR WATER-BASED RECREATION.- The demand for water-based recreation is evidenced by the increase in visitation to existing reservoirs under the jurisdiction of the Corps of Engineers; the increase in the number of hunting and fishing licenses being issued; and the increase in sales of boats, motors, and equipment used for camping, fishing, and hunting, and other recreation activities. Visitation to reservoir projects under the jurisdiction of the Southwestern Division is shown in figure 2. Visitation to reservoir projects under the jurisdiction of the Fort Worth District is shown in figure 3. It will be noted that visitation to projects in the Southwestern Division almost quadrupled during the past 10-year period, and that visitation to Fort Worth District projects has increased at approximately the same rate. A substantial part of this increase has resulted from filling or completion of additional reservoirs. However, the visitation figures are indicative of the increasing demand for water-based recreation. They point to the fact that this demand is far from being satisfied. In a recent analysis of these nine existing projects in the Fort Worth District, the ratio of visitors to the projects versus population within the affected areas indicated an average of five visits per person. However, since there are surrounding projects adjacent to the study area and some of these visitors will be drawn from the Edwards Underground area, it has been estimated that four visits per person would be a conservative estimate for purposes of this report. A projection of attendance based on this ratio of visits is shown on figure 1.

11. RECREATION PROJECTIONS FOR AREA OF INFLUENCE.- In projecting the demand for water-based recrration in the Edwards Underground Reservoir area, several factors were considered, including those cited in paragraphs 8 and 9. Cognizance was taken of the report published by Resources for the Future entitled, "The Crisis in Outdoor Recreation," and the report entitled, "Water Recreation Needs in the United States, 1960-2000," contained in Committee Print No. 17, 86th Congress, 2d Session. These reports indicate increases in outdoor recreation visitation of tenfold or more by the year 2000, of which 75 percent is estimated to be water-oriented. Studies indicate that the water-based recreation demand of the Edwards Reservoir area will not be satisfied, even though the projects recommended in this report are developed. This conclusion is based on the existing and projected population, the



CIVIL WORKS COMPLETED PROJECTS

YEAR	NO.
THRU 1952	21
1952	5
1954 - 1958	1
1959	1
1960 - 1961	1
TOTAL	29

MAY 1962

FIGURE 2

PUBLIC RECREATIONAL USE
RESERVOIR ATTENDANCE
SWD COMPLETED PROJECTS

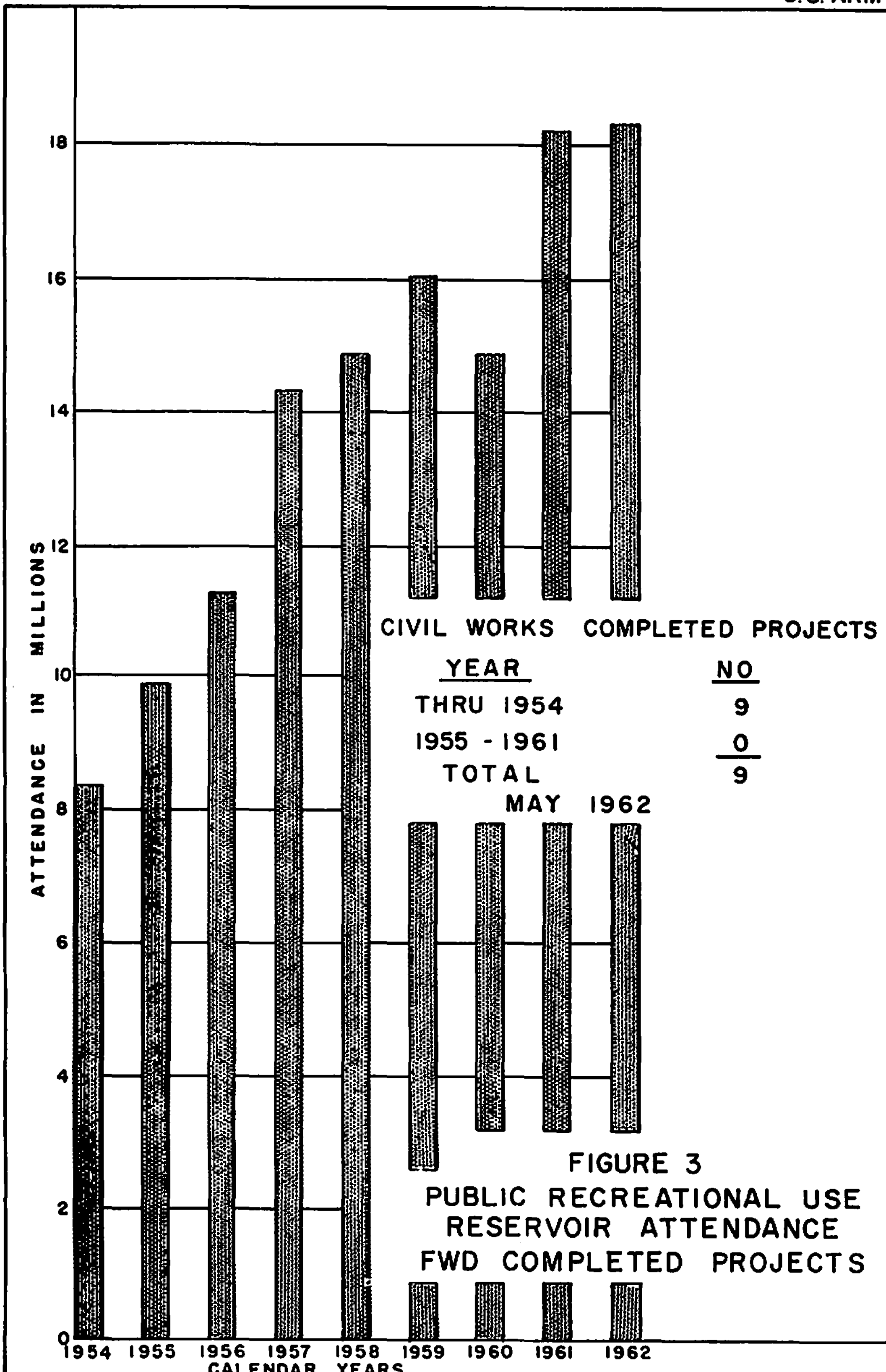


FIGURE 3
PUBLIC RECREATIONAL USE
RESERVOIR ATTENDANCE
FWD COMPLETED PROJECTS

number and locations of existing and recommended projects, and the anticipated dates of placing the projects in operation. Results of these studies and the projected demands are outlined below.

12. Also shown on figure 1 is the projected recreational capacity of the Edwards Underground area with respect to proposed recreational facilities presently existing and to be provided in the future. This projection shows that there is still considerable need for future recreational facilities and development in order to satisfy the recreation demands determined on the basis of either ORRRC projections or Corps of Engineers projections of four visits per person.

13. Canyon Reservoir has not been in operation for a sufficient period of time to obtain an actual annual visitation count. The best estimate available at this time is included in the project master plan which indicates that Canyon Reservoir would support an annual visitation of about 3,000,000 over the projected life of the project. If Cloptin Crossing Reservoir is constructed by the Corps of Engineers and Dam No. 7 Reservoir is constructed by local interests, they will supplement the recreational development of the surrounding area provided at the Canyon project, thus maintaining or possibly increasing the estimated attendance over the life of the project.

14. The existing Medina Reservoir is owned by the Bexar-Medina-Atascosa Counties Water Improvement District Number 1. Water from the project is used to irrigate lands within the district. The reservoir, at top of conservation pool elevation, has a surface area of 5,575 acres. Even though operation of the project for irrigation and leakage from the reservoir cause drastic fluctuation of the water level, the reservoir is used extensively for hunting and fishing. However, development around the perimeters of the reservoir for general recreation is rather limited because most of the land around the lake is leased to private concerns for cottage and camp sites. Visitation figures are not available for the project.

15. Garner State Park, located on the Frio River in the north portion of Uvalde County, is probably one of the best recreation areas for the general public in the Edwards Underground Reservoir area. This 640-acre park, owned and operated by the Texas Parks and Wildlife Commission, offers practically all types of recreational facilities for public use. A concrete low-water dam across the river forms a 10-acre lake in the park. This lake is a very popular place as a swimming beach during the summer months. From September 1961 through October 1962, there were 899,033 visitors at this park. It will be noted from plate 1, Plan of Improvement, that the recommended Concan Reservoir in its upper reaches will affect, to a small degree, some of the park development. Some relocation and protective works to existing facilities may be necessary.

16. The authorized Blieders Creek Reservoir is a local flood protection project for the city of New Braunfels, which will be constructed by the Corps of Engineers. Since all of the lands are being furnished by local interests and there will be no conservation storage in the reservoir, recreational development is not proposed for the project.

17. PROJECT VISITATION.- In estimating the number of annual recreation visits that would be made to the several reservoirs recommended for construction in this report, it has been assumed that the projects would be physically complete in 1975. It is estimated that visitation to the project sites included in the plan of improvement would be as follows:

VISITATION

Project site	Initial 1975	Average annual	Optimum annual visitation
Montell	100,000	150,000	200,000
Cloptin Crossing	1,000,000	1,900,000	2,300,000
Concan	10,000	20,000	30,000
Sabinal	10,000	20,000	30,000
Total	1,120,000	2,090,000	2,560,000

18. The unique recreational potential of two of the projects, namely, Concan and Sabinal Reservoirs, makes it difficult to estimate the future possibilities of these projects from the standpoint of visitation and recreational development. Even though these projects will have no water surface a considerable percent of the time, it is believed they will have an unusual attraction as recharge reservoirs. The Montell Reservoir will also serve essentially as a recharge project, but there will be a small conservation pool (260 acres) which will induce some limited water-related recreational development. Visitors will be able to see large quantities of floodwater being released from these reservoirs to disappear underground in the Edwards Outcrop area. During these periods, it is believed sightseers will visit the projects in considerable numbers and in future years this visitation will increase.

