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

LETTER

FROM

THE SECRETARY OF THE ARMY

TRANSMITTING

A LETTER FROM THE CHIEF OF ENGINEERS, DEPARTMENT OF THE ARMY, DATED DECEMBER 6, 1971, SUBMITTING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, ON EDWARDS UNDERGROUND RESERVOIR, GUADALUPE, SAN ANTONIO AND NUECES RIVERS AND TRIBUTARIES, TEXAS, AUTHORIZED BY SECTION 209 OF PUBLIC LAW 86-645 APPROVED JULY 14, 1960

Volume 2

SEPTEMBER 25, 1972.—Referred to the Committee on Public Works and ordered to be printed with illustrations

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SURVEY REPORT
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AND TRIBUTARIES, TEXAS

APPENDIX II

HYDROLOGY AND HYDRAULIC DESIGN

GENERAL

1. SCOPE.- This appendix presents analyses of problems associated with the water resources of the Edwards Reservoir and the analyses of some of the water resource problems of the Nueces, Guadalupe, and San Antonio River Basins. Only those portions of these three river basins which would be affected by projects constructed to alter the existing recharge of the Edwards Reservoir are considered to be within the scope of this report. Such projects were investigated with a view toward the possible improvement of the yield of the underground reservoir together with the provision of flood control and water conservation measures.

2. It is noted that because of its importance, the Edwards Reservoir is the most intensely studied aquifer in Texas. A voluminous amount of data relative to the aquifer have been published as a result of investigations by the U. S. Geological Survey and by private consultants in cooperation with the Texas Water Commission, the San Antonio City Water Board, the San Antonio City Public Service Board, the Bexar County Metropolitan Water District, and the Edwards Underground Water District.

3. The investigation of those items covered by reports of these agencies was limited to checking the accuracy of the basic data contained and determining the reasonableness of the approach to the analysis and of conclusions reached. The maximum practicable use was made of the data contained in these reports which are listed in the Bibliography, exhibit 1.

4. DESCRIPTION OF STUDY AREA.- The area covered by this study lies in the south-central portion of the state of Texas, approximately between 98°00' and 100°30' west longitude and 29°00' and 30°15' north latitude. It is bound on the west by the Rio Grande River Basin, on the north by the Colorado River Basin, and on the south and east by the Balcones Escarpment. The study area includes an area of nearly 6,400 square miles consisting of parts of the upper basins of the Nueces River, the San Antonio River, and the Guadalupe River.

5. From west to east the area in the Nueces River Basin is drained by the West Nueces River, the Nueces River, the Dry Frio River, the Frio River, Blanco Creek, the Sabinal River, Seco Creek, Hondo Creek, and Verde Creek. The area in the San Antonio River Basin is drained by the Medina River, Leon Creek, Salado Creek, and Cibolo Creek. The area in the Guadalupe River Basin is drained by Dry Comal Creek, the Guadalupe River, and the Blanco River. In general, these streams originate on the Edwards Plateau, commonly known as the "hill country" north of the Balcones Escarpment.

6. The terrain of the plateau is rough and broken with thin soil cover and the drainage is characterized by steep slopes, resulting in sharp-peaked runoff hydrographs. In addition, most of the streams exhibit a small base flow except in periods of drought. The Edwards limestone covers most of the surface through the Edwards Plateau except in portions of the Guadalupe and San Antonio River Basins where remnants of the limestone cap the hills. For the most part, the streams have cut deep gorges through the Edwards limestones and are bedded in the more impervious Glen Rose limestones. The Edwards limestone absorbs a substantial amount of rainfall. This water percolates downward through cracks and fissures to the lower parts of the Edwards formation where it comes in contact with relatively impermeable formations, forming an unconfined water body. The water then moves by gravity flow laterally through the limestone with much of it reappearing as springflow at or near the contact between the pervious and impervious zones in the valleys that have been cut by the streams. These springs are the source of the base flow of the streams that drain the Edwards Plateau country. Each of the streams then, with the exception of the Guadalupe River, lose their entire base flow and much of their flood flow to the Edwards Reservoir as they cross long stretches of honeycombed and cavernous limestone in the Balcones fault zone. The location of the Edwards Reservoir is shown on plate 1.

7. Those streams crossing the recharge area and the approximate lengths and drainage areas above the downstream limit of the recharge area are shown in table 1. The major watershed drainage areas are delineated and tabulated on plates 2 and 3, Drainage Areas, Nueces and Guadalupe-San Antonio River Basins.

8. EXISTING AND AUTHORIZED FEDERAL IMPROVEMENTS.- The Federal improvements in the study area are limited to those constructed and authorized by the Corps of Engineers and the Soil Conservation Service of the Department of Agriculture. These improvements are discussed in the following paragraphs.

a. Corps of Engineers Projects.- The Canyon Reservoir is the only Corps of Engineers reservoir in operation in the study area and is located at river mile 303.0 on the Guadalupe River

CORPS OF ENGINEERS

U.S. ARMY

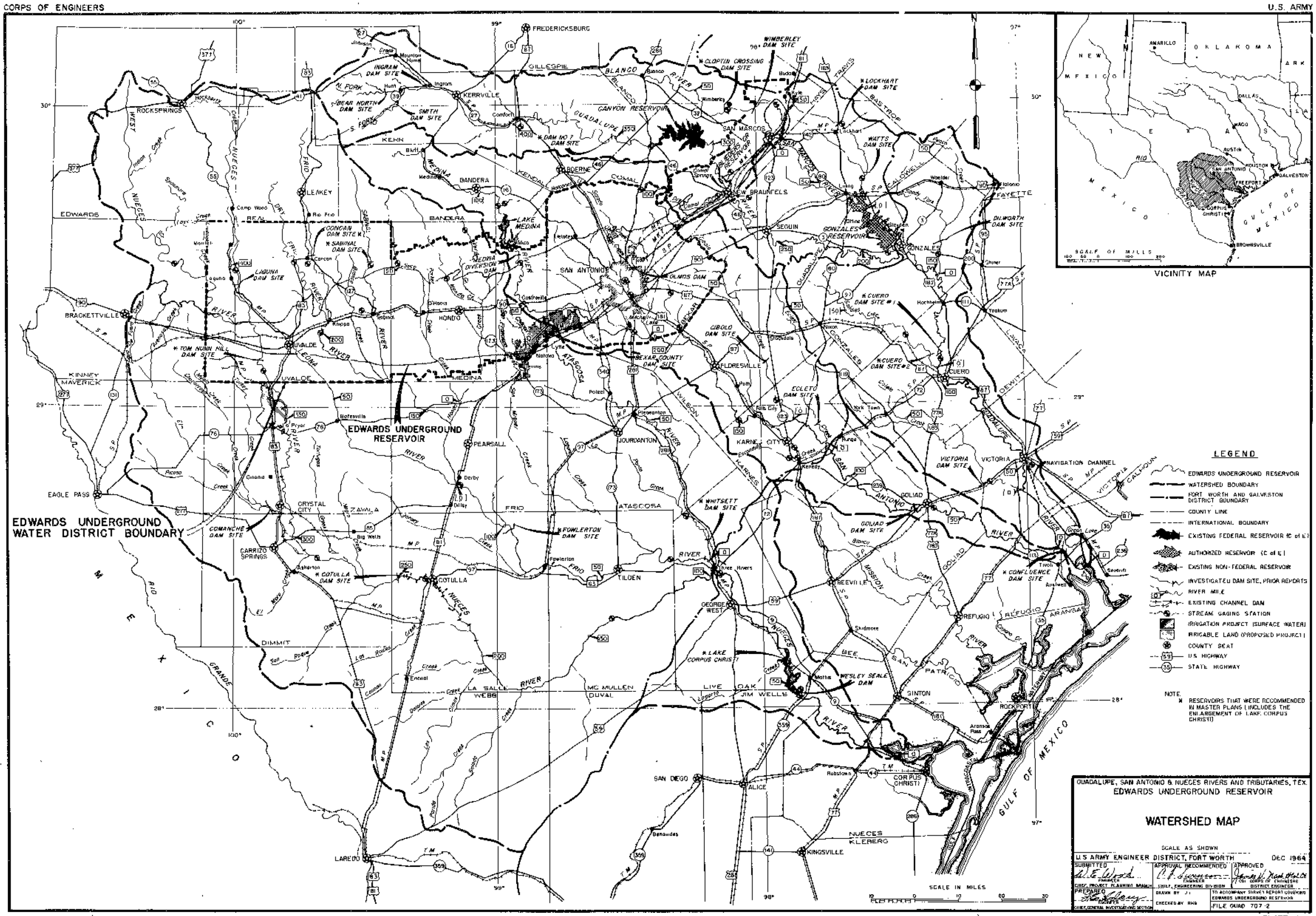

PLATE I

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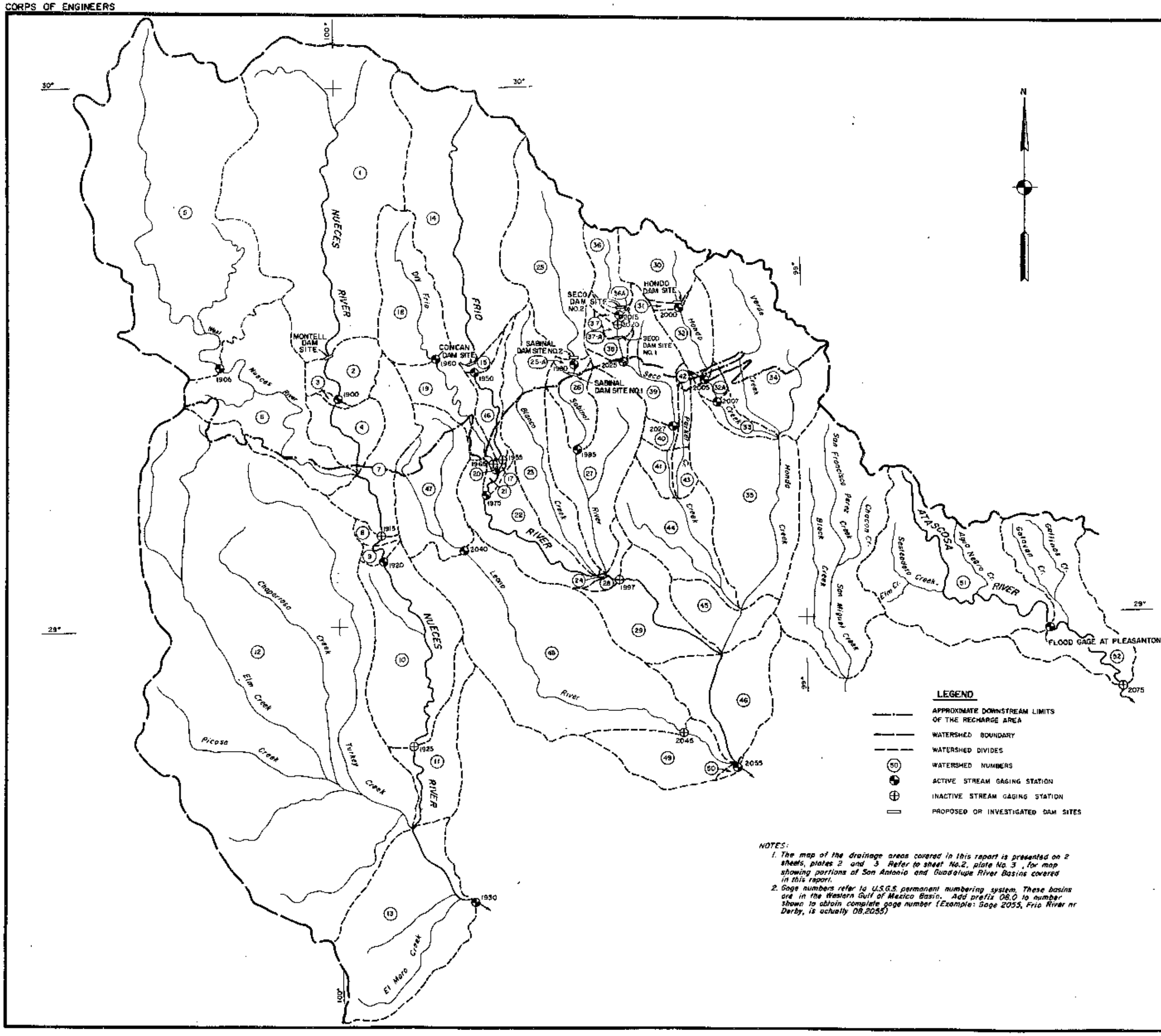
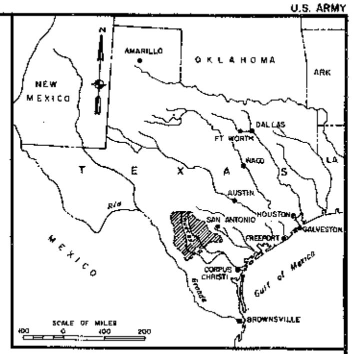
CORPS OF ENGINEERS