19. GENERAL RECREATION VS. FISH AND WILDLIFE.- Nine completed reservoirs in the Fort Worth District have a total water surface area of 88,550 acres and have surface areas ranging from 510 acres to 23,470 acres at the top of the conservation or power storage levels. Visitor attendance statistics compiled for these projects are as follows:

Year	Total recreation visitors (millions)	General recreation Visitors (millions)	General recreation Percent	Fish and wildlife recreation Visitors (millions)	Fish and wildlife recreation Percent
1957	14.4	9.8	68	4.6	32
1958	15.0	9.0	60	6.0	40
1959	16.0	9.5	59	6.5	41
1960	15.0	8.5	57	6.5	43
1961	18.3	12.0	66	6.3	34
1962	18.3	10.7	58	7.6	42
Average			61		39

20. From the data presented above, an average of 61 percent of the visitors participated in general recreation, picnicking, camping, etc., and 39 percent participated in fish and wildlife recreation activities such as sport fishing, hunting, etc. It is possible that fish and wildlife activities may be even greater in the Edwards Reservoir area since there is an abundant population of wild game. Many hunters will be attracted to the area. However, for the purpose of this report, it is assumed that 65 percent of the estimated visitors would participate in general recreation activities and 35 percent would participate in fish and wildlife recreation activities.

PLAN OF IMPROVEMENT

21. STUDIES.- Preliminary studies indicate that the recreation resources are sufficient to justify general recreation and fish and wildlife recreation as project purposes for one multiple-purpose reservoir project. It is also assumed that local interests will develop the recreation potential of the water conservation project recommended for construction by others in this report. Pertinent information relative to size, land requirements, and benefits of the recreational purposes in the proposed projects to be constructed by the Corps of Engineers are shown in table 1 and described in the following paragraphs.

TABLE 1

PERTINENT DATA - GENERAL RECREATION AND FISH AND WILDLIFE RECREATION

Project	Water surface area, acres	Recreation lands (including sport fishing & hunting), acres: Project purposes(1)	Public use and access	Total	Benefits
		Multiple-purpose projects			
Montell	260	-	100	100	$ 101,500
Cloptin Crossing	6,060	1,310	900	2,210	1,285,800
		Recharge projects			
Sabinal	0	-	10	10	13,500
Concan	0	-	10	10	13,500
Total	6,320	1,310	1,020	2,330	$1,414,300

(1) Joint use lands.

22. The location, size, and number of areas to be developed at each authorized project will be presented in a preliminary master plan. Additional details regarding the proposed development to provide for public recreation and the conservation and management of fish and wildlife will also be presented in a master plan for each project. Basic recreational facilities to be provided would include access roads, parking areas, public camping and picnicking areas, water supply, sanitary facilities, boat launching ramps, signs, essential safety devices, etc. Group picnic shelters, beach improvements for public swimming, including simple change houses, and boat anchorage areas would also be provided where such facilities are warranted. Additional facilities and services necessary or desirable for full development of the recreation potential will normally be provided through concessionaires and by permits to private organizations or individuals, or by leases to other Federal, State, and local governmental agencies.

23. MONTELL PROJECT.- The proposed Montell Dam will be located at about river mile 402 on the Nueces River, approximately 20 miles northwest of Uvalde, Texas. This multiple-purpose project (flood control, water conservation, and recreation) will be operated essentially as a recharge reservoir where floodwater will be held for short periods of time and then released underground. The flood

pool will be drawn down to a small permanent pool of 260 acres (conservation pool). Due to this drawdown, no recreational development is proposed in the reservoir area. However, in the vicinity of the dam, an area of about 50 acres is proposed for recreational development. This area will be of the observation type and will consist of picnic areas, parking areas, an access road to the water and a boat ramp. Access to the recreation area will be afforded by the road to be constructed to the dam. Another recreation area, consisting of about 50 acres, is proposed about 14 river miles downstream from the Montell Dam where the water goes underground. A low water channel dam will be constructed across the river in this area and water running over the dam will disappear underground. This recreation area will be essentially an observation type area and will consist of picnic areas, parking areas, observation points, and foot trails to the river. In addition to sightseers, there will be fishermen along the river, since constant releases will assure perennial streamflow. Access to this recreation area will be provided by State Highway No. 55, which crosses the Nueces River in the vicinity of the proposed development.

24. Based on existing and projected population for this area and the number of visitors that existing projects have attracted, it is estimated that the proposed Montell Reservoir project would attract an initial visitation of about 100,000 visitors. The project would eventually attract a total of 200,000 visitors, or an average of about 150,000 visitors annually over the period 1975-2075. The total lands required for public use and access are estimated to be about 200 acres. Of this amount, 100 acres would be acquired under the 1962 joint land acquisition policy for project purposes. The estimated costs for lands, clearing, and facilities in the interest of public use are shown in table 2.

25. CLOPTIN CROSSING PROJECT.- The Cloptin Crossing Dam will be located at about river mile 33 on the Blanco River approximately 11 miles northwest of San Marcos, Texas. The impounded water would cover 6,060 acres at the top of the conservation pool. Full development of basic recreation facilities would be accomplished at this project. These facilities would include roads, parking areas, boat launching ramps, sanitary facilities, potable water supplies, public camping and picnic areas, and essential safety measures required in connection with such facilities. Based on existing and projected populations for this area and the number of visitors that existing projects have attracted, it is estimated that the proposed Cloptin Crossing Reservoir project would attract an initial visitation of about 1,000,000 visitors. The project would eventually attract a total of about 2,300,000 visitors, or an average of approximately 1,900,000 visitors annually over the period 1975-2075. The total lands required for public use and access are estimated to be

2,210 acres. Of this amount, 1,310 acres would be acquired under the 1962 joint land acquisition policy for project purposes. The remainder, consisting of 900 acres, would be acquired for public use and access. The estimated costs for lands, clearing, and facilities in the interest of public use are shown in table 2.

26. CONCAN PROJECT.- The proposed Concan Dam will be located at about river mile 226 on the Frio River about a mile north of Concan, Texas. This project will be operated as a flood-control and recharge reservoir. Although no permanent pool will be maintained at the Concan project, recreation development has been included as part of the project plans. The Frio River is a perennial stream and will have flow most of the time, except in periods of severe drought. However, the recreation potential of the project will be enhanced when large quantities of floodwater are stored in the reservoir for sufficient periods of time. The release of these floodwaters to recharge the underground reservoir will provide a scenic attraction for sightseers. A recreation area of about 10 acres is proposed in this vicinity. This recreation area will be essentially an observation type area and will consist of picnic areas, a parking area, observation points, and foot trails to the river below the dam. Access to the area will be afforded by the road to be constructed to the dam.

27. Based on existing and projected population for this area and the number of visitors that existing projects have attracted, it is estimated that the proposed Concan Reservoir project would attract an initial visitation of about 10,000 visitors. It is estimated that the project would eventually attract a total of 30,000 visitors, or an average of about 20,000 visitors annually over the period of 1975-2075. The total additional lands required for one public use area are estimated to be 10 acres. All this land would be acquired for public use. The estimated costs for lands, clearing, and facilities in the interest of public use are shown in table 2.

28. SABINAL PROJECT.- The proposed Sabinal Dam will be located at about river mile 42 on the Sabinal River in the northeast portion of Uvalde County, Texas. This project will be operated as a flood-control and recharge reservoir. Although no permanent pool will be maintained at the Sabinal project, recreation development has been included as part of the project plans. The Sabinal River will have no flow at the dam site approximately 25 percent of the time. Nevertheless, the project will have a recreation potential since large quantities of floodwater will be stored in the reservoir for sufficient periods of time to permit recreational use. The release of these floodwaters to recharge the underground reservoir will provide a scenic attraction for sightseers. A recreation area, consisting of about 10 acres, is proposed in the vicinity of the dam. This recreation area will be essentially an observation type area and

TABLE 2

ESTIMATED COST OF LANDS AND FACILITIES FOR PUBLIC USE AND ACCESS

Project	Lands (1) Public use and access		Clearing (1)		Facilities (2)			Total
					Initial Dev. (3)	Future Development	Optimum Development	
	Acres	Cost	Acres	Cost	Cost	Cost	Cost	
				Multiple-purpose projects				
Montell	100	$ 26,000	250	$ 25,000	$ 224,000	-	$ 224,000	$ 275,000
Cloptin Crossing	900	210,000	2,420	111,300	977,500	$1,078,000	2,055,500	2,376,800
				Recharge projects				
Sabinal	10	3,000	30	3,000	57,000	-	57,000	63,000
Concan	10	3,000	30	3,000	57,000	-	57,000	63,000
Total	1,020	$242,000	2,730	$142,300	$1,315,500	$1,078,000	$2,393,500	$2,777,800

(1) Separable cost over and above flood-control and water conservation project requirements.
(2) Does not include engineering and design or supervision and administration costs.
(3) Includes cost of access roads.

will consist of picnic areas, a parking area, observation points, and foot trails to the river below the dam. Access to the area will be afforded by the road to be constructed to the dam.

29. Based on existing and projected population for this area and the number of visitors that existing projects have attracted, it is estimated that the proposed Sabinal Reservoir project would attract an initial visitation of about 10,000 visitors. It is estimated that the project would eventually attract a total of 30,000 visitors, or an average of about 20,000 visitors annually over the period 1975-2075. The total additional lands required for one public use area are estimated to be 10 acres. All of this land would be acquired for public use. The estimated costs for lands, clearing, and facilities in the interest of public use are shown in table 2.

30. DAM NO. 7 PROJECT.- The recommended Dam No. 7 Dam will be located at about river mile 351 on the Guadalupe River in Kendall County, Texas. As stated in the latter part of paragraph 6 of this appendix, this project is recommended for construction by local interests and no credit for any recreational development has been shown in this appendix. Projections in figure 1 show a definite need for recreational development of this project when comparing the projected recreation demand to the capacity of projected recreational development in the area. It has further been determined that if local interests would develop the full recreational potential of this project, a recreation benefit of over $2,800,000 could be realized.

31. ECONOMIC BENEFITS OF RECREATION.- In computing the economic benefits resulting from the development of the recreation resources of the four reservoir projects recommended for construction by the Corps of Engineers in this report, reference is made to the following directive: Multiple letter, ENGCW-PM, dated 16 July 1964, subject: "Supplement No. 1 to Senate Document No. 97, 87th Congress, 2d Session: 'Evaluation Standards for Primary Outdoor Recreation Benefits'."