U.S. ARMY





VICINITY MAP

WATERSHED AREAS

COMPONENT AREAS: WATERSHED NUMBER	COMPONENT AREAS: AREA SQ. MI.	CUMULATIVE AREAS: AREA SQ. MI.	CUMULATIVE AREAS: POINT OF MEASUREMENT
NUECES RIVER			
1	707	707	ABOVE MONTELL DAM SITE
2	57	764	ABOVE GAGE NO. 1900 AT LAGUNA
3	4	768	ABOVE LAGUNA DAM SITE
4	68	836	ABOVE MOUTH WEST NUECES RIVER
5-6	937	1,773	BELOW MOUTH WEST NUECES RIVER
7	157	1,930	ABOVE GAGE NO. 1915 NR. UVALDE (DISCONTINUED)
8	7	1,937	ABOVE TOM NUNN HILL DAM SITE
9	10	1,947	ABOVE GAGE NO. 1920 NR. UVALDE
10	203	2,150	ABOVE GAGE NO. 1925 NR. CINONIA (DISCONTINUED)
11	97	2,247	ABOVE MOUTH TURKEY CREEK
12	1,569	3,816	BELOW MOUTH TURKEY CREEK
13	266	4,082	ABOVE GAGE NO. 1930 NR. ASHERTON
WEST NUECES RIVER			
5	700	700	ABOVE GAGE NO. 1905 NR. BRACKETTVILLE
6	237	937	ABOVE MOUTH WEST NUECES RIVER
FRIO RIVER			
14	391	391	ABOVE CONCAN DAM SITE
15	14	405	ABOVE GAGE NO. 1950 AT CONCAN
16	63	468	ABOVE GAGE NO. 1955 AT KNIPPA (DISCONTINUED)
17	1	469	ABOVE MOUTH DRY FRIO RIVER
18-20	187	656	BELOW MOUTH DRY FRIO RIVER
21	5	661	ABOVE GAGE NO. 1975 NR UVALDE
22	161	822	ABOVE MOUTH BLANCO RIVER
23	183	1,005	BELOW MOUTH BLANCO RIVER
24	1	1,006	ABOVE MOUTH SABINAL RIVER
25-27	437	1,443	BELOW MOUTH SABINAL RIVER
28	17	1,460	ABOVE GAGE NO. 1997 NR FRIO TOWN (DISCONTINUED)
29	122	1,582	ABOVE MOUTH HONDO CREEK
30-45	1,086	2,668	BELOW MOUTH HONDO CREEK
46	142	2,810	ABOVE MOUTH LEONA RIVER
47-49	680	3,490	BELOW MOUTH LEONA RIVER
50	3	3,493	ABOVE GAGE NO. 2055 NR DERBY
DRY FRIO RIVER			
18	117	117	ABOVE GAGE NO. 1960 NR. REAGAN WELLS
19	62	179	ABOVE GAGE NO. 1965 AT KNIPPA (DISCONTINUED)
20	8	187	ABOVE MOUTH DRY FRIO RIVER
SABINAL RIVER			
25	206	206	ABOVE SABINAL DAM SITE NO.2 (GAGE NO. 1980 NR. SABINAL)
25-A	4	210	ABOVE SABINAL DAM SITE NO.1
26	41	247	ABOVE GAGE NO. 1985 AT SABINAL
27	190	437	ABOVE MOUTH SABINAL RIVER
HONDO CREEK			
30	96	96	ABOVE HONDO DAM SITE
31	5	101	ABOVE GAGE NO. 2000 NR TARPLEY
32	31	132	ABOVE GAGE NO. 2005 NR HONDO
32A	10	142	ABOVE GAGE NO. 2007 AT KING'S WATERHOLE NR HONDO
33	23	165	ABOVE MOUTH VERDE CREEK
34	245	410	BELOW MOUTH VERDE CREEK
35	239	649	ABOVE MOUTH SECO CREEK
36-44	369	1,017	BELOW MOUTH SECO CREEK
45	69	1,086	ABOVE MOUTH HONDO CREEK
SECO CREEK			
36	36	36	ABOVE SECO DAM SITE NO.2
36-A	7	43	ABOVE GAGE NO. 2015 AT MILLER'S RANCH NR UTOPIA
37	10	53	ABOVE GAGE NO. 2020 NR UTOPIA (DISCONTINUED)
37-A	6	59	ABOVE SECO DAM SITE NO.1
38	28	87	ABOVE GAGE NO. 2025 NR D'HANIS
39	81	168	ABOVE GAGE NO 2027 CROOK'S RANCH NR. D'HANIS
40	16	184	ABOVE D'HANIS
41	22	206	ABOVE MOUTH PARKER CREEK
42-43	32	238	BELOW MOUTH PARKER CREEK
44	130	368	ABOVE MOUTH SECO CREEK
PARKER CREEK			
42	16	16	ABOVE D'HANIS
43	16	32	ABOVE MOUTH PARKER CREEK
LEONA RIVER			
47	146	146	ABOVE GAGE NO. 2040 NR UVALDE
48	419	565	ABOVE GAGE NO. 2045 NR. DIVOT (DISCONTINUED)
49	115	680	ABOVE MOUTH LEONA RIVER
ATASCOSA RIVER			
51	341	341	ABOVE FLOOD GAGE AT PLEASANTON
52	189	530	ABOVE GAGE NO. 2075 NR. McCOY (DISCONTINUED)

LEGEND

- APPROXIMATE DOWNSTREAM LIMITS OF THE RECHARGE AREA
- WATERSHED BOUNDARY
- WATERSHED DIVIDES
- (50) WATERSHED NUMBERS
- ACTIVE STREAM GAGING STATION
- INACTIVE STREAM GAGING STATION
- PROPOSED OR INVESTIGATED DAM SITES

NOTES:

1. *The map of the drainage areas covered in this report is presented on 2 sheets, plates 2 and 3. Refer to sheet No.2, plate No. 3, for map showing portions of San Antonio and Guadalupe River Basins covered in this report.*
2. *Gage numbers refer to U.S.G.S. permanent numbering system. These basins are in the Western Gulf of Mexico Basin. Add prefix 08.0 to number shown to obtain complete gage number (Example: Gage 2055, Frio River nr Derby, is actually 08.2055)*

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

NUECES RIVER BASIN
DRAINAGE AREA MAP

SCALE IN MILES

5 0 5 10

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

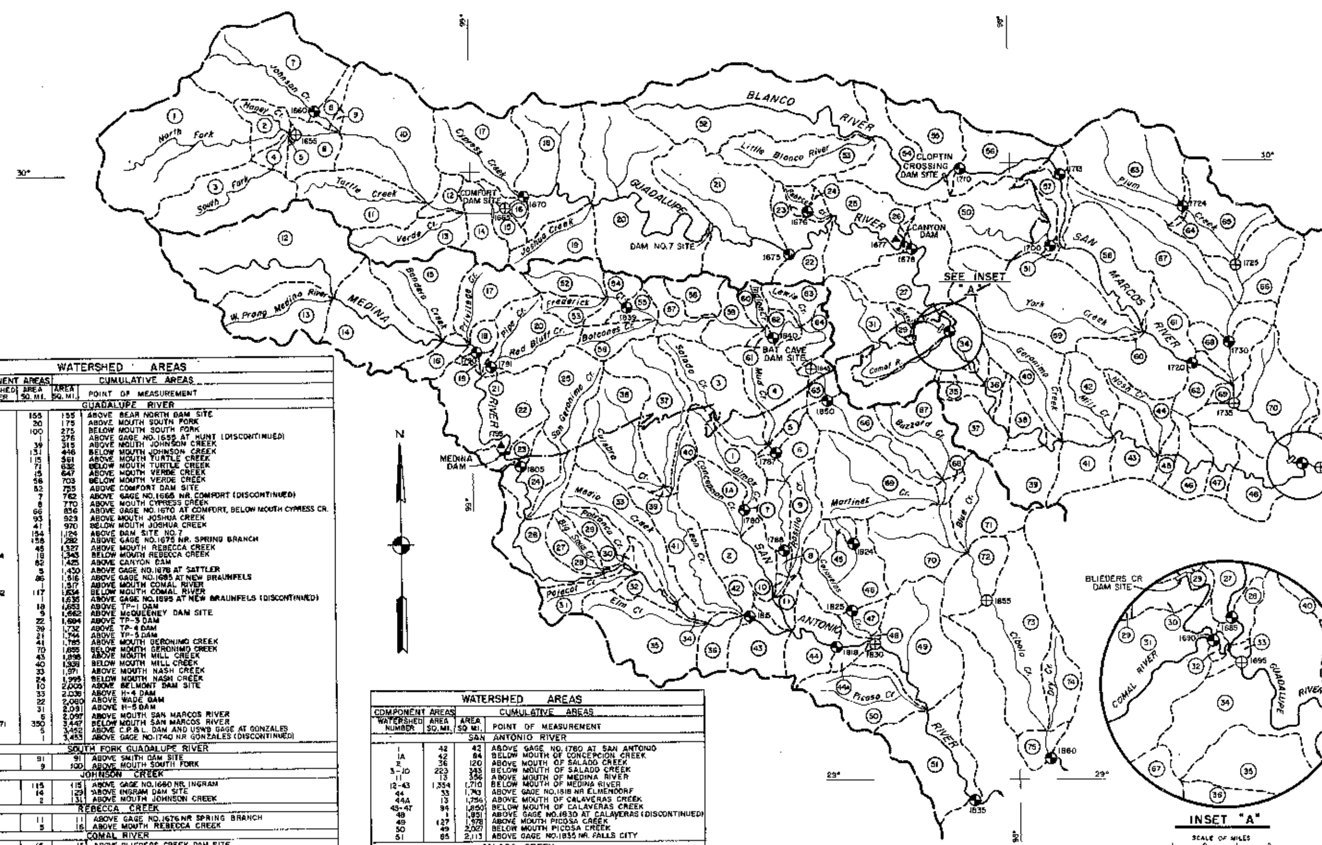
SUBMITTED: ENGINEER, CHIEF, PROJECT PLANNING BRANCH | APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION | APPROVED: COL., CORPS OF ENGINEERS, DISTRICT ENGINEER

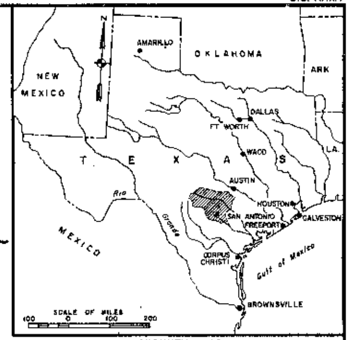
PREPARED: ENGINEER, CHIEF, HYDROLOGY SECTION | DRAWN BY: A.M.F. | CHECKED BY: R.H.Q.

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

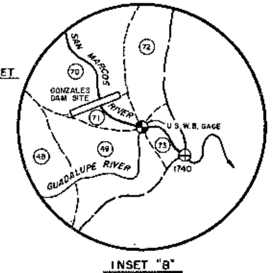
FILE: GUAD 707-2

PLATE 2





VICINITY MAP



INSET "B"

LEGEND

- APPROXIMATE DOWNSTREAM LIMITS OF THE RECHARGE AREA
- WATERSHED BOUNDARY
- WATERSHED DIVIDE
- WATERSHED NUMBER
- ACTIVE STREAM GAGING STATION
- INACTIVE STREAM GAGING STATION
- ACTIVE RESERVOIR GAGING STATION
- EXISTING DAM
- PROPOSED OR INVESTIGATED DAM SITE

NOTES:
1. The map of the drainage areas covered in this report is presented on 2 sheets, plates 2 and 3. Refer to sheet No.1, plate No. 2, for map showing portions of Nueces River Basin covered in this report.
2. Gage numbers refer to U.S.G.S. permanent numbering system. These basins are in the Western Gulf of Mexico Basin. Add prefix 08.0 to number shown to obtain complete gage number (Example: Gage 1835, San Antonio River nr. Falls City, is actually 08.1835).

WATERSHED AREAS

COMPONENT AREAS: WATERSHED NUMBER	COMPONENT AREAS: AREA SQ. MI.	CUMULATIVE AREAS: AREA SQ. MI.	CUMULATIVE AREAS: POINT OF MEASUREMENT
			GUADALUPE RIVER
1	155	155	ABOVE BEAR NORTH DAM SITE
2	20	175	ABOVE MOUTH SOUTH FORK
3-4	100	275	BELOW MOUTH SOUTH FORK
5	1	276	ABOVE GAGE NO.1655 AT HUNT (DISCONTINUED)
6	39	315	ABOVE MOUTH JOHNSON CREEK
7-9	131	446	BELOW MOUTH JOHNSON CREEK
10	115	561	ABOVE MOUTH TURTLE CREEK
11	71	632	BELOW MOUTH TURTLE CREEK
12	15	647	ABOVE MOUTH VERDE CREEK
13	56	703	BELOW MOUTH VERDE CREEK
14	52	755	ABOVE COMFORT DAM SITE
15	7	762	ABOVE GAGE NO.1665 NR. COMFORT (DISCONTINUED)
16	8	770	ABOVE MOUTH CYPRESS CREEK
17	66	836	ABOVE GAGE NO.1670 AT COMFORT, BELOW MOUTH CYPRESS CR.
18	93	929	ABOVE MOUTH JOSHUA CREEK
19	41	970	BELOW MOUTH JOSHUA CREEK
20	154	1,124	ABOVE DAM SITE NO.7
21	158	1,282	ABOVE GAGE NO.1675 NR. SPRING BRANCH
22	45	1,327	ABOVE MOUTH REBECCA CREEK
23-24	18	1,345	BELOW MOUTH REBECCA CREEK
25	82	1,425	ABOVE CANYON DAM
26	5	1,430	ABOVE GAGE NO.1678 AT SATTLER
27	86	1,516	ABOVE GAGE NO.1685 AT NEW BRAUNFELS
28	1	1,517	ABOVE MOUTH COMAL RIVER
29-32	117	1,634	BELOW MOUTH COMAL RIVER
33	1	1,635	ABOVE GAGE NO.1695 AT NEW BRAUNFELS (DISCONTINUED)
34	18	1,653	ABOVE TP-1 DAM
35	9	1,662	ABOVE McQUEENEY DAM SITE
36	22	1,684	ABOVE TP-3 DAM
37	39	1,732	ABOVE TP-4 DAM
38	21	1,744	ABOVE TP-5 DAM
39	41	1,785	ABOVE MOUTH GERONIMO CREEK
40	70	1,855	BELOW MOUTH GERONIMO CREEK
41	43	1,898	ABOVE MOUTH MILL CREEK
42	40	1,938	BELOW MOUTH MILL CREEK
43	33	1,971	ABOVE MOUTH NASH CREEK
44	24	1,995	BELOW MOUTH NASH CREEK
45	10	2,005	ABOVE BELMONT DAM SITE
46	33	2,038	ABOVE H-4 DAM
47	22	2,060	ABOVE WADE DAM
48	31	2,091	ABOVE H-5 DAM
49	6	2,097	ABOVE MOUTH SAN MARCOS RIVER
50-71	350	3,447	BELOW MOUTH SAN MARCOS RIVER
72	5	3,452	ABOVE C.P.&L. DAM AND USWB GAGE AT GONZALES
73	1	3,453	ABOVE GAGE NO.1740 NR GONZALES (DISCONTINUED)
			SOUTH FORK GUADALUPE RIVER
3	91	91	ABOVE SMITH DAM SITE
4	9	100	ABOVE MOUTH SOUTH FORK
			JOHNSON CREEK
7	115	115	ABOVE GAGE NO.1660 NR. INGRAM
8	14	129	ABOVE INGRAM DAM SITE
9	2	131	ABOVE MOUTH JOHNSON CREEK
			REBECCA CREEK
23	11	11	ABOVE GAGE NO.1676 NR SPRING BRANCH
24	5	16	ABOVE MOUTH REBECCA CREEK
			COMAL RIVER
29	15	15	ABOVE BLIEDERS CREEK DAM SITE
30	3	18	BLIEDERS CREEK ABOVE COMAL SPRINGS (COMAL RIVER)
31	99	117	ABOVE GAGE NO.1690 AT NEW BRAUNFELS
32	0.35	117	ABOVE MOUTH COMAL RIVER
			SAN MARCOS RIVER
50	64	64	ABOVE SPRING FLOW GAGE NO.1700 AT SAN MARCOS
51	2	66	ABOVE MOUTH BLANCO RIVER
52-57	428	514	BELOW MOUTH BLANCO RIVER
58	94	608	ABOVE MOUTH YORK CREEK
59	143	751	BELOW MOUTH YORK CREEK
60	1	752	ABOVE FENTRESS DAM SITE
61	81	833	ABOVE GAGE NO. 1720 AT LULING
62	21	854	ABOVE MOUTH PLUM CREEK
63-68	386	1,240	BELOW MOUTH PLUM CREEK
69	9	1,249	ABOVE GAGE NO.1735 AT OTTINE (DISCONTINUED)
70	95	1,344	ABOVE GONZALES DAM SITE
71	6	1,350	ABOVE MOUTH SAN MARCOS RIVER
			BLANCO RIVER
52	170	170	ABOVE MOUTH LITTLE BLANCO RIVER
53	69	239	BELOW MOUTH LITTLE BLANCO RIVER
54	68	307	ABOVE CLOPTIN CROSSING DAM SITE
55	46	353	ABOVE GAGE NO.1710 AT WIMBERLEY
56	57	410	ABOVE GAGE NO.1713 NR. KYLE
57	18	428	ABOVE MOUTH BLANCO RIVER
			PLUM CREEK
63	113	113	ABOVE GAGE NO.1724 AT LOCKHART
64	5	118	ABOVE LOCKHART DAM SITE
65	66	184	ABOVE GAGE NO.1725 NR LOCKHART (DISCONTINUED)
66	61	245	ABOVE WATTS DAM SITE
67	111	356	ABOVE GAGE NO.1730 NR. LULING
68	30	386	ABOVE MOUTH PLUM CREEK

WATERSHED AREAS

COMPONENT AREAS: WATERSHED NUMBER	COMPONENT AREAS: AREA SQ. MI.	CUMULATIVE AREAS: AREA SQ. MI.	CUMULATIVE AREAS: POINT OF MEASUREMENT
			SAN ANTONIO RIVER
1	42	42	ABOVE GAGE NO.1780 AT SAN ANTONIO
1A	42	84	BELOW MOUTH OF CONCEPCION CREEK
2	36	120	ABOVE MOUTH OF SALADO CREEK
3-10	223	343	BELOW MOUTH OF SALADO CREEK
11	13	356	ABOVE MOUTH OF MEDINA RIVER
12-43	1,354	1,710	BELOW MOUTH OF MEDINA RIVER
44	33	1,743	ABOVE GAGE NO.1818 NR. ELMENDORF
44A	13	1,756	ABOVE MOUTH OF CALAVERAS CREEK
45-47	94	1,850	BELOW MOUTH OF CALAVERAS CREEK
48	1	1,851	ABOVE GAGE NO.1830 AT CALAVERAS (DISCONTINUED)
49	27	1,878	ABOVE MOUTH PICOSA CREEK
50	49	2,027	BELOW MOUTH PICOSA CREEK
51	85	2,113	ABOVE GAGE NO.1835 NR. FALLS CITY
			SALADO CREEK
3	75	75	ABOVE MOUTH OF MUD CREEK
4	51	126	BELOW MOUTH OF MUD CREEK
5	11	137	ABOVE GAGE NO.1787 AT UPPER SAN ANTONIO
6	23	160	BELOW RITTMAN ROAD
7	29	189	ABOVE GAGE NO.1785 AT LOWER SAN ANTONIO
8	3	192	ABOVE MOUTH OF ROSILLO CREEK
9	28	220	BELOW MOUTH OF ROSILLO CREEK
10	3	223	ABOVE MOUTH OF SALADO CREEK
			MEDINA RIVER
12	180	180	ABOVE MOUTH WEST PRONG MEDINA RIVER
13	76	256	BELOW MOUTH WEST PRONG MEDINA RIVER
14	100	356	ABOVE MOUTH BANDERA CREEK
15	67	423	BELOW MOUTH BANDERA CREEK
16	18	441	ABOVE MOUTH PRIVILEGE CREEK
17	41	482	BELOW MOUTH PRIVILEGE CREEK
18	12	494	ABOVE GAGE NO.1790 NR. PIPE CREEK
19	4	498	ABOVE MOUTH RED BLUFF CREEK
20-21	58	556	BELOW MOUTH RED BLUFF CREEK
22	78	634	ABOVE MEDINA DAM SITE & GAGE NO.1795
23	16	650	ABOVE GAGE NO.1805 NR. RIOMEDINA
24	33	683	ABOVE MOUTH SAN GERONIMO CREEK
25	76	759	BELOW MOUTH SAN GERONIMO CREEK
26	57	816	ABOVE MOUTH BIG SOUS CREEK
27	24	840	BELOW MOUTH BIG SOUS CREEK
28	2	842	ABOVE MOUTH POTRANCA CREEK
29	25	867	BELOW MOUTH POTRANCA CREEK
30	2	869	ABOVE MOUTH POLECAT CREEK
31	19	888	BELOW MOUTH POLECAT CREEK
32	22	910	ABOVE MOUTH MEDIO CREEK
33	53	963	BELOW MOUTH MEDIO CREEK
34	8	971	ABOVE MOUTH ELM CREEK
35	78	1,049	BELOW MOUTH ELM CREEK
36	20	1,069	ABOVE MOUTH LEON CREEK
37-41	237	1,306	BELOW MOUTH LEON CREEK
42	11	1,317	ABOVE GAGE NO.1815 NR. SAN ANTONIO
43	37	1,354	ABOVE MOUTH MEDINA RIVER