32. Records of attendance at Corps of Engineers projects in the Fort Worth District were related to the population totals in adjoining areas. Using this indicator and population estimates developed in the economic base study, an estimate was made of the potential demand for water-related recreational activities at proposed reservoir sites in this report. Benefits for recreation were estimated on the basis of a constant unit value of increased annual attendance at the project locality. Average annual attendance at each of the proposed reservoirs was estimated as shown in paragraph 16 above. Since the visitation figure includes sightseers, for which a

lesser unit value would result, it has been determined that a unit value of $0.50 is reasonable for general recreation. Therefore, a unit value of $0.50 per visitor-day was used for a variety of recreational activities, including picnicking, swimming, boating, sightseeing, camping, and other outdoor pursuits, a total of $679,200. Recreational benefits for fisherman's catch and hunter's bag were computed on the basis that 35 percent of the total visitation would be for the purpose of fishing and hunting, 34.65 percent of the total visitation is for the purpose of fishing, and 0.35 percent of the total visitation is for the purpose of hunting. It was estimated that the unit value for fishing should be $1.00 per visit and that the unit value for hunting should be $1.50, resulting in a total benefit for sport fishing and hunting of $735,100. The total recreational benefits are estimated at $1,414,300, as shown in table 1.

33. Using criteria for consideration of recreation alternatives in project formulation contained in Supplement No. 1 to Senate Document No. 97, it was determined that there is no alternative for water-related recreation that is economically feasible when evaluated on a basis comparable to that provided by the Edwards Underground project.

34. While values used indicate substantial benefits from recreational aspects of the project, they are considered most conservative and in many ways do not indicate fully the economic import of recreation and related activities associated with large water resource projects. Recreation invariably improves the local economy, the degree depending primarily on the recreation demand of the area and the quality of recreation facilities afforded.

35. Records and studies in connection with existing projects in the Southwestern Division show that counties in which large reservoirs are wholly or partially located have a notably better economy than those counties which do not have any large reservoirs. Population, per capita income, wages, retail trade, and bank deposits show a marked increase. There are many reasons for this rise in the general economy of the influenced area. Of basic importance is the fact that each reservoir project provides new opportunities for capital to be profitably used in the development of businesses associated with recreation, thereby putting capital to work in an economically productive manner.

36. Recreation associated with major water resource projects attracts outside dollars and investment in the area affected in a number of ways. Particularly significant are the following:

a. Recreation attracts visitors who in the aggregate spend large sums at lakeshore resorts and service establishments.

b. Recreational visitation induces private investors to finance or develop overnight accommodations, marinas, and many other recreation-related sales and service facilities. The Corps of Engineers encourages location of needed service facilities on Federal lands and waters by concession agreements and special use permits.

c. Recreational aspects of projects attract many newcomers to the reservoir area who construct homes and cabins for themselves as near the shoreline as possible.

d. Industry is attracted to the general area because of the recreation climate afforded its employees, even though the industry itself may not be a heavy water user.

COORDINATION WITH OTHER FEDERAL AGENCIES

37. U. S. FISH AND WILDLIFE SERVICE.- The U. S. Fish and Wildlife Service was furnished data and information applicable to the proposed plan of improvement for the Edwards Reservoir area. The Service was requested to prepare a report on the fish and wildlife aspects relative to the developments proposed by the Corps of Engineers. The Service's report is presented as an attachment to this appendix. The report contains several recommendations with regard to the development of the fish and wildlife resources of the Edwards Reservoir area.

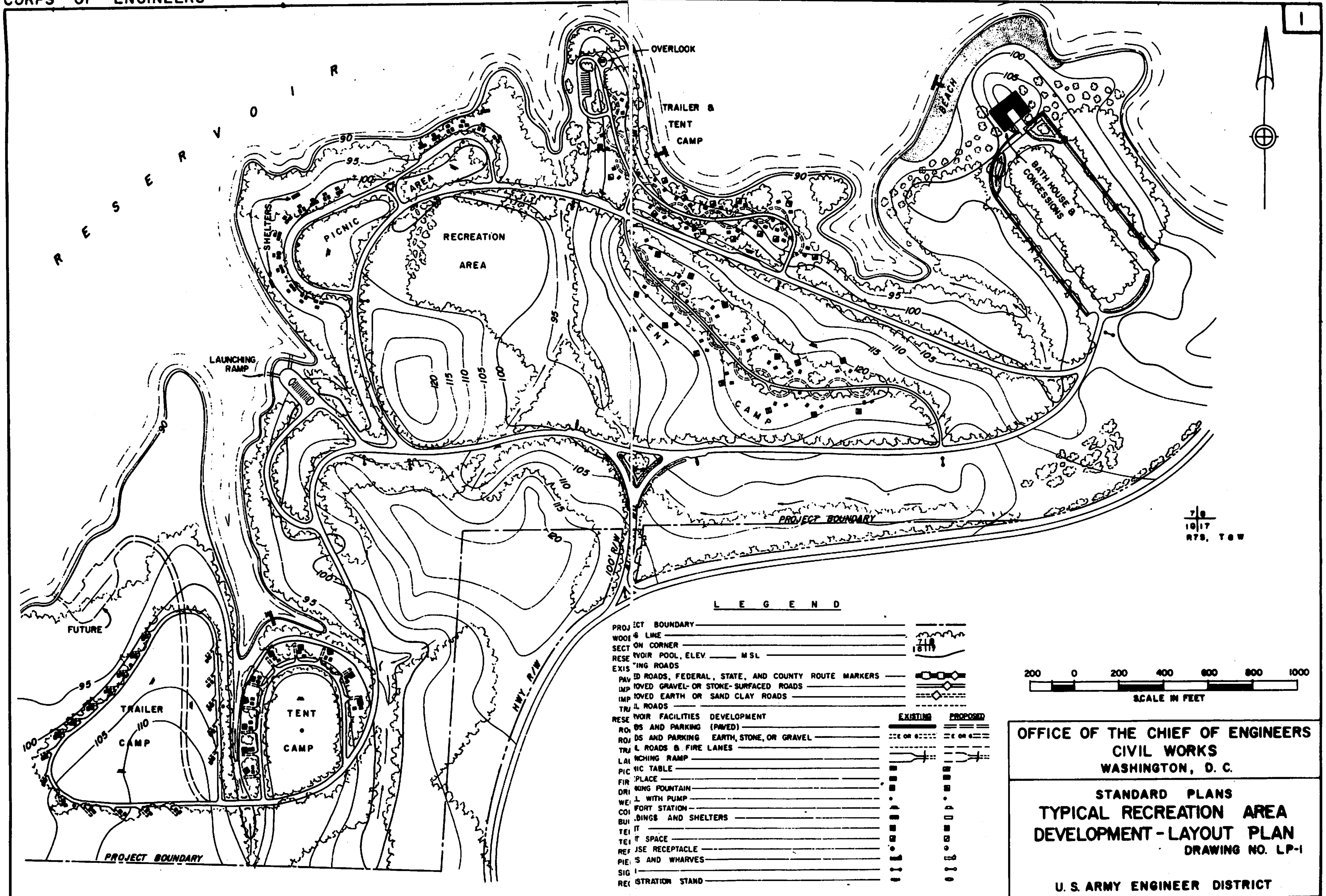
38. NATIONAL PARK SERVICE.- This report has been furnished to the National Park Service for review and their comments are included in the report.

39. TYPICAL LAYOUTS.- The preliminary studies were based on providing necessary facilities required for access and internal roads, picnicking, camping, sanitary facilities, potable water supplies, parking areas, boat launching ramps, play areas, etc. The recreation facilities would be generally as shown on the typical layout for reservoir projects, plate 2.

CONCLUSIONS

40. The existing and projected effective population and resulting recreation needs within the Edwards Reservoir area and surrounding area of influence have been determined and consideration has been given to fulfilling these requirements in the development of the plan of improvement. Analysis of the proposed multiple-purpose projects, which include recreational facilities to meet requirements for the average annual visitation, indicate that the proposed projects are fully justified from an economic standpoint.

41. Satisfaction of the ultimate outdoor recreation requirements in the Edwards Reservoir area would come from supplementary development of needed facilities by the State and local governmental agencies. Also, private enterprise should construct additional water resource facilities in the vicinity of the projects recommended in this report.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RESERVOIR
OVERLOOK
TRAILER & TENT CAMP
BEACH
BATH HOUSE & CONCESSIONS
SHELTERS
PICNIC AREA
RECREATION AREA
LAUNCHING RAMP
TENT CAMP
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CIVIL WORKS
WASHINGTON, D. C.
STANDARD PLANS
TYPICAL RECREATION AREA
DEVELOPMENT - LAYOUT PLAN
DRAWING NO. LP-1
U. S. ARMY ENGINEER DISTRICT

ATTACHMENT

REPORT BY
BUREAU OF SPORT FISHERIES AND WILDLIFE
FISH AND WILDLIFE SERVICE
U. S. DEPARTMENT OF THE INTERIOR

UNITED STATES
DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF SPORT FISHERIES AND WILDLIFE
POST OFFICE BOX 1306
ALBUQUERQUE, NEW MEXICO 87103

February 3, 1965

District Engineer
Corps of Engineers, U. S. Army
P.O. Box 1600
Fort Worth, Texas

Dear Sir:

The Bureau of Sport Fisheries and Wildlife presents herein a report on the fish and wildlife resources to be affected by the Corps of Engineers' Edwards Underground Reservoir Project, Guadalupe, San Antonio, and Nueces Rivers and Tributaries, Texas. This report reflects a 100-year period of analysis from 1975 to 2075 and is intended to accompany the Corps of Engineers survey report. Prepared under the authority and in accordance with the provisions of the Fish and Wildlife Coordination Act (48 Stat. 401, as amended; 16 U.S.C. 661 et seq.), this report has been coordinated with the Bureau of Commercial Fisheries and has received concurrence from the Texas Parks and Wildlife Department, as indicated by the enclosed copy of a letter from Mr. J. Weldon Watson, Executive Director, dated January 13, 1965.