WATERSHED AREAS

COMPONENT AREAS: WATERSHED NUMBER	COMPONENT AREAS: AREA SQ. MI.	CUMULATIVE AREAS: AREA SQ. MI.	CUMULATIVE AREAS: POINT OF MEASUREMENT
			RED BLUFF CREEK
20	56	56	ABOVE GAGE NO.1791 NR. PIPE CREEK
21	2	58	ABOVE MOUTH RED BLUFF CREEK
			LEON CREEK
37	77	77	ABOVE MOUTH CULEBRA CREEK
38	83	160	BELOW MOUTH CULEBRA CREEK
39	1	161	ABOVE MOUTH HUEBNER CREEK
40	12	173	BELOW MOUTH HUEBNER CREEK
41	64	237	ABOVE MOUTH LEON CREEK
			CALAVERAS CREEK
45	7	7	ABOVE GAGE NO.1824 NR ELMENDORF
46	70	77	ABOVE GAGE NO 1825 NR ELMENDORF
47	17	94	ABOVE MOUTH CALAVERAS CREEK
			CIBOLO CREEK
52	35	35	ABOVE MOUTH OF FREDERICK CREEK
53	17	52	BELOW MOUTH OF FREDERICK CREEK
54	16	68	ABOVE GAGE NO 1839 NR. BOERNE
55	11	79	ABOVE MOUTH BALCONES CREEK
56	23	102	BELOW MOUTH BALCONES CREEK
57	26	128	ABOVE MOUTH CREEK AT RM 115.4
58	24	152	BELOW MOUTH CREEK AT R.M. 115.4
59	30	182	ABOVE MOUTH INDIAN CREEK
60	11	193	ABOVE BULVERDE DAM SITE (BELOW MOUTH INDIAN CR.)
61	5	198	ABOVE GAGE NO.1840 NR BULVERDE
62	10	208	ABOVE MOUTH LEWIS CREEK
63	23	231	BELOW MOUTH LEWIS CREEK
64	19	250	ABOVE BAT CAVE DAM SITE [GAGE NO. 1845 AT BRACKEN] (DISCONT.)
65	24	274	ABOVE GAGE NO.1850 AT SELMA

WATERSHED AREAS

COMPONENT AREAS: WATERSHED NUMBER	COMPONENT AREAS: AREA SQ. MI.	CUMULATIVE AREAS: AREA SQ. MI.	CUMULATIVE AREAS: POINT OF MEASUREMENT
			CIBOLO CREEK (CONTD.)
66	45	319	ABOVE MOUTH BUZZARD CREEK
67	63	382	BELOW MOUTH BUZZARD CREEK
68	6	388	ABOVE MOUTH MARTINEZ CREEK
69	88	476	BELOW MOUTH MARTINEZ CREEK
70	69	545	ABOVE MOUTH BLUE CREEK
71	59	604	BELOW MOUTH BLUE CREEK
72	43	647	ABOVE GAGE NO.1855 AT SUTHERLAND SPRINGS (DISCONTINUED)
73	130	777	ABOVE MOUTH DRY CREEK
74	33	810	BELOW MOUTH DRY CREEK
75	17	827	ABOVE GAGE NO.1860 NR FALLS CITY

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

GUADALUPE & SAN ANTONIO RIVER BASINS

DRAINAGE AREA MAP

SCALE IN MILES
5 0 5 10

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

SUBMITTED: ENGINEER, CHIEF, PROJECT PLANNING BRANCH
APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION
APPROVED: COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF, HYDROLOGY SECTION
DRAWN BY: J.W.F.
CHECKED BY: R.H.G.
TO ACCOMPANY SURVEY REPORT CONCERNING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2

PLATE 3

TABLE 1

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

Stream	Above downstream limits of recharge area*: Approx. length (miles)	Above downstream limits of recharge area*: Drainage area (sq.mi.)
GUADALUPE RIVER BASIN		
Blanco River and adjacent area	70	514
Guadalupe River	155	1,510
Dry Comal Creek	8	98
Sub-total		2,122
SAN ANTONIO RIVER BASIN		
Cibolo Creek	61	258
Salado Creek	18	
San Geronimo Creek	19	270
Leon Creek	19	
Medina River	83	630
Sub-total		1,158
NUECES RIVER BASIN		
Verde Creek	27	
Hondo Creek	32	412
Seco Creek	21	
Sabinal River	38	256
Blanco Creek	14	
Frio River	58	450
Dry Frio River	45	193
Nueces River	64	896
West Nueces River	76	905
Sub-total		3,112
Total		6,392

* See plates 2 and 3

about 12 miles northwest of New Braunfels. It was constructed for flood control, water supply, and recreational purposes. Construction of the project began in April 1958 and deliberate impoundment began on June 16, 1964. Blieders Creek Reservoir, a flood control only project to be located at river mile 5.8 on Blieders Creek, 1.5 miles north of New Braunfels, is in the advance planning stage. Blieders Creek Reservoir, when constructed, will control the runoff from a 14.8 square mile area and provide flood protection to the city of New Braunfels. The Corps of Engineers also has under construction a channel improvement project in the city of San Antonio which includes the clearing, widening, deepening, and straightening of approximately 31 miles of river and creek channels and construction of certain related structures. This project was begun in November 1957 and, when completed, will control the runoff from approximately 114 square miles of drainage area in and adjacent to the city of San Antonio. Pertinent data for the Canyon and Blieders Creek Reservoir projects and the San Antonio Channel Improvement project are given in tables 2, 3, and 4, respectively.

b. Soil Conservation Service Program.-

(1) Watershed Work Plans.- The Soil Conservation Service of the U. S. Department of Agriculture has formulated "Work Plans" for the Martinez, York, and Salado Creeks watershed within the Edwards Reservoir area. The plans provide for construction of 38 watershed protection and floodwater retarding structures to provide control over a drainage area of about 218 square miles. The structures will contain a total of about 63,767 acre-feet of detention storage. On July 1, 1964 the Soil Conservation Service had in operation 18 structures in two of the watersheds in the study area. Of these structures, five are located in the watershed on Martinez Creek, a tributary of Cibolo Creek in Bexar County, and 13 are in the watershed of York Creek, a tributary of the San Marcos River. Pertinent data on the projects which have been constructed and on those additional projects which are planned for the watersheds listed above are presented in table 5, and the locations of the projects are given on plate 4.

(2) Projected Development.- In connection with the report of the United States Study Commission - Texas, the Soil Conservation Service published the results of investigations of the long-range needs for floodwater retarding structures in most of the Texas river basins. These reports were titled "Upstream Flood Prevention and Water Resources Development." The reports for the three basins being studied in this report were published as follows: Guadalupe River Basin, August 1960; San Antonio River Basin, September 1960; and the Nueces River Basin, November 1960. These data have been summarized and supplemented in another SCS publication, "Upstream Flood Prevention in Texas - A Summary Report",

dated June 1963. Pertinent data taken from these reports for additional SCS projects in the study area are given in table 5.

9. EXISTING NON-FEDERAL IMPROVEMENTS.- Development of surface water resources by local interests in the Edwards Reservoir area has been minimal due largely to the availability of ground-water resources. The principal reservoir projects within the three basins are described below.

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

b. San Antonio River Basin.- Local interests developments on the San Antonio River and tributaries consist of Lake Medina and Medina Diversion Reservoir on the Medina River, and Olmos Reservoir on Olmos Creek in San Antonio. Lake Medina with a capacity of 254,000 acre-feet, and Medina Diversion Reservoir with a capacity of 5,750 acre-feet, were completed in 1913. These projects are owned and operated by the Bexar-Medina-Atascosa Counties Water Improvement District No. 1 to provide a water supply and gravity diversion for irrigation of lands in the District. In 1926 the City of San Antonio constructed Olmos Reservoir on Olmos Creek to provide flood protection for certain urban areas of the city. Olmos Reservoir has a storage capacity of about 15,500 acre-feet at top of dam and controls the runoff from about 32 square miles of drainage area. Upon completion of the San Antonio Channel Improvement Project, discussed previously, Olmos Reservoir will become an integral part of the plan for flood protection of the San Antonio area. Pertinent data for the Olmos and Medina Reservoir projects are presented in tables 6 and 7.

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

TABLE 2

CANYON RESERVOIR
(EXISTING)

LOCATION:
R.M. 303 on Guadalupe River and about 12 mi. N.W. of New Braunfels, Texas, in Comal County

DRAINAGE AREA: 1,425 sq. mi.

DAM:

Type:	Rolled earth fill w/spwy in saddle about 2,500 from rt. abutment
Length:	4,410 (main emb.)
Max. Height:	224 ft.
Top Width:	20 ft.
Dike:	10 ft.

SPILLWAY:

Crest:	943.0 ft msl
Length:	1,260 ft. net @ crest
Type:	Broadcrested
Control:	None

INFLOW:

Spillway design flood peak, cfs	687,000
Spillway design flood volume, ac-ft	1,285,800
Spillway design flood runoff, in.	16.92

OUTFLOW: (El. 969.1)

Total routed peak outflow, cfs	508,000
Spillway	502,800
Outlet Works	5,200

OUTLET WORKS:

Type:	1 gate controlled conduit
Dimension:	10' dia.
Invert:	775.0 ft msl
Control:	2 - 5'8"x10' hydraulically operated slide gates

POWER FEATURES:
None

RESERVOIR DATA

Feature	Elev. feet msl	Reservoir Area (acres)	Reservoir Capacity: Accumulative (ac-ft)	Runoff (inches)	Incremental (ac-ft)	Spillway Capacity (cfs)	Outlet Works Capacity (cfs)
Top of Dam	974.0						
Maximum Water Surface	969.1	17,120	1,129,300	14.84		502,800	5,200
Flood Control Pool	943.0	12,890	740,900	9.75	346,400		
Spillway Crest	943.0	12,890	740,900	9.75			
Conservation Pool	909.0	8,240	386,200	5.08	366,400		
Sediment Reserve					28,100*		
Total Storage					740,900		
Maximum tailwater	813.9						
Streambed	750.0						

*Sediment distributed as follows:
19,800 ac-ft below El. 909.0
8,300 ac-ft between El. 909.0 & 943.0

TABLE 3

BLIEDERS CREEK RESERVOIR
(ADVANCE PLANNING)

LOCATION:
R.M. 5.8 on Blieders Creek, Guadalupe River Basin, 1.5 miles N. of New Braunfels, Texas

DRAINAGE AREA:
14.8 sq. mi.

DAM:

Type:	Earth fill
Length:	3130' plus 600' dike
Max. height:	84'
Top width:	20'

SPILLWAY:

Crest:	750.5 ft msl
Length:	Variable
Type:	Natural saddle, left bank
Control:	None

INFLOW:

Spillway design flood peak, cfs	70,300
Spillway design flood volume, ac-ft	27,310
Spillway design flood runoff, in.	34.6

OUTFLOW: (El. 763.1)

Total routed peak outflow, cfs	59,000

OUTLET WORKS:

Type:	1 - conduit
Dimension:	60"
Invert:	
Intake	700.0 ft msl
Outlet	698.0 ft msl
Control	None

POWER FEATURES:
None

RESERVOIR DATA

Feature	Elev. feet msl	Reservoir Area (acres)	Reservoir Capacity: Accumulative (ac-ft)	Reservoir Capacity: Runoff (inches)	Reservoir Capacity: Incremental (ac-ft)	Spillway Capacity (cfs)	Outlet Works Capacity (cfs)
Top of Dam	768.0	684					
Maximum Water Surface	763.1	575	13,657	17.3		58,270	730
Top of Flood Control Pool and Spillway Crest	750.5	368	7,712	9.8	7,312		660
Invert of Outlet Conduit	700.0	16	88	0.1			
Conservation Storage					None		
Sediment Reserve (below el 750.5)					400		
Total storage					7,712		
Streambed	684.0						

TABLE 4

SAN ANTONIO CHANNEL IMPROVEMENT

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

TABLE 5

SUMMARY OF PERTINENT DATA FOR PROPOSED
SOIL CONSERVATION SERVICE RESERVOIRS

Basin	Watershed	Total drainage area (sq.mi.)	No. of structures	Drainage area controlled (sq.mi.)	Pool capacity: Sediment (ac.ft.)	Pool capacity: Flood control (ac.ft.)	Service spillway release rate (cfs)	Number of structures completed
				WORK PLAN DATA (1)				
San Antonio River	Salado Creek	218	16	118	5,263	42,005	1,190	-
San Antonio River	Martinez Creek	87	6	29	2,478	6,511	369	5
Guadalupe River	York Creek	147	16	71	4,950	15,251	393	13
				USSC-T DATA (2)				
Nueces River	NE Utopia Community	4	1	14	42	395	15	-
San Antonio River	Santa Clara Creek	66	8	19	2,127	6,411	190	-
Guadalupe River	Comal Creek	91	6	39	1,280	12,130	240	-

(1) Data from published work plans available as of July 1, 1964; also, see plate 4 for location.

(2) Data from published reports titled "Upstream Flood Prevention and Water Resources Development" prepared by SCS in 1960 for United States Study Commission, Texas.

TABLE 6
OLMOS RESERVOIR
(EXISTING)

LOCATION:
On Olmos Creek in north part of San Antonio, Bexar County, approximately 0.8 mile above confluence of Olmos Creek and San Antonio River.

DRAINAGE AREA: 32 sq. mi.

DAM:
- Type: Concrete, gravity-type
- Length: 1,941 ft.
- Max. height: 57 ft.
- Top width: 25 ft.

SPILLWAY:
None

OUTLET WORKS:
- Type: 6-gate controlled rectangular conduits
- Dimensons: 5'9" x 7'10" each
- Invert: 679.53 ft. msl
- Control: 6 slide gates

USE:
Flood control

RESERVOIR DATA

Feature	Elev. feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac.ft.)	Reservoir capacity: Runoff (inches)	Reservoir capacity: Incremental (ac.ft.)	Outlet works capacity (cfs)
Top of railing	731.0	1,194	18,800	11.01	3,300	13,500
Top of dam	728.0	1,045	15,500	9.08	10,500	13,100
Floor of gate motor operating room	713.5	458	5,000	2.93	5,000	10,900
Outlet works	679.53	4.5	0			
Total storage					18,800	
Streambed	671.4					

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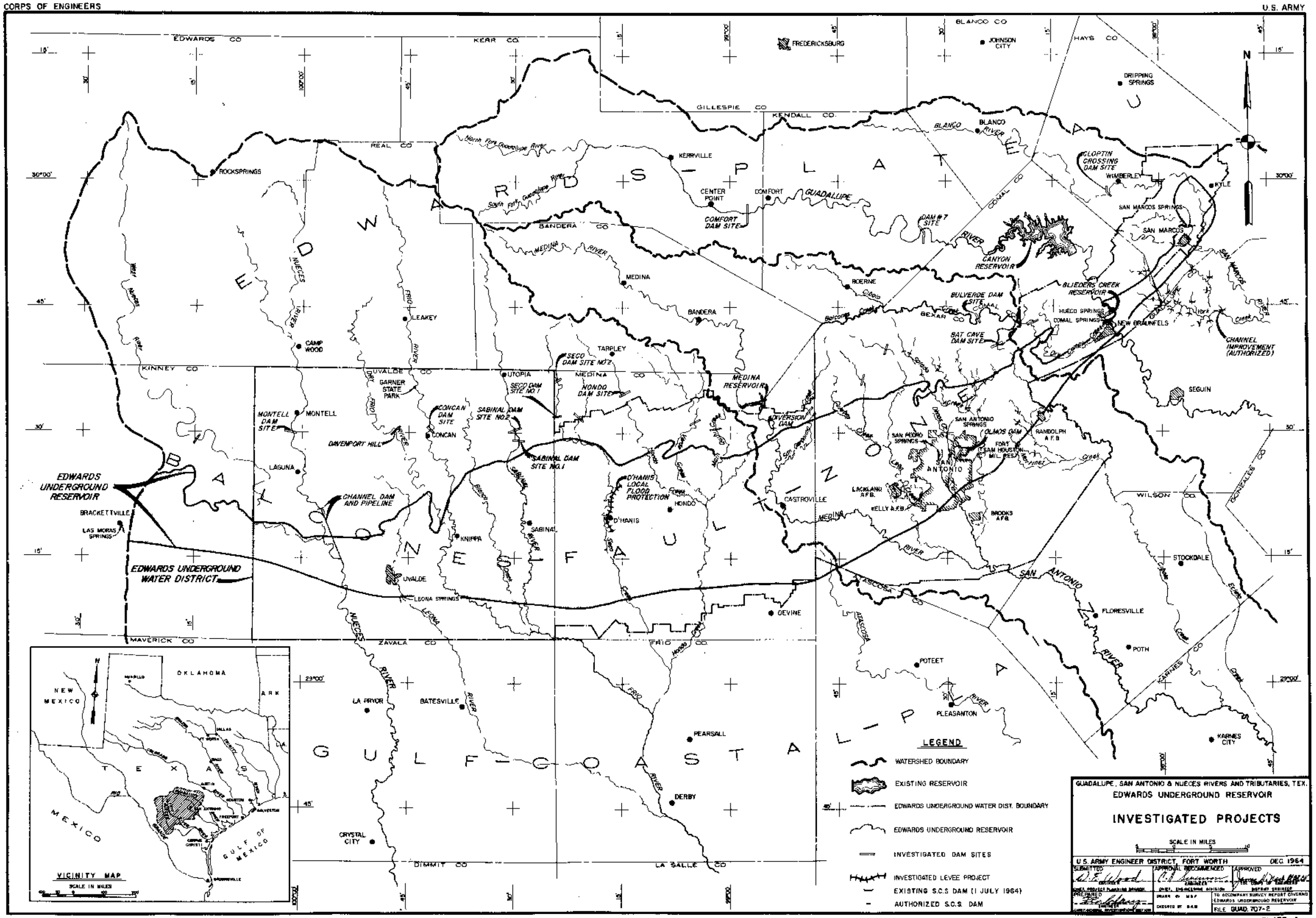


PLATE 4

TABLE 7
MEDINA RESERVOIR
(EXISTING)

LOCATION:
R.M. 70.4 on Medina River 13 mi. north of Castroville, Medina County, and about 28 miles west of San Antonio

DRAINAGE AREA: 633 sq. mi.

DAM:

Type:	Concrete, ogee, gravity-type w/spwy in saddle in right abutment adjacent to west end of dam
Length:	1580 ft.
Max. height:	164 ft.
Top width:	25 ft. w/23' roadway

SPILLWAY:

Crest:	1072 ft. msl
Length:	880 ft.
Type:	Broadcrested
Control:	None

OUTLET WORKS:

Left Bank:

Type:	3-gate controlled conduits
Diameter:	60"
Invert:	966.5 ft. msl
Control:	Lift-type gates

Right Bank:

Type:	2-gate controlled sluices
Diameter:	30"
Invert:	922.5 ft. msl
Control:	Lift-type gates

USE:
Irrigation

RESERVOIR DATA

Feature	Elev. feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac.ft.)	Reservoir capacity: Runoff (inches)	Reservoir capacity: Incremental (ac.ft.)	Spillway capacity (cfs)	Outlet works capacity (cfs)
Top of dam	1084.0						
Maximum water surface	1072.0	5,600	254,000	7.52			
Spillway crest	1072.0	5,600	254,000	7.52	249,200		
Sediment reserve	966.5	328	4,800	0.14	4,800		
Total storage					254,000		
Streambed	920.0						

10. CLIMATE.- The climate over the Edwards Plateau is generally mild with hot summers and cool winters. Freezing temperatures and snowfalls are experienced occasionally, caused by the rapid movement of cold high-pressure air masses from the northwestern highlands.

11. The general elevation of the Edwards Plateau ranges from about 3000 feet above mean sea level in the headwaters of the Nueces River Basin to about 600 feet above mean sea level at San Marcos. The only important topographic feature affecting climate in this area is the Balcones Escarpment which extends from Brackettville eastward through San Marcos.

12. Table 8 gives climatological data relative to temperature, growing season, wind velocity, and humidity at representative United States Weather Bureau stations in and adjacent to the Edwards Plateau.

13. HUMIDITY.- The relative humidity over the Edwards Reservoir area is generally moderate, with the humidity decreasing from Austin westward across the Plateau.

14. WINDS.- The prevailing winds are from the south or southeast during the greater part of the year. Dry southwesterly winds are experienced occasionally. During the winter months, December, January, and February, the high-pressure air masses approaching from the north cause the prevailing wind direction to shift to the north. Wind movements are strongest in March and April; and the lightest wind movements generally occur during August, September, and October. The maximum published wind velocity of 74 miles per hour occurred at San Antonio in August 1942, during a severe tropical storm which swept inland over the Matagorda Bay section. In general, wind movements over the basin are relatively mild.

15. TEMPERATURE.- The mean annual temperature varies from 70.0 degrees at Uvalde in the southwestern part of the Edwards Plateau to 64.4 degrees at Kerrville in the north central part of the Plateau. The mean annual temperature over the Edwards Plateau is about 68 degrees. Temperatures in the Edwards Plateau have ranged from a maximum of 114 degrees recorded at Uvalde to a minimum of minus 7 degrees recorded at Kerrville.

16. GROWING SEASON.- The growing season between killing frosts normally varies from 221 days at Kerrville in the upper portion of the Edwards area to 280 days at San Antonio. The average growing season for the Edwards Plateau is about 254 days.