The Edwards Underground Reservoir Project investigation was authorized by Section 209 of Public Law 86-645, approved July 14, 1960, as a cooperative study with the State of Texas. The purpose of the project is to recharge and replenish the Edwards Underground Reservoir as part of a plan to provide for flood control, water conservation storage for municipal, industrial, and irrigation uses, recreation, and fish and wildlife.

The project is located in the upper portions of the Nueces, San Antonio, and Guadalupe River Basins in the Edwards Plateau section of the Great Plains Physiographic Province. The project will influence a portion of the West Gulf Coastal Plains section of the Coastal Plain Physiographic Province within the Nueces River Basin.

The project area is characterized by rolling to broken, greatly dissected terrain. It has rugged hills and narrow, deep valleys and is sharply accentuated at the southern and eastern edge by steep hills terminating in limestone bluffs known as the Balcones Escarpment, the "upthrown" or upper portion of the Edwards and associated limestones in the Balcones Fault Zone. Downstream from the escarpment, the terrain comprises rolling hills and broad plains, changing to flat prairie near the coast.

Streams above the Balcones Escarpment are typically spring-fed, gravel-bottomed, and generally clear. Several small channel dams have been constructed on these stream reaches. Downstream from the escarpment, the streams are characteristically sluggish, silt laden, and turbid.

Most of the flows of the Nueces, Frio, and Sabinal Rivers are lost at the fault zone to the underground aquifer as the streams cross the outcrop of the Edwards limestone in the Balcones Fault Zone. Some flows reappear in downstream reaches of these streams below the fault zone.

The Frio River at the Concan Gage has had an average annual discharge of 98 second-feet over a 38-year period of record (1924-29 and 1930-63). The maximum flow was 162,000 second-feet. No flows were recorded from August 5, 1956, to January 6, 1957.

The average annual discharge of the Sabinal River at a gage located 12 miles north of Sabinal was 36 second-feet for a 21-year period of record (1942-63). The maximum discharge was 55,200 second-feet. Zero flows were recorded many times.

The average annual discharge of the Blanco River at the Wimberly Gage was 111 second-feet for a 37-year period of record (1924-26 and 1928-63). The maximum flow was 113,000 second-feet, and the minimum flow was 0.6 second-feet.

The average annual discharge of the Nueces River at the Laguna Gage was 137 second-feet for a 40-year period of record (1923-63). The maximum discharge was 307,000 second-feet. The minimum flow was 2.6 second-feet.

Native grasses, various shrubs, and scrubby trees are the predominant vegetation of the project area. Cypress, pecan, and oak trees line many of the perennially flowing streams. Oak, juniper, and mesquite form the most common brush overstory. Huisache, blackbrush, and other shrubs are common below the Balcones Escarpment.

The economy of the area depends primarily upon cattle, goat, and sheep ranching. This is one of the nation's leading Angora goat-producing regions. Tourist trade, deer and turkey hunting, and other recreational activities associated with fishing and hunting bolster the area's economy.

Garner, Blanco, Frio, and Kerrville State Parks; Ingram, Medina and San Marcos State Fish Hatcheries; and the Kerr State Wildlife Management Area are located in the project area. National fish hatcheries are located at San Marcos and Uvalde, Texas.

Montell, Concan, and Sabinal reservoir sites are located in a sparsely populated area, but they are within day-use distance of the densely populated San Antonio area. Cloptin Crossing Reservoir, however, will be located near the City of San Marcos about midway between the cities of Austin and San Antonio. About 1,150,000 people resided within a 60-mile radius of the proposed sites in 1960. The population is expected to increase to about 3,900,000 by the year 2020. Two-thirds of this population will live in the metropolitan San Antonio area.

The proposed plan of development includes the construction of Montell, Concan, and Sabinal Reservoirs in the upper Nueces River Basin; Cloptin Crossing Reservoir in the upper Guadalupe River Basin; a 6-foot-high channel dam at about river mile 387.0 on the Nueces River; and a 8.5-mile-long, 24-inch-diameter pipeline from the channel dam across the outcrop of the Edwards limestone in the Balcones Fault, terminating at river mile 376.5 on the Nueces River. Principal project features are shown on Plate 1.

Montell Dam will form a multiple-purpose reservoir on the Nueces River in Uvalde County about 25 miles northwest of Uvalde, Texas. The reservoir will provide a total storage capacity of 252,300 acre-feet, of which 239,300 acre-feet will be for joint-use for flood control and recharge purposes; 1,000 acre-feet for conservation storage for a downstream water supply; and 12,000 acre-feet for sediment storage. The reservoir will have a surface area of 260 acres and a capacity of 2,200 acre-feet at conservation pool elevation 1,237 feet. About 800 acres of land will be purchased in fee title, and flowage easement will be taken on an additional 6,140 acres to guide taking line elevation 1,336 feet. The dam will be at river mile 401.6 on the Nueces River.

Concan Reservoir will be a detention-type structure on the Frio River in Uvalde County about 22 miles northeast of Uvalde, Texas. The reservoir will provide a storage capacity of 149,000 acre-feet, About 141,200 acre-feet will be for joint-use for flood control and recharge purposes and 7,800 acre-feet for sediment reserve. About 400 acres of land will be purchased in fee title, and flowage easement will be taken on an additional 3,960 acres of land to the guide taking line elevation 1,371.5 feet. The dam will be at river mile 226.2 on the Frio River.

Sabinal Reservoir also will be a detention-type structure located on the Sabinal River in Uvalde County about 10 miles north of Sabinal, Texas. This reservoir will have a storage capacity of 93,300 acre-feet, of which 89,100 acre-feet will be for joint-use for flood control and recharge purposes and 4,200 acre-feet for sediment reserve. About 400 acres of land will be purchased in fee title, and flowage easement will be taken on an additional 3,000 acres to the guide taking line elevation 1,229.5 feet. The dam will be at river mile 42.3 on the Sabinal River.

Cloptin Crossing Dam will form a multiple-purpose reservoir on the Blanco River in Hays and Comal Counties about 15 miles northwest of San Marcos, Texas. The reservoir will provide a total storage capacity of 404,000 acre-feet. Approximately 119,900 acre-feet will be for flood control, 274,900 acre-feet for conservation storage, and 9,200 acre-feet for sediment storage. The reservoir will have a surface area of 6,060 acres at conservation pool elevation 980.5 feet. About 10,600 acres of land will be purchased in fee title. The dam will be at river mile 32.5 on the Blanco River.

All storage dams will be of rock and earth-fill construction. Sabinal Dam will have a gated channel spillway controlled by six 40-foot by 30-foot tainter gates. The other storage dams will have uncontrolled broad-crested spillways. The outlet works will consist of gate-controlled conduits with inverts at elevation 855 feet in Cloptin Crossing Dam, elevation 1,216 feet in Montell Dam, and elevation 1,240 feet in Concan Dam. The outlet works at Sabinal Dam will consist of gate-controlled sluices with invert elevation 1,130 feet.

Water from the conservation storage of Montell Reservoir will be released into the Nueces River at a constant rate of at least 6 second-feet. This release will be made to meet downstream water demands in the vicinity of La Pryor, Texas. About 14.0 miles downstream from the dam, a 6-foot-high channel dam will divert the water into a 8.5-mile-long pipeline which will carry it across the Edwards outcrop in the Balcones Fault Zone to the Nueces River at river mile 376.5.

Floodflows that enter Montell Reservoir will be released into the Nueces River, where those in excess of 6 second-feet will pass over the channel dam and percolate into the outcrop of the Balcones Fault Zone aquifer at a point immediately downstream from the channel dam. Water will flow over the channel dam about 99 percent of the time. Maximum intake capacity of the fault zone in this area is about 1,000 second-feet.

No conservation storage will be provided in Concan or Sabinal Reservoirs. Low flows of the Frio and Sabinal Rivers will be passed on through the dams; consequently, the reservoirs will be dry most of the time. Floodwaters entrapped by these reservoirs will be released consistent with downstream conditions in the Frio and Sabinal Rivers at a rate equal to the maximum intake capacity of the Edwards outcrop in the Balcones Fault Zone. Maximum intake capacities of the outcrop in this area are about 750 second-feet below Concan Reservoir and 500 second-feet below Sabinal Reservoir.

No definite plan of operation has been developed for the conservation storage in Cloptin Crossing Reservoir. Water may be pumped from the reservoir, or it may be released into the stream to be diverted at some downstream point. The water will be used for municipal, industrial, and irrigation purposes.

FISH

Without the Project

Portions of the Nueces, Blanco, Frio, and Sabinal Rivers will be inundated or temporarily flooded by Montell, Cloptin Crossing, Concan, and Sabinal Reservoirs, respectively. Also influenced by the project will be the downstream reaches of the Nueces River to the vicinity of the town of La Pryor, the Blanco River to its mouth, and the Frio and Sabinal Rivers to the Balcones Fault Zone.

Project streams are clear-flowing during years of normal rainfall but are interspersed with intermittent pools and riffles during years of drought. Sharp-crested floods of short duration scour streambeds of fauna and flora and leave behind extensive deposits of silt. The Balcones Fault Zone, by dewatering the streams, acts as a natural barrier precluding upstream fish migrations on the Nueces, Frio, and Sabinal Rivers except during times of flood.

Within the project's area of influence, good quality fish habitat occurs in about 46 miles of the Blanco River and 14 miles of the Frio River. Good to mediocre fish habitat is present in about 60 miles of the Nueces River. Excess aquatic vegetation and low flows result in poor quality fish habitat in about 10 miles of the Sabinal River.

Principal stream-fish species are channel catfish, flathead catfish, largemouth bass, warmouth, bluegill, green and longear sunfish, longnose gar, Mexican tetra, Rio Grande perch, blacktail shiner, river carpsucker, yellow bullhead, and black bullhead. Sunfishes, bass, and catfishes inhabit the shallower stream areas, while gars and carpsuckers frequent the deeper pools. Nongame fishes predominate in the Nueces River below the fault zone. Casting, still fishing, fly fishing, and trotlining are the principal methods of fishing.