17. SNOWFALL.- Snowfall is generally light over the Edwards Plateau. It occurs at infrequent intervals over the area and melts rapidly. Seasonal accumulations are not experienced in this area and snowfall therefore does not constitute a flood hazard.

18. PRECIPITATION.- Precipitation near the Edwards Reservoir area has been observed officially at Austin since 1858 and at San Antonio since 1866 when stations were established by the U. S. Weather Bureau at these locations. Three other recording gages have been established at Fredericksburg, LaPryor and Rocksprings, in and near the area at later dates. Plate 5 shows the locations of the rainfall stations in and adjacent to the area.

19. Mean annual rainfall over the Edwards area is approximately 27.8 inches, and varies from about 34.0 inches in the eastern part to about 22.0 inches in the western part. Plate 5 shows isohyetals of mean annual precipitation over the area and mean monthly distribution of rainfall at Hondo, San Marcos, and Carr Ranch. Table 9 shows the maximum, minimum, and United States Weather Bureau published normal annual precipitation at stations in and near the area. It is noted that 11 of the stations listed in table 9 were established prior to 1900.

20. Periods of excessive rainfall have been experienced over all parts of the area. Generally, the highest 24-hour and monthly periods have occurred during major storms. However, there are many instances of heavy precipitation resulting from local thunderstorms. Maximum 24-hour and maximum monthly precipitation for representative stations in and adjacent to the area are given in table 10. Table 11 lists rainfall intensities for stations in and near the Edwards Reservoir area for durations of less than 24 hours.

21. EVAPORATION.- Evaporation records from six stations located adjacent to the Edwards Reservoir area were analyzed and adopted for use in this report. These stations and their operating agency are: Austin, Del Rio and Dilley, by the U. S. Weather Bureau; Sonora and Winter Haven by the Texas Agricultural Experiment Station; and San Antonio by the U. S. Field Station, Department of Agriculture. Austin and San Antonio are located northeast and south, respectively, and adjacent to the Edwards Reservoir area. Sonora is 40 miles northwest of the area. Del Rio is 40 miles west. Dilley and Winter Haven are 60 and 70 miles, respectively, south from the area. Austin, Dilley, and Winter Haven each have records for 30 years or more. San Antonio has records for 24 years while Del Rio and Sonora have records of 12 and 11 years, respectively. Table 12 gives pertinent data for the six evaporation stations. Evaporation is greatest in the higher portion of the area to the northwest and least in the lower and more humid southeastern area. Approximately two-thirds of the annual evaporation normally occurs during the six warm months, April through September.

22. RIVER STAGE AND DISCHARGE.- The discussion of the stream gages in the Nueces River Basin is confined to the gages above the Asherton gage on the Nueces River, the Derby gage on the Frio River, and the city of Three Rivers on the Atascosa River. Plate 2 shows

TABLE 8

CLIMATOLOGICAL DATA

Station	Years of complete record (1)	Temperature in degrees Fahrenheit: Mean Annual	Maximum recorded	Minimum recorded
Austin AP (2)	107	68.2	109	-2
Blanco	63	66.4	110	-6
Boerne	69	66.2	112	-4
Del Rio (2) *	14	69.8	111	11
Fredricksburg (2)	54	67.1	109	-5
Hondo	59	69.3	112	4
Kerrville	66	64.4	110	-7
Luling (2)	75	68.9	110	-3
New Braunfels	76	70.0	110	2
San Antonio AP	77	68.7	107	0
San Marcos	59	67.9	111	-2
Seguin (2)	36	69.2	110	0
Uvalde	59	70.0	114	6

Station	Growing season: Av. length (days)	Wind velocity: Av. mph	Fastest mile	Relative humidity in percent (years): 6 a.m.	Noon	6 p.m.	Midnight
Austin AP (2)	263	9.5	57	81	51	48	71
Del Rio (2) *	287	7.4	62	79	53	46	64
San Antonio AP	280	9.3	74	83	54	52	76

(1) All data as of Dec. 31, 1962.
(2) Station outside of basin.
* Data as of Dec. 31, 1958.

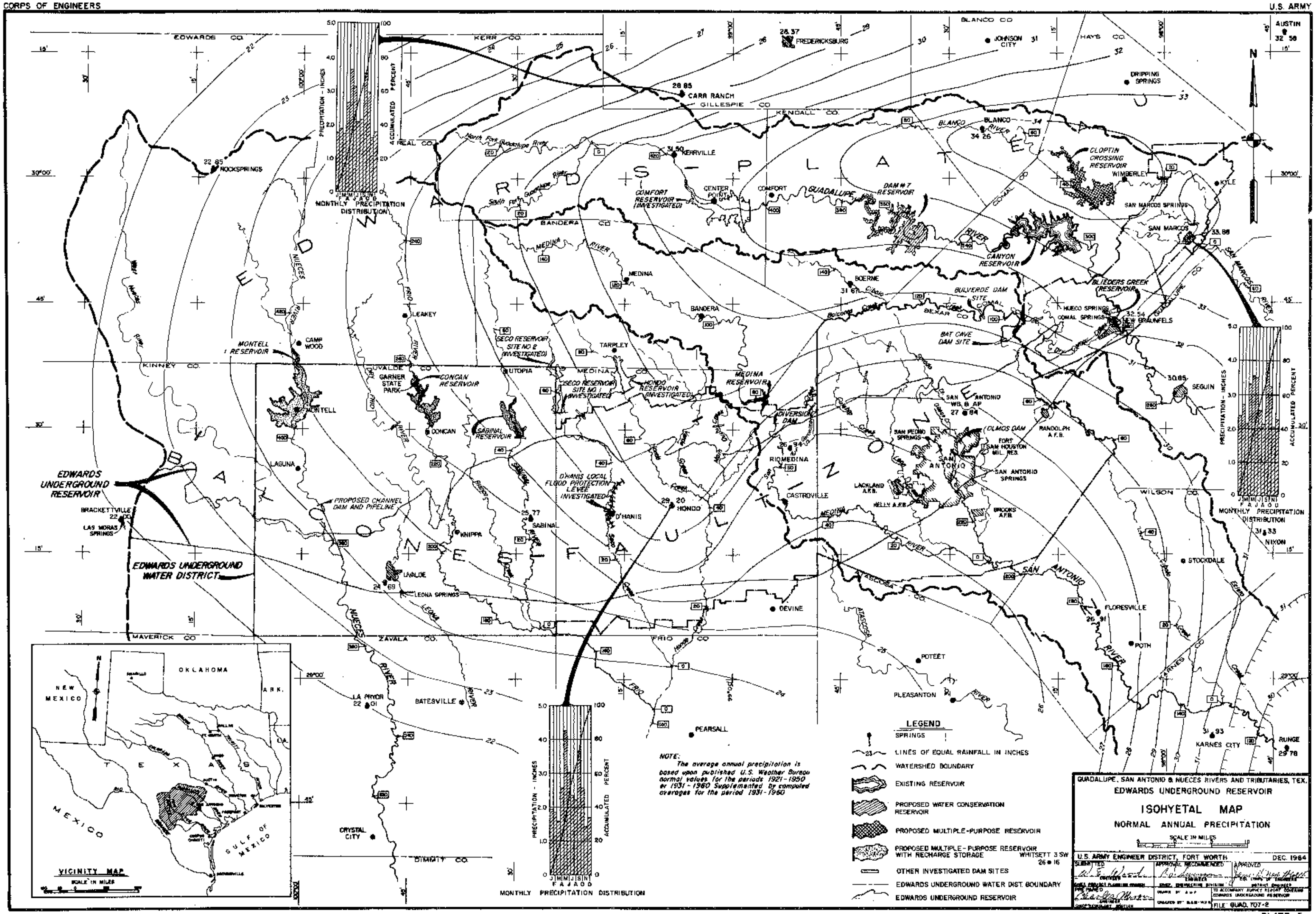

CORPS OF ENGINEERS
U.S. ARMY
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
EDWARDS PLATEAU
BALCONES FAULT ZONE
MONTHLY PRECIPITATION DISTRIBUTION
PRECIPITATION - INCHES
ACCUMULATED PERCENT
NOTE:
The average annual precipitation is based upon published U.S. Weather Bureau normal values for the periods 1921-1950 or 1931-1960 Supplemented by computed averages for the period 1931-1960
LEGEND
SPRINGS
LINES OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
VICINITY MAP
SCALE IN MILES
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
NORMAL ANNUAL PRECIPITATION
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: QUAD. 707-2

PLATE 5

TABLE 9

PRECIPITATION DATA

Station	Years of complete record (1)	Annual precipitation (in.) Maximum	Minimum	U.S.W.B. normal (2)
Austin *	104	64.68	11.42	32.58
Blanco	66	55.06	12.98	34.26
Boerne	74	62.47	10.29	31.67
Brackettville	85	45.37	6.45	22.00
Carr Ranch *	41	49.31	9.82	28.85
Floresville *	46	46.32	7.88	26.91
Fredericksburg *	54	47.23	11.29	28.37
Hondo	67	58.73	11.92	29.20
Karnes City *	23	56.57	16.68	31.93
Kerrville	66	57.57	12.33	31.50
LaPryor *	44	42.01	5.94	22.01
New Braunfels	74	60.21	10.12	32.54
Nixon *	41	58.10	16.64	31.33
Rio Medina	39	46.27	12.25	26.94
Rock Springs	30	38.16	10.26	22.85
Runge *	66	46.81	13.60	29.78
Sabinal	58	48.21	11.29	25.77
San Antonio *	96	50.30	10.11	27.84
San Marcos	66	52.24	13.42	33.88
Seguin *	58	49.47	13.80	30.85
Uvalde	68	45.02	9.29	24.69
Whitsett *	46	49.36	5.19	26.16

(1) To 31 December 1962. (2) The average annual precipitation is based upon published US Weather Bureau normal values for the periods 1921-1950 or 1931-1960 supplemented by computed averages for the period 1931-1960.
* Outside Edwards Plateau.

TABLE 10

MAXIMUM 24-HOUR AND MAXIMUM MONTHLY PRECIPITATION

Station	Years of complete record through 1962	Maximum 24-hour rainfall (inches)	Maximum monthly rainfall (inches)
Austin AP	104	19.03	20.78
Bankersmith	22	12.95	17.51
Blanco	66	17.51	22.66
Fredericksburg	54	8.03	16.48
Garner State Park	11	4.17	10.97
Hall Ranch	22	3.73	10.26
Hye	22	22.96	24.12
Kerrville	76	11.60	19.94
LaPryor	44	7.78	14.56
Luling	74	6.51	13.76
New Braunfels	74	9.41	16.41
Rocksprings	30	4.47	16.57
San Antonio AP	96	7.08	11.64
Tarpley	24	4.73	10.35

TABLE 11

RAINFALL INTENSITIES IN AND NEAR
THE EDWARDS UNDERGROUND AREA

Station	Total precipitation in inches *				
	1 hr	2 hr	3 hr	6 hr	12 hr
Austin	3.46	4.41	5.47	7.02	8.51
San Antonio	3.07	4.64	5.82	6.11	6.81
Hall Ranch	1.85	3.25	3.25	3.25	3.35
Rocksprings	1.56	2.14	2.47	3.08	3.91
Tarpley	1.90	3.40	4.00	4.41	4.47
Garner State Park	2.23	2.48	2.90	3.59	3.97

* Records published in U. S. Weather Bureau Technical Paper No. 15.