Public access to the project streams is limited by rugged terrain and restrictions by landowners. Most of the fishing occurs at road crossings, resort camps, and channel impoundments along the rivers.

Projected over the period of analysis without the project, sport fishing would amount to 2,800 man-days annually on the Blanco River; 5,200 man-days annually on the Nueces River; 4,200 man-days annually on the Frio River; and 400 man-days annually on the Sabinal River. Of this use, about 2,100 man-days on the Blanco River; 3,900 man-days on the Nueces River; 1,800 man-days on the Frio River; and 100 man-days on the Sabinal River would occur downstream from the damsites.

No commercial fishing of importance occurs in the streams within the area of influence.

With the Project

Project developments will inundate 13.5 miles of the Blanco River and 1.5 miles of the Nueces River at conservation pool elevation. Temporary flooding and resultant deposition of sediment will affect an additional 7.0 miles of the Nueces River, 8.0 miles of the Frio River, 7.0 miles of the Sabinal River and less than one-half mile of the Blanco River.

Cloptin Crossing and Montell Reservoirs will be clear, attractive impoundments which will provide high quality fish habitat, primarily for largemouth bass, catfishes, white crappies, other sunfishes, carp, river carpsuckers, and gizzard shad.

Although sport-fishing demands will be partially satisfied by the existing nearby Canyon and Medina Reservoirs, and by streams and farm ponds, Cloptin Crossing and Montell Reservoirs will be fished heavily. Located in beautiful valleys flanked by scenic terrain, these reservoirs will attract large numbers of visitors, many of whom will fish. Projected over the period of analysis with the project, sport fishing will amount to 200,000 man-days annually in Cloptin Crossing Reservoir and 30,000 man-days annually in Montell Reservoir.

The productivity of the Blanco River downstream from Cloptin Crossing Reservoir will depend upon the amount, duration, and frequency of water releases from the reservoir. Occasional flood spills and discharges from tributary streams will maintain some water in channel pools, but flows will not be sufficient to maintain good quality fish habitat. The Blanco River will support about 1,200 man-days of fishing annually with the project.

Operation of Montell Reservoir to provide a 6 second-foot release of water into the Nueces River will improve about 41 miles of fish habitat in the Nueces River to the vicinity of La Pryor, Texas. Fish habitat in the 11 miles of the river bypassed by the pipeline will not be changed significantly. Flood flows and sediment entrapped by the reservoir will reduce sediment deposits downstream and will stabilize the streambanks. About 15,300 man-days of fishing annually will occur in the Nueces River downstream from Montell Reservoir.

Lack of conservation storage will preclude any significant development of fish habitat in Concan and Sabinal Reservoirs. Within the reservoir areas, fish habitat will be reduced in quality on the Frio and Sabinal Rivers by deposition of sediment.

Sport fishing will be insignificant in the Sabinal River in the Sabinal Reservoir area. There will be about 2,000 man-days of sport fishing annually in the Frio River in the Concan Reservoir area.

Fish habitat will improve in the Frio River downstream from Concan Reservoir to the fault zone. Sport fishing will amount to 2,100 man-days annually on this stream reach. Dense growths of aquatic vegetation are expected to occupy most of the water areas downstream from Sabinal Reservoir to the fault zone. As a result, sport fishing will be insignificant in the Sabinal River downstream from Sabinal Reservoir.

It is possible that a commercial fishery may develop in Cloptin Crossing and Montell Reservoirs. Development of such a fishery depends upon local regulations, future demands for new food sources, and future advances in the technology of catching, processing, and marketing potentially valuable commercial fish. It is not possible to present a monetary evaluation of commercial fishing at this time. There will be no commercial fishing of importance in the rivers downstream from the reservoirs.

Project construction and operation will result in a gain of 8,000 man-days of stream fishing and 230,000 man-days of reservoir fishing annually. Sport fishing benefits attributable to the project will be $238,000 annually.

Table 1 presents a summary of sport fishing on project streams and reservoirs.

Table 1. Summary of Sport Fishing in Man-days Annually

Area	Without the Project	With the Project	Gain or Loss
Blanco River	2,800	1,200	-1,600
Cloptin Crossing Reservoir	0	200,000	200,000
Nueces River	5,200	15,300	10,100
Montell Reservoir	0	30,000	30,000
Frio River	4,200	4,100	-100
Concan Reservoir	0	0	0
Sabinal River	400	0	-400
Sabinal Reservoir	0	0	0

WILDLIFE

The total acreage within the area of project influence for wildlife amounts to about 47,580 acres. This consists of 24,480 acres within the reservoir sites and 23,100 acres in the Nueces River floodplain. Wildlife habitat on the floodplains of the Blanco River, Sabinal River, and Frio River downstream from the damsites will not be affected significantly.

Without the Project

The project area contains some of the most important wildlife habitat in Texas, especially for white-tailed deer, wild turkeys, raccoons, and ring-tailed cats. Other wildlife found within the project area includes mourning doves, skunks, opossums, fox squirrels, gray foxes, rabbits, and collared peccaries. Several exotic species of wildlife, such as the European boar, black buck antelope, axis deer, Barbary sheep (aoudad), and mouflon sheep, have been introduced in the project area.

Most of the hunting is for deer, turkeys, and doves. Leasing of deer-hunting rights, which cost about $100 per gun per season and usually includes turkey-hunting privileges, constitutes a major source of ranch income.

White-tailed deer and collared peccary are the only big-game species present in the project area. Peccary populations are low and would be expected to remain so, due to habitat destruction through brush-clearing operations. Deer populations presently exceed the carrying capacity of the habitat; however, it is anticipated that they would be reduced by careful management.

Projected analysis without the project indicates that big-game hunting would amount to 14,600 man-days annually. About 9,100 man-days of hunting would occur in the reservoir areas; and 5,500 man-days in the floodplain of the Nueces River downstream from Montell Reservoir.

Most of the upland-game hunting is for wild turkeys and mourning doves. Peak populations of wild turkeys occur in the fall and winter, when the turkeys roost in stands of cypress, oak, and pecan trees bordering many of the river-bottom streams. Turkey populations have been declining in the Edwards Plateau for several years due to brush clearing and overgrazing. Their populations could be expected to remain low during the period of analysis.

Populations of mourning doves are low in the Montell, Sabinal, and Concan Reservoir areas and in the floodplain downstream from Montell Reservoir. They are high in the Cloptin Crossing Reservoir area where they receive heavy hunting.

Projected analysis without the project indicates that upland-game hunting would amount to 8,600 man-days annually, of which 7,200 man-days would occur in the reservoir areas and 1,400 man-days in the floodplain downstream from Montell Reservoir.

Fur trapping in the project area is insignificant and would continue to be so due to low pelt values. Local ranchers and sportsmen, however, hunt raccoons and ring-tailed cats for sport. Sport hunting of fur animals would amount to about 1,300 man-days annually without the project.

A few mallards, pintails, blue-winged teals, green-winged teals, and coots occur in the project area, but there is little hunting for them. No change in waterfowl use or hunting could be expected over the period of analysis.

With the Project

Project development will affect wildlife habitat and resources on 47,580 acres of land through dam construction, periodic and prolonged inundation, flood prevention, and human disturbance and developments associated with reservoir use.

Loss of bottomland habitat through inundation by the reservoirs and by clearing for added cultivation downstream from Montell Reservoir will result in losses to big-game and upland-game populations and associated hunting.

Project analysis indicates that big-game hunting will amount to 7,900 man-days annually, of which 2,900 man-days will occur in the reservoir areas and 5,000 man-days in the floodplain of the Nueces River downstream from Montell Reservoir.

Upland-game hunting will amount to 3,400 man-days annually. About 2,200 man-days will occur in the reservoir areas and 1,200 man-days in the Nueces River floodplain downstream from Montell Reservoir.

Fur trapping will remain insignificant during the period of analysis with the project. Sport hunting for fur animals will amount to about 900 man-days annually.

Waterfowl populations will remain low in the project area. A few ducks and coots will use the Cloptin Crossing and Montell Reservoirs during periods of migration, but no significant hunting will take place.

In summary, the project will affect wildlife populations and hunting in the proposed reservoir areas and in the Nueces River floodplain downstream from Montell Reservoir. There will be a loss of 6,700 man-days annually of big-game hunting, 5,200 man-days annually of upland-game hunting, and 400 man-days annually of sport hunting for fur animals. The project's effect on waterfowl hunting and fur-animal trapping will be insignificant. Table 2 presents a summary of man-days of hunting without and with the project.

Table 2. Summary of Hunting in Man-days Annually

Area	Without the Project	With the Project	Gain or Loss
Cloptin Crossing Reservoir			
Big game	4,300	0	-4,300
Upland game	4,800	500	-4,300
Fur animals (sport hunting)	400	100	-300
Montell Reservoir			
Big game	2,100	900	-1,200
Upland game	600	300	-300
Fur animals (sport hunting)	300	300	0
Downstream floodplain			
Big game	5,500	5,000	-500
Upland game	1,400	1,200	-200
Fur animals (sport hunting)	200	100	-100
Concan Reservoir			
Big game	1,100	800	-300
Upland game	1,000	800	-200
Fur animals (sport hunting)	200	200	0
Sabinal Reservoir			
Big game	1,600	1,200	-400
Upland game	800	600	-200
Fur animals (sport hunting)	200	200	0

DISCUSSION

To assure adequate management for fishing, seining areas should be provided in Montell and Cloptin Crossing Reservoirs. These areas should be about 1,000 feet wide and should extend from the stream channel to the top of conservation pool elevation. They should be cleared of all obstructions. Such areas would assist the Texas Parks and Wildlife Department in managing the fisheries of the reservoirs by providing seining sites where the Department could determine abundance, composition, and distribution of fish. These areas also would assist commercial fishermen in their operations should commercial fishing become practical.

The number and location of seining areas will be made known to the Corps of Engineers by the Texas Parks and Wildlife Department during the planning stage of project development. Costs for clearing of the required seining areas would be minimal.

The sites of Montell and Cloptin Crossing Reservoirs contain moderate to dense growths of timber. These timber areas could serve as fish attractors and as shelter for boat fishermen and hunters. Except for that clearing required for seining areas, boat lanes, safety, and efficient operation of the reservoirs, timber clearing should be kept to a minimum.

Clearing of boat lanes through the timbered areas of Cloptin Crossing Reservoir will be required to provide adequate access for fishing. These lanes should be 20 feet wide and should extend from the inundated streams to the headwaters in each major cove. Lateral lanes, 10 feet wide and extending from each of the main 20-foot-wide boat lanes, should be cleared from the main lanes to shore. The lateral lanes should be spaced 100 feet apart on alternate sides of the main boat lanes.

To facilitate access for hunters and fishermen to project land and water areas, adequate parking areas should be provided around the perimeter of the conservation pools at Cloptin Crossing Reservoir and at Montell Reservoir. A parking area also should be provided at the tailwater immediately downstream from Montell Dam. It is assumed that the project will provide adequate public access areas at the two reservoirs.

Public access and parking, sanitary, and drinking-water facilities also should be provided to the proposed channel dam located on the Nueces River about 14 miles downstream from Montell Dam. The parking area should cover two surface acres and should be cleared of all obstructions and graveled. It should be served by an all-weather road. Approximately 10,000 man-days of sport fishing annually would occur from these developments resulting in additional fishing benefits of $10,000 per year.

High quality fish habitat will be affected by Cloptin Crossing Dam and Reservoir when Blanco River flows are entirely curtailed downstream from the dam. The loss of this habitat could be prevented if a constant flow of water were released into the stream. The provision of a minimum instantaneous release of at least 10 second-feet not only would prevent the deterioration of stream fish habitat but would provide attractive tail water fish habitat thereby enhancing fishing. In addition to mitigating the loss of 1,600 man-days of stream fishing, approximately 25,000 man-days of fishing annually would be realized from this release. Additional benefits of $25,000 annually would be associated with this release.

Cloptin Crossing and Montell Reservoirs will be located in a scenic part of the State where many people go for relaxation and enjoyment. The reservoirs will add charm to the scenic surroundings and will receive heavy use by recreationists, primarily fishermen, speedboaters, and waterskiers. Unless these reservoirs are zoned, conflicting use will occur, the reservoirs will be unsafe for boat fishing, and optimum fishing will not be possible.

Establishment of zoned areas in Cloptin Crossing Reservoir, where fishermen would be able to fish in safety, would increase fishing and provide additional benefits. Until details of a zoning plan are worked out and accepted, however, it is not possible to estimate specific monetary benefits. The location of the zoned areas would be determined by the Texas Parks and Wildlife Department, in cooperation with the Corps of Engineers, during the detailed planning stage of project development.

Montell Reservoir, because of its small size, cannot accommodate speedboating and waterskiing without causing extremely hazardous conditions for the general public. For this reason, the recreation-management plan for Montell Reservoir should make provision for prohibiting speedboating and waterskiing. An additional 10,000 man-days of fishing annually resulting in added benefits of $10,000 could be attributed to the reservoir if speedboating and waterskiing were not permitted.

Construction of Montell and Cloptin Crossing Reservoirs will eliminate high quality deer habitat and force many deer onto adjacent lands already taxed by high deer populations. The increase of deer on lands surrounding the reservoir will cause overbrowsing of vegetation and result in further depletion of deer habitat. To cope with this situation, project lands in Federal ownership should be clearly marked and, consistent with State hunting regulations, be opened to public hunting as soon as possible after the land is purchased. Hunting of deer prior to impoundment would reduce the populations to a point where the displaced animals would not seriously compete with deer in adjacent areas.

Some domestic animals, primarily goats, are in direct competition with deer for food. Overstocking of goats on deer habitat seriously depletes the range within a short time. To alleviate this condition on project lands, the Corps of Engineers should institute a grazing-conservation program limiting the stocking rate of livestock, primarily goats, by persons leasing project lands for grazing. Such a program should be rigidly enforced to prevent overgrazing of the habitat by livestock and to comply with Article 22 of the Department of the Army long-term lease (Engineering Form 1366, dated 1 October 1962). Article 22 states, in part, "That the lessee will cooperate in programs for the management and improvement of fish and wildlife and in furtherance thereof the leased premises will be subject to free public use for fishing and hunting."

RECOMMENDATIONS

It is recommended:

1. That the conservation, improvement, and development of fish and wildlife resources be included among the purposes for which the project is to be authorized.

2. That seining areas be provided by the project at Cloptin Crossing and Montell Reservoirs to aid fishery management and commercial fishing. These areas should be about 1,000 feet wide, should extend from the stream channels to the top of conservation pool, and should be cleared to ground level of all obstructions. The Texas Parks and Wildlife Department will determine specific numbers and locations of these areas during the planning stage of the project.

3. That timber clearing in Cloptin Crossing and Montell Reservoirs be kept to a minimum, except for boat lanes, seining, parking, and boat-launching areas, and for areas reserved for safety and efficient operation of the reservoirs.

4. That, in the timbered areas of Cloptin Crossing Reservoir, 20-foot-wide boat lanes be cleared extending from the main stream channel to the headwaters in each major cove and that 10-foot-wide lateral lanes be cleared every 100 feet on alternate sides of the 20-foot boat lanes extending from the 20-foot boat lanes to the top of the conservation pool.

5. That public access and parking, sanitary, and drinking-water facilities be provided by the project at the proposed channel dam located on the Nueces River about 14 miles downstream from Montell Dam. The parking area should be about two surface acres in size and should be cleared of all obstructions and graveled.

6. That a minimum instantaneous release of at least 10 second-feet be made from Cloptin Crossing Reservoir to prevent the loss of fish habitat and to enhance fishing in the Blanco River.

7. That Cloptin Crossing Reservoir be zoned to promote safety and to insure that certain areas will be available for fishing and hunting without conflict with competing recreational uses such as speedboating and waterskiing.

8. That speedboating and waterskiing be prohibited on Montell Reservoir to preclude unsafe conditions which would prevail because of the small size of the reservoir.

9. That, except for those areas reserved for safety and project operation, lands in Federal ownership acquired for Montell and Cloptin Crossing Reservoirs be marked clearly at project expense and opened to public hunting, consistent with State hunting regulations, as soon as the land is purchased.

10. That a grazing-conservation program limiting the stocking rate of livestock, primarily goats, be instituted and enforced by the Corps of Engineers on all federally owned project lands for the preservation of wildlife habitat.

CONCLUSIONS

The Edwards Underground Reservoir Project will provide increased fishing but will cause the loss of valuable wildlife habitat and hunting. As currently planned, sport fishing benefits of $238,000 annually can be attributed to the project.

Development of measures outlined in Recommendations Nos. 2, 3, and 4 would assist in the management of Cloptin Crossing and Montell Reservoirs for fishing.

Provisions for public access, parking, sanitary, and drinking-water facilities at the proposed channel dam, as mentioned in Recommendation No. 5, would provide additional sport-fishing benefits of $10,000 annually.

Provisions for a minimum instantaneous release as mentioned in Recommendation No. 6 would increase sport-fishing benefits an additional $25,000 annually. Adoption of an adequate zoning plan for Cloptin Crossing Reservoir as proposed in Recommendation No. 7 would increase sport fishing and contribute to safety. Prohibiting speedboating and waterskiing on Montell Reservoir as proposed in Recommendation No. 8 would preclude unsafe conditions and provide benefits of $10,000 annually.

Adoption of Recommendations Nos. 9 and 10 would preserve wildlife habitat and assist the management of big game on project lands.

This report is based upon data received from the Corps of Engineers, Fort Worth District, prior to January 6, 1965, and any modifications should be brought to the attention of the Texas Parks and Wildlife Department and the Bureau of Sport Fisheries and Wildlife.

We appreciate the cooperation of your staff during our investigation of this project.

Sincerely yours,

John C. Gatlin

John C. Gatlin
Regional Director

Enclosure

Copies (10)

Distribution:

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(2) Regional Director, Bureau of Commercial Fisheries, Region 2, St. Petersburg Beach, Florida
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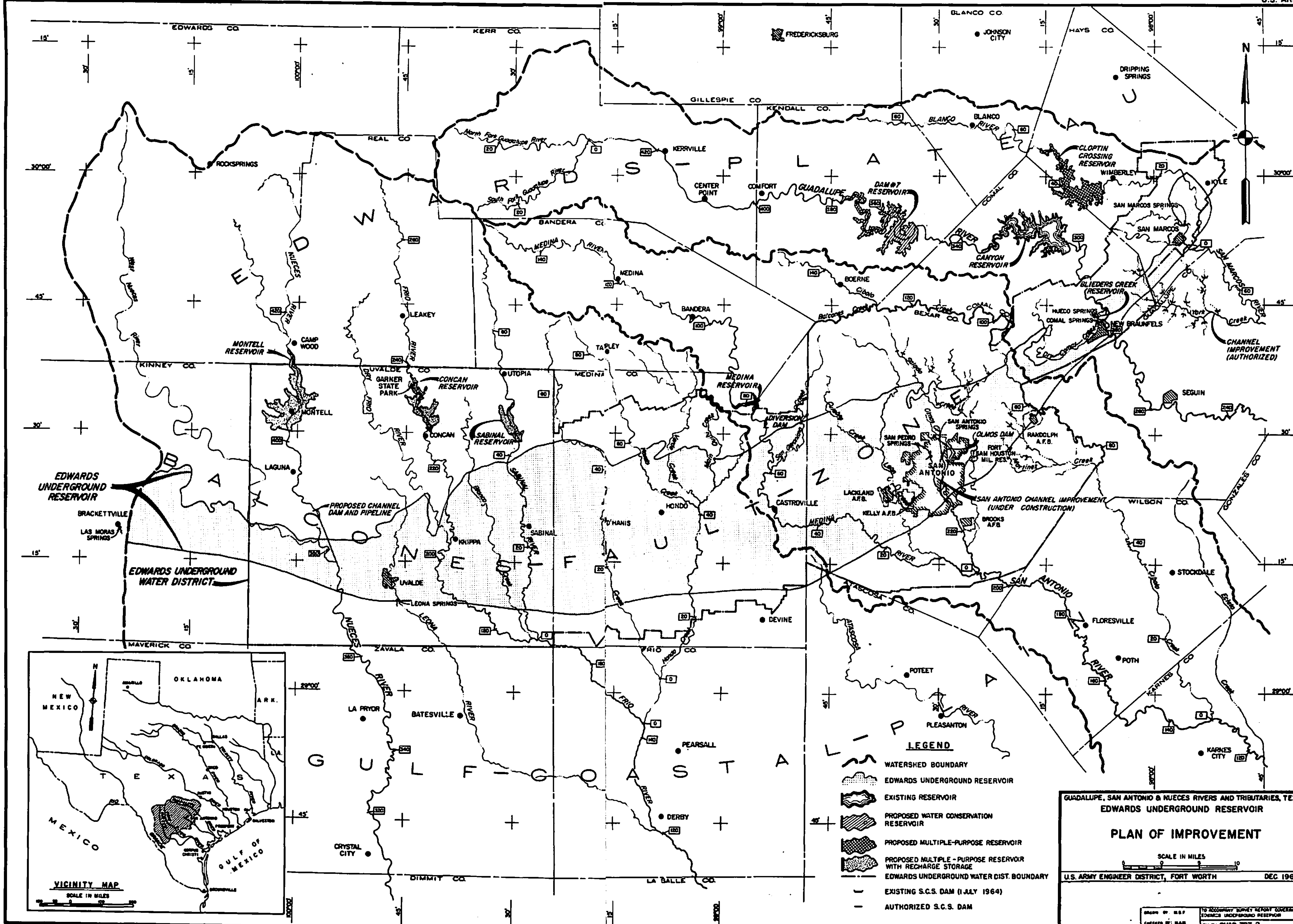