Note: Unofficial observations indicate published records have been exceeded in some areas.

the location of the gages installed by the U. S. Geological Survey for the systematic collection of records in the study area. The first gages installed in the Nueces River Basin were near Cinonia on the Nueces River and near Derby on the Frio River. The former was installed July 5, 1915 and the latter August 1, 1915. Only a partial record was maintained at the Cinonia gage which was discontinued in September 1925. The record at Derby is complete from time of installation of the gage to date. Gages were established in the latter part of 1923 at Laguna on the Nueces River and Concan on the Frio River. The largest increase in the number of gages took place when seven recording gages were installed in 1952. There were 18 recording gages operating in the upper watershed of the Nueces River Basin as of September 30, 1962.

23. The discussion of the stream gages in the Guadalupe and San Antonio River Basins is confined to the gages upstream from Gonzales on the Guadalupe River and Falls City on the San Antonio River. Plate 3 shows the location of the gages. Observation of streamflow on the Guadalupe River began on September 1, 1904, when the U. S. Weather Bureau established a staff gage at the Gonzales Water Power Company in Gonzales, Texas. The daily stages are published for this gage. The U. S. Geological Survey established gages at New Braunfels and near Comfort in January 1915 and January 1918, respectively. In January 1928, the gage at New Braunfels was moved upstream above the mouth of Comal River eliminating the springflow from Comal Springs from the base flow that was recorded as runoff at the lower site. Since the 1920's, numerous gages have been installed in the Guadalupe and San Antonio River Basins. There were 28 recording streamflow gages and one non-recording gage in the basins as of September 30, 1962.

24. ANNUAL RUNOFF.- The observed average annual runoff at the principal gages in those portions of the Nueces, Guadalupe, and San Antonio River Basins covered by this report are given in tables 13 and 14. Also given are the minimum and maximum annual runoff for the purpose of illustrating the extremes to which the annual runoff in these basins are subject.

25. DROUGHTS.- Hydrologic records for the Edwards Plateau illustrate recurring patterns of long to moderate drought and periods of heavy rainfall. The period of streamflow measurements used in this report includes the most severe drought that has been experienced since accurate records became available. The recent drought which ended in the early part of 1957 is the critical drought of record.

26. The prolonged drought of the period 1947 through 1956, which was experienced over most of the Guadalupe River Basin, was broken by one of the most intense storms of record, that of September 1952. Rainfall records for Blanco and Kerrville, however, show that despite this storm, there was an accumulated rainfall deficiency

of approximately 70 inches and 59 inches, respectively, for the 10-year period. The normal annual rainfall at Blanco is 34.26 inches. The annual rainfall at Blanco during the 1947-1956 period varied from 14.4 inches in 1954 to 53.7 inches in 1952, with an average for the period of 27.3 inches. The normal annual rainfall at Kerrville is 31.50 inches, while the annual rainfall during the 1947-1956 period varied from 14.04 inches in 1956 to 40.9 inches in 1952, with an average for the period of 25.6 inches. The drought ended in the Guadalupe River Basin during the spring of 1957 when over 21 inches of rain fell during the months of April and May.

27. The prolonged drought of the period 1950 through 1956 which was experienced over most of the Nueces River Basin, was broken in the Upper Nueces River watershed in September 1955 by one of the most intense storms of records over the Upper Nueces watershed. The storm, which was centered over the Nueces River upstream of Montell Dam site, produced the maximum known peak discharge at the Laguna gage, downstream from Montell Dam site. The average rainfall during the drought period was approximately 20.0 inches over the Nueces River Basin above the Balcones Fault Zone while the normal annual rainfall is between 26 and 27 inches.

28. STORM CHARACTERISTICS.- The storms that cause precipitation on the Edwards Plateau are of three general types: (1) thunderstorms, resulting in devastating cloudbursts; (2) frontal storms; and (3) cyclonic storms originating in the tropics or the Western Gulf of Mexico. The majority of the precipitation on the plateau results from disturbances of the first two types. Thunderstorms, as here described, are produced and maintained by local convectional currents of the vertical type. They are sometimes accompanied by excessive rainfall for periods up to about 6 or 8 hours, but rarely produce excessive rainfall over extensive areas. Thunderstorms cause major flooding in localized areas and particularly in the headwaters of the basins in the Edwards Plateau. Frontal storms that cause rainfall in the area result from the forced ascension of warm moisture-laden air masses originating over the warm oceanic areas to the south. The lifting of the warmer air mass is accomplished either by direct convergence of a tropical air mass and a polar air mass, or by the convergence and partial encompassing of a tropical air mass by several denser air masses. The cyclonic storms originate in the tropics and the Western Gulf of Mexico. When these storms move inland they tend to curve to the northeast and to pass up the Mississippi Valley. In following this course, the heaviest precipitation is generally experienced in the lower part of the basin with little effect on the Edwards Plateau.

29. MAJOR BASIN STORMS.- Some of the major flood-producing storms that have occurred on or near the Edwards Plateau are as follows: May 25-30, 1929; June 30-July 2, 1932; May 31, 1935; June 10-15, 1935; September 26-27, 1946; September 9-11, 1952;

TABLE 12

AVERAGE MONTHLY EVAPORATION DATA
AUSTIN, DEL RIO, DILLEY, SAN ANTONIO, SONORA, AND WINTER HAVEN, TEXAS

Month	Austin, Texas 1930-1960 U. S. Weather Bureau Pan Coefficient 0.69			Del Rio, Texas 1946-1957 U. S. Weather Bureau Pan Coefficient 0.69			Dilley, Texas 1931-1960(1) U. S. Weather Bureau Pan Coefficient 0.69			San Antonio, Texas 1907-1930 Bureau of Plant Industry Pan Coefficient 0.94			Sonora, Texas 1950-1960(2) Bureau of Plant Industry Pan Coefficient 0.94			Winter Haven, Texas 1936-1960 Bureau of Plant Industry Pan Coefficient 0.94		
	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)	Observed Pan Evaporation (inches)	Evaporation from Reservoir Surface (inches)	Observed Precipitation (inches)
January	2.73	1.88	2.32	3.43	2.37	.79	2.94	2.03	1.30	2.46	2.32	1.15	2.56	2.41	1.34	2.09	1.96	1.18
February	3.21	2.21	2.55	4.61	3.18	1.08	3.51	2.42	1.43	3.03	2.85	1.50	3.16	2.97	1.15	2.74	2.58	1.14
March	5.11	3.53	2.09	8.05	5.55	.67	6.08	4.20	0.93	4.46	4.19	1.87	4.97	4.67	1.14	4.66	4.38	1.00
April	6.19	4.27	3.47	9.45	6.52	1.91	7.21	4.96	2.03	5.53	5.20	3.19	5.96	5.60	1.25	5.52	5.19	1.81
May	7.44	5.13	3.88	10.75	7.42	2.51	8.51	5.87	2.90	6.51	6.12	3.15	6.20	5.83	1.86	6.54	6.15	3.46
June	8.95	6.18	3.18	12.58	8.68	1.89	9.89	6.82	2.81	7.95	7.47	2.43	7.71	7.25	2.75	7.93	7.45	2.09
July	9.90	6.83	2.11	14.38	9.92	.97	11.07	7.64	2.12	9.09	8.55	1.66	8.98	8.44	1.62	8.80	8.27	1.74
August	9.79	6.76	1.94	13.37	9.23	1.09	10.87	7.50	1.68	9.19	8.64	1.69	8.37	7.87	1.49	8.70	8.18	2.33
September	7.35	5.07	3.43	9.90	6.83	2.28	11.24	7.76	2.65	6.81	6.40	2.65	6.40	6.02	2.36	6.29	5.91	2.79
October	5.65	3.90	3.00	7.34	5.06	1.23	5.85	4.04	2.08	5.10	4.79	2.91	5.06	4.76	2.09	4.54	4.27	2.13
November	3.64	2.51	2.11	4.97	3.43	.45	3.73	2.57	1.22	3.16	2.97	2.13	3.49	3.28	.50	3.02	2.84	.82
December	2.66	1.84	2.56	3.61	2.49	.52	2.78	1.92	1.56	2.45	2.30	1.75	2.84	2.67	.58	2.14	2.01	1.09
ANNUAL	72.62	50.11	32.64	102.44	70.68	15.39	83.68	57.73	22.71	65.74	61.80	26.08	65.70	61.77	18.13	62.97	59.19	21.58
NET ANNUAL LOSS FROM RESERVOIR SURFACE		17.47"			55.29"			35.02			35.72"			43.64"			37.61"	

(1) No record May-August 1943; January, February 1950.

(2) No record January-May 1950; June 1953.

TABLE 13

ANNUAL RUNOFF DATA (OBSERVED)

NUECES RIVER BASIN

Stream-gaging stations	Drainage area (sq.mi.)	Period of record				Annual runoff (inches)		
		From	Through	Length Years	Length Months	Maximum (1)	Minimum (1)	Mean
Nueces at Laguna	764	10/23	9/62	39	0	10.85	0.41	2.45
Nueces nr Uvalde	1,930	10/28	4/39	11	7	7.18	0.06	1.61
Nueces below Uvalde	1,947	5/39	9/62	23	5	3.13	0.03	0.61
Nueces nr Cinonia	2,150	7/15	9/25	9	9	1.26	0.04	0.35
Nueces at Asherton	4,082	10/40	9/62	23	0	1.68	0.02	0.56
West Nueces nr Brackettville (2)	700	10/40	9/62	17	6	4.60	0.00	0.67
Frio at Concan (3)	405	11/23	9/62	38	11	14.21	0.29	3.35
Frio nr Uvalde	661	9/52	9/62	10	1	1.92	0.00	0.40
Frio nr Derby	3,493	8/15	9/62	47	2	4.23	0.007	0.52
Dry Frio nr Reagan Wells	117	9/52	9/62	10	1	11.74	0.35	3.60
Sabinal nr Sabinal	206	10/42	9/62	20	0	11.39	0.05	2.47
Sabinal at Sabinal	247	9/52	9/62	10	1	7.45	0.02	1.46
Hondo nr Tarpley	101	9/52	9/62	10	1	16.66	0.06	4.24
Hondo nr Hondo	132	9/52	9/62	10	1	9.46	0.00	1.81
Hondo at King's Waterhole	142	10/61	9/62	1	0	-	-	-
Seco at Miller's Ranch	43	5/61	9/62	1	5	-	-	-
Seco nr Utopia	53	9/52	9/61	9	1	15.19	0.09	4.02
Seco nr D'Hanis	87	9/52	9/62	10	1	10.56	0.00	1.56
Seco nr Crook's Ranch	168	10/61	9/62	1	0	-	-	-
Leona nr Uvalde (4)	146	1/39	9/62	24	9	-	-	-
Atascosa at Pleasanton (5)	341	1/54	9/62	8	9	-	-	-

(1) Water year.
(2) Station discontinued September 30, 1950 and re-established March 29, 1956.
(3) Runoff for 1930 was estimated (USCE).
(4) Springflow only from Leona Springs.
(5) Staff gage established by USGS for the USCE. Gage used for high stages only.