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
PLAN OF IMPROVEMENT
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
FILE: GUAD. 707-2
LEGEND
WATERSHED BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR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

.RKS AND WILDLIFE DEPARTMENT

J. WELDON WATSON
EXECUTIVE DIRECTOR

JOHN H. REAGAN BUILDING
AUSTIN, TEXAS 78701

January 13, 1965

Mr. Carey H. Bennett
Chief, Division of Technical Services
Bureau of Sport Fisheries and Wildlife
P. O. Box 1306
Albuquerque, N. M.

Dear Mr. Bennett:

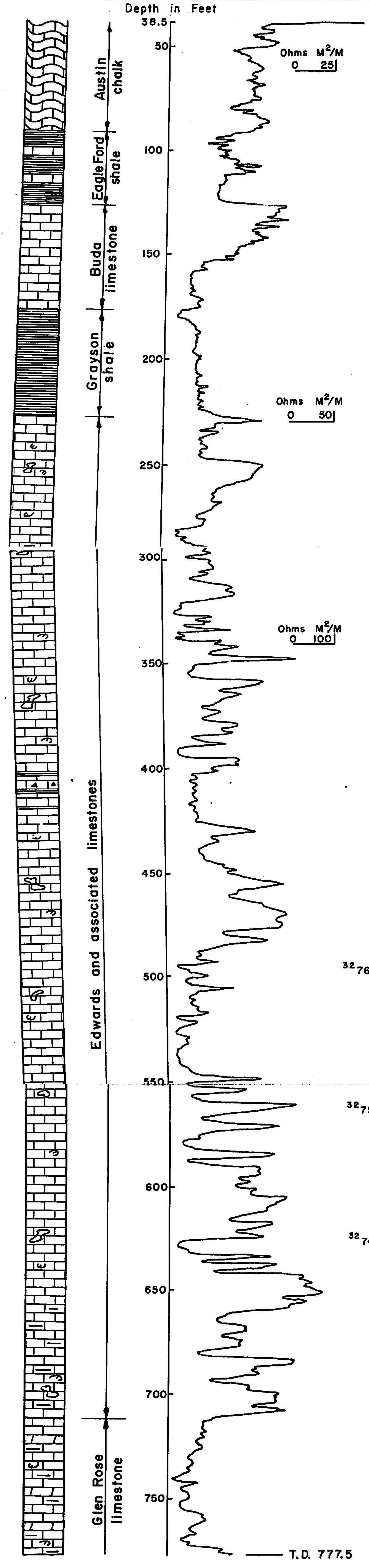
This is in reference to your letter of December 30, 1964 and the attached copies of your review draft report concerning the Corps of Engineers' proposed Edwards Underground Reservoir Project, Texas.

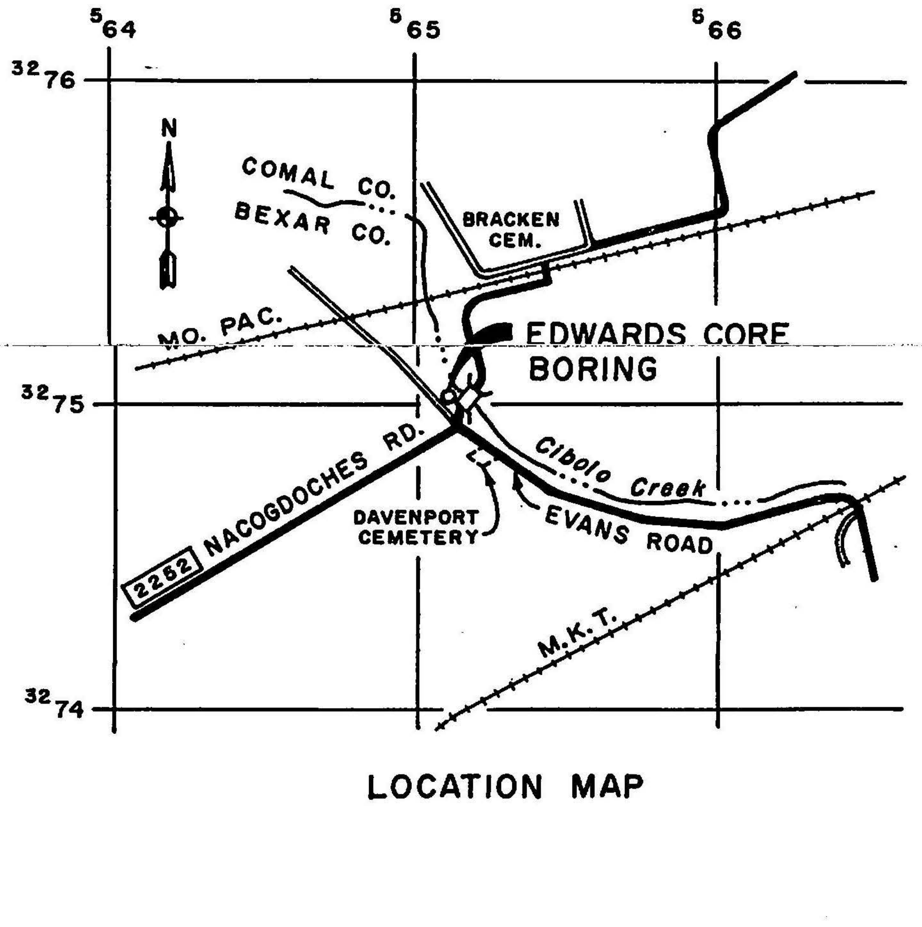
We have reviewed this report and this letter will constitute the concurrence of the Parks and Wildlife Department with the report as submitted.

Sincerely yours,

J. Weldon Watson

JWW:AJS:lf





LOCATION MAP

SCALE IN MILES

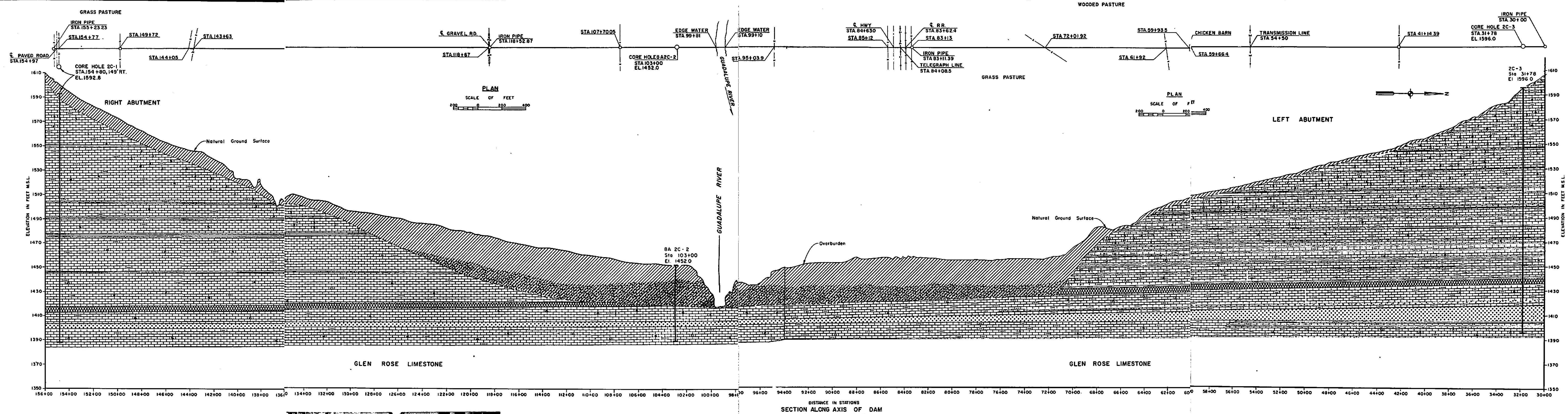
2 0 2 4

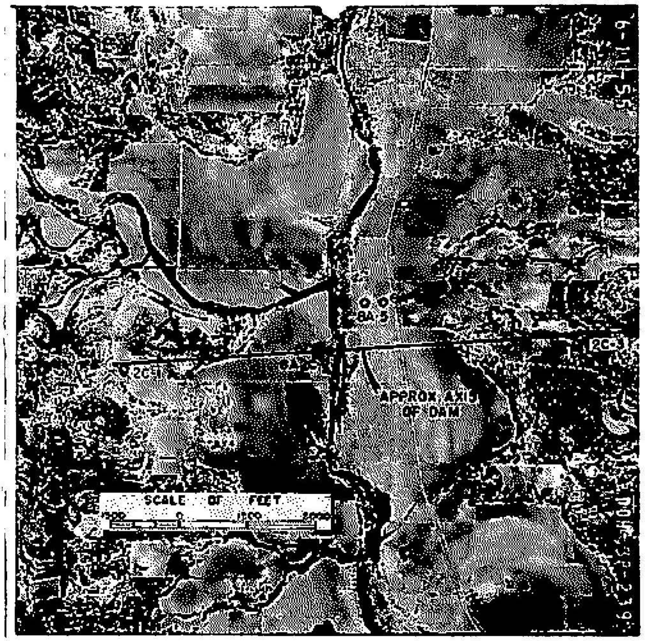
EDWARDS UNDERGROUND RESERVOIR

ELECTRIC LOG OF
EDWARDS CORE BORING

DEC. 1964 PLATE 5

III-53
PLATE 5





LEGEND

OVERBURDEN

- Clay or Gravelly Sandy Clay
- Gravelly Clayey Sand

PRIMARY STRATA

- Limestone, soft to moderately hard, argillaceous
- Shale, soft, gray
- Sandstone, moderately hard, friable
- Gypsum, soft
- Weathering
- Fossiliferous
- 8A — 8" Auger boring
- 2C — 2" Core boring

NOTES:

Horizontal extent of shale and sandstone seams unknown and generalized on this section.

Detailed description of material is shown on Plate 33, Logs of Borings.

See Plate 33 for pressure test results and data.

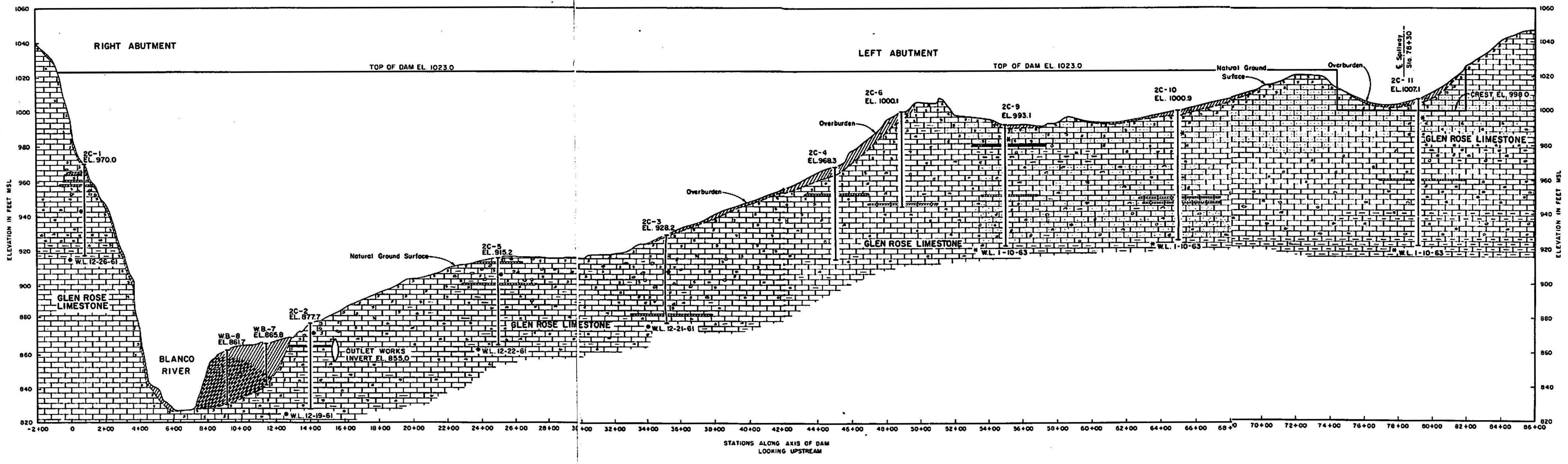
Absence of ground water level opposite borings does not mean that water was not encountered

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE RIVER
GEOLOGIC PROFILE
COMFORT DAM SITE

IN 2 SHEETS — SCALE AS SHOWN — SHEET NO 1

U S ARMY ENGINEER DISTRICT, FORT WORTH — DEC 1964

SUBMITTED: Engineer, Chief, Project Planning Branch
APPROVAL RECOMMENDED: Engineer, Chief, Engineering Division
APPROVED: District Engineer
PREPARED: Engineer, Chief, Foundation & Materials Br.
DRAWN BY B G S
CHECKED BY M G G
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2



LEGEND

OVERBURDEN

- Clay–Black to brown, sandy, organic, limestone fragments
- Sand–Brown to tan, fine to medium-grained, clayey.

PRIMARY STRATA

- Limestone–Gray to dark-gray, medium hard to hard, argillaceous, arenaceous, thin to massive-bedded, stylolitic, vuggy with occasional solution cavity.
- Shale–Gray, medium hard, calcareous, slightly sandy
- Clay–Gray to brown, soft to medium hard, medium to highly plastic, calcareous.
- Shaly Limestone
- Arenaceous Limestone
- Fossiliferous
- Weathering

* W.L. Water Level on Date Indicated
W.B. Wash Boring
2C 2" Core Boring

NOTES:

Elevations from Stations 0+00 to -2+00 taken from Plane Table sheet

See Plate No.33 for pressure test results and data.

Horizontal extent of clay seams shown on Geologic Profile is unknown but will be delineated by additional borings. Because of small scale not all clay seams are shown in Profile but appear on Plate 33, Logs of Borings.

Absence of ground water levels opposite boring logs does not mean that ground water will not be encountered at the locations or within the vertical reaches of the borings.

For location of borings see plate 31.

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER
GEOLOGIC PROFILE
CLOPTIN CROSSING DAM SITE

SCALE AS SHOWN

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

SUBMITTED: W.E. Wood, Engineer, Chief, Project Planning Branch
APPROVAL RECOMMENDED: [signature], Engineer, Chief, Engineering Division
APPROVED: [signature], Col., Corps of Engineers, District Engineer
PREPARED: A.M. Hull, Engineer, Chief, Foundations & Materials Br.
DRAWN BY: RC & DE
CHECKED BY: M.G.O.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD 707-2

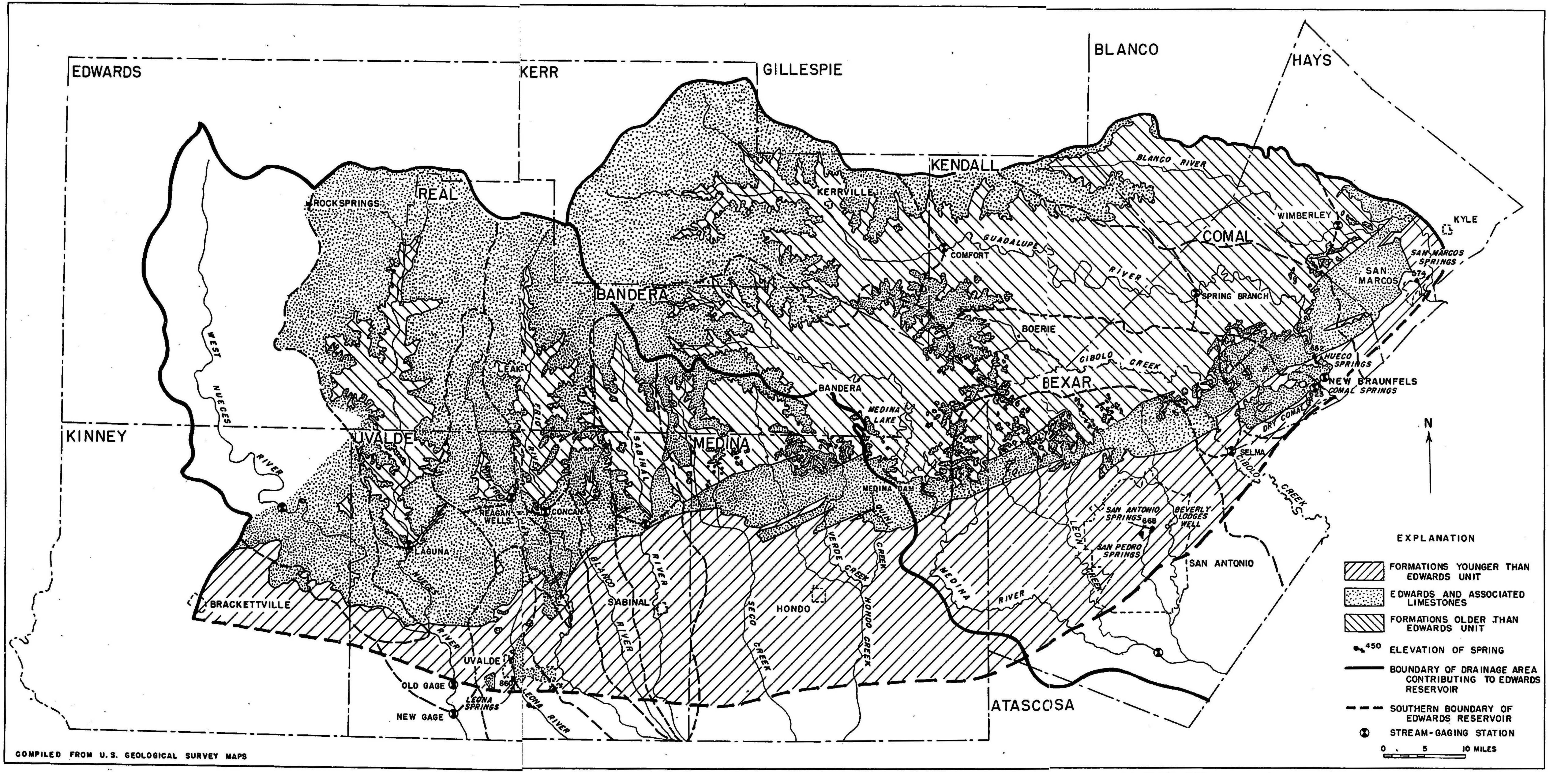


FIGURE 1.- GEOLOGIC MAP SHOWING EXTENT OF EDWARDS RESERVOIR AND AREA CONTRIBUTING RECHARGE.