TABLE 14

ANNUAL RUNOFF DATA (OBSERVED)

GUADALUPE AND SAN ANTONIO RIVER BASINS

Stream-gaging stations	Drainage area (sq.mi.)	Period of record: From	Period of record: Through	Length: Years	Length: Months	Annual runoff (inches): Maximum (1)	Annual runoff (inches): Minimum (1)	Annual runoff (inches): Mean
Guadalupe nr Comfort (2)	762	1/18	9/32	13	6	6.75	0.91	2.37
Guadalupe at Comfort	836	6/39	9/62	23	4	5.81	0.24	2.36
Guadalupe nr Spring Branch	1,282	7/22	9/62	40	3	8.37	0.14	2.81
Guadalupe at Sattler	1,430	3/60	9/62	2	7	-	-	-
Guadalupe at New Braunfels	1,516	1/28	9/62	34	9	9.25	0.12	3.28
Guadalupe at New Braunfels (3)	1,635	2/15	12/27	12	11	13.07	2.85	6.39
Guadalupe at Gonzales (4)	3,452	9/04	9/62	58	1	-	-	-
Johnson Cr. nr Ingram (5)	115	10/42	9/62	19	2	3.76	0.56	1.68
Rebecca Cr. nr Spring Branch	11	2/60	9/62	2	7	-	-	-
Comal at New Braunfels (6)	117	1/28	9/62	34	9	-	-	-
San Marcos at San Marcos (6) (7)	84	7/15	9/62	11	7	-	-	-
San Marcos at Luling (8)	833	5/39	9/62	23	5	12.41	1.23	5.46
Blanco at Wimberley	353	7/28	9/62	33	6	13.69	0.25	4.67
Blanco nr Kyle	410	6/56	9/62	6	4	11.69	1.40	-
Plum Creek at Lockhart	113	5/59	9/62	3	5	-	-	-
Plum Creek nr Luling	356	4/30	9/62	32	6	10.08	0.28	3.51
San Antonio at San Antonio (9)	42	2/15	9/62	38	4	-	-	-
San Antonio nr Elmendorf	1,743	Installed September 1962				-	-	-
San Antonio nr Falls City (10)	2,113	5/25	9/62	37	5	-	-	-
Salado Creek at Upper San Antonio	137	9/60	9/62	2	1	-	-	-
Salado Creek at Lower San Antonio	189	9/60	9/62	2	1	-	-	-
Medina nr Pipe Creek (11)	474	10/22	9/62	23	6	10.70	0.15	3.09
Medina nr Rio Medina (12)	650	2/22	9/62	21	7	-	-	-
Medina nr San Antonio (13)	1,317	8/39	9/62	23	2	-	-	-
Red Bluff Creek nr Pipe Creek	56	4/56	9/62	6	6	6.28	0.009	-
Calaveras Creek nr Elmendorf (14)	7	1/57	9/62	5	9	-	-	-
Calaveras Creek nr Elmendorf (15)	77	9/54	9/62	8	1	-	-	-
Cibolo Creek nr Boerne	68	Installed March 1, 1962				-	-	-
Cibolo Creek nr Bulverde	198	5/46	9/62	16	5	3.15	0.00	0.61
Cibolo Creek at Selma	274	3/46	9/62	16	7	2.76	0.00	0.47
Cibolo Creek nr Falls City	827	10/30	9/62	32	0	5.20	0.17	1.81

(1) Water year. (2) Partial record 1/18 through 5/22. (3) Base flow includes springflow from Comal Springs. March 1898 to December 1899, gage heights and occasional discharge measurements; 1900-1902, occasional discharge measurements only; published in reports of Geological Survey. (4) U. S. Weather Bureau staff gage, stage only. (5) Gage discontinued November 30, 1959, re-established November 9, 1961. (6) Normal flow of river comes from springs, drainage area of stream not applicable. (7) Partial record 7/15 through 8/21; discontinued September 7, 1921, re-established May 26, 1956. (8) Base flow is mostly from large springs near San Marcos. (9) Normal flow of river formerly came from springs and in later years from release of pumpage from wells. The station was discontinued November 16, 1929; re-established February 15, 1939. (10) Flow partly regulated by Medina Lake and Olmos flood-control reservoir. (11) This gage discontinued September 30, 1934; re-established December 21, 1952. (12) All flow is seepage under and around Medina Dam except for occasional flow over spillway. This gage discontinued September 30, 1934; re-established January 29, 1953. Annual figures only are available for water years 1923-34. (13) 633 square miles controlled by Medina Reservoir. (14) Gage installed to measure contents of SCS reservoir. (15) 25.5 square miles are above 7 flood-control structures.

September 23-24, 1955. Isohyetal maps and typical mass curves of precipitation are shown on plates 6 through 12, and a description of these storms is given in the following paragraphs.

30. STORM OF MAY 25-30, 1929.- The center of this storm was in the Blanco River watershed about six miles north of the Cloptin Crossing Dam site. At the storm center rainfall of 15.0 inches was recorded for the storm period, of which about 12.0 inches fell in a 6-hour period. Other rainfall amounts in the area were as follows: Fischer's Store, 10.4 inches; San Marcos, 9.8 inches; Henly, 15.0 inches; Dripping Springs, 8.0 inches. The average depth of precipitation over the Blanco River watershed was about 10.7 inches. The depth of rainfall from the maximum depth-area curve for the 1929 storm is 13.7 inches for a drainage area of 428 square miles (equivalent to the drainage area above the mouth of the Blanco River). This storm produced the maximum stages on the Blanco River at Wimberley and Kyle since 1869 and 1882, respectively. The isohyetal map and typical mass curves of precipitation are shown on plate 6.

31. STORM OF JUNE 30-JULY 2, 1932.- This storm had several centers; however, the most intense center was located in the Upper Guadalupe River Basin at the State Fish Hatchery near Ingram. The State Fish Hatchery recorded 35.6 inches of rainfall. Another center was located in the Upper Sabinal Basin near the Humble Pump Station. The pump station recorded 33.5 inches of rainfall. Rio Frio recorded 24.0 inches of rainfall in the Frio River Basin. Other rainfall amounts in the area were as follows: Tarpley, 2 miles northwest, 22.0 inches; Uvalde, 20.2 inches; Rothe Ranch, 18.3 inches; Sabinal, 17.5 inches; Utopia, 14.0 inches. This was considered a 42-hour storm; however, the majority of the rainfall occurred in an 18-hour period. This storm produced the maximum stage since 1869 on the Frio River at Concan; the maximum stage since 1892 on the Sabinal River near Sabinal; and the maximum stage since 1900 on the Guadalupe River at Comfort. The isohyetal map and typical mass curves of precipitation are shown on plate 7.

32. STORM OF MAY 31, 1935.- The center of the storm was located in the Seco Creek watershed near Woodward's Ranch, about 17 miles north of D'Hanis. The Woodward Ranch reported 22.0 inches of rainfall during a 3-4 hour period on the morning of May 31. Lutz Ranch reported 12.5 inches of rainfall. D'Hanis and Hondo reported 12.0 and 9.2 inches, respectively. Sabinal reported 7.7 inches of rainfall. This storm produced the maximum stage since at least 1866 on Seco Creek near D'Hanis. The isohyetal map and typical mass curves of precipitation are shown on plate 8.

33. STORM OF JUNE 10-15, 1935.- The center of the storm was located slightly west of the Nueces River Basin approximately 15 miles south of Carta Valley. The amount of rainfall that was

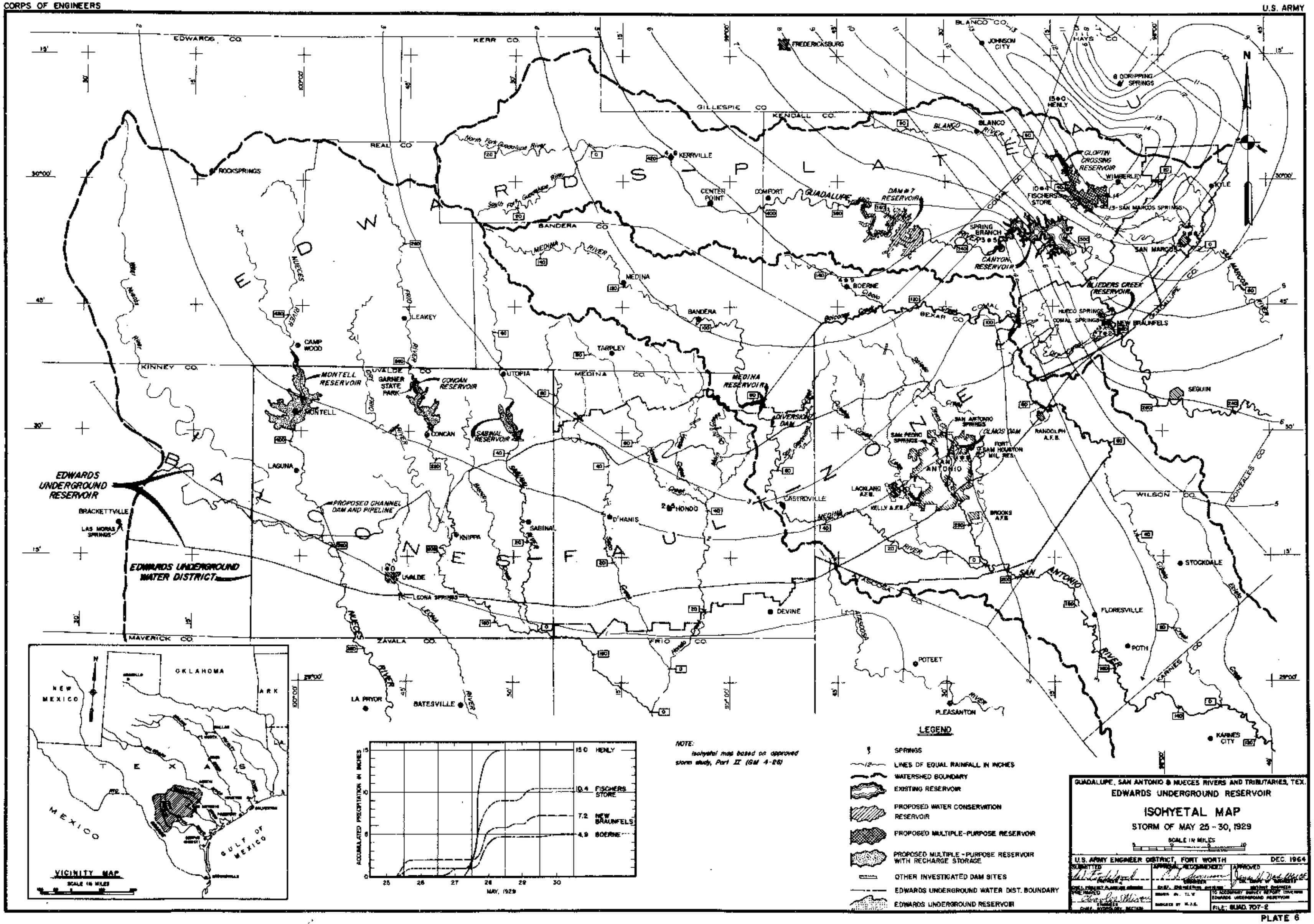
recorded at the storm center was 17.6 inches. Forty-two miles north of Brackettville 14.2 inches of rain was reported. Rocksprings and Montell reported 12.1 and 8.5 inches, respectively. This storm produced the maximum stage since at least 1879 on the West Nueces near Brackettville, and the maximum stage since at least 1836 on the Nueces River at Cotulla. The isohyetal map and typical mass curves of precipitation are shown on plate 9.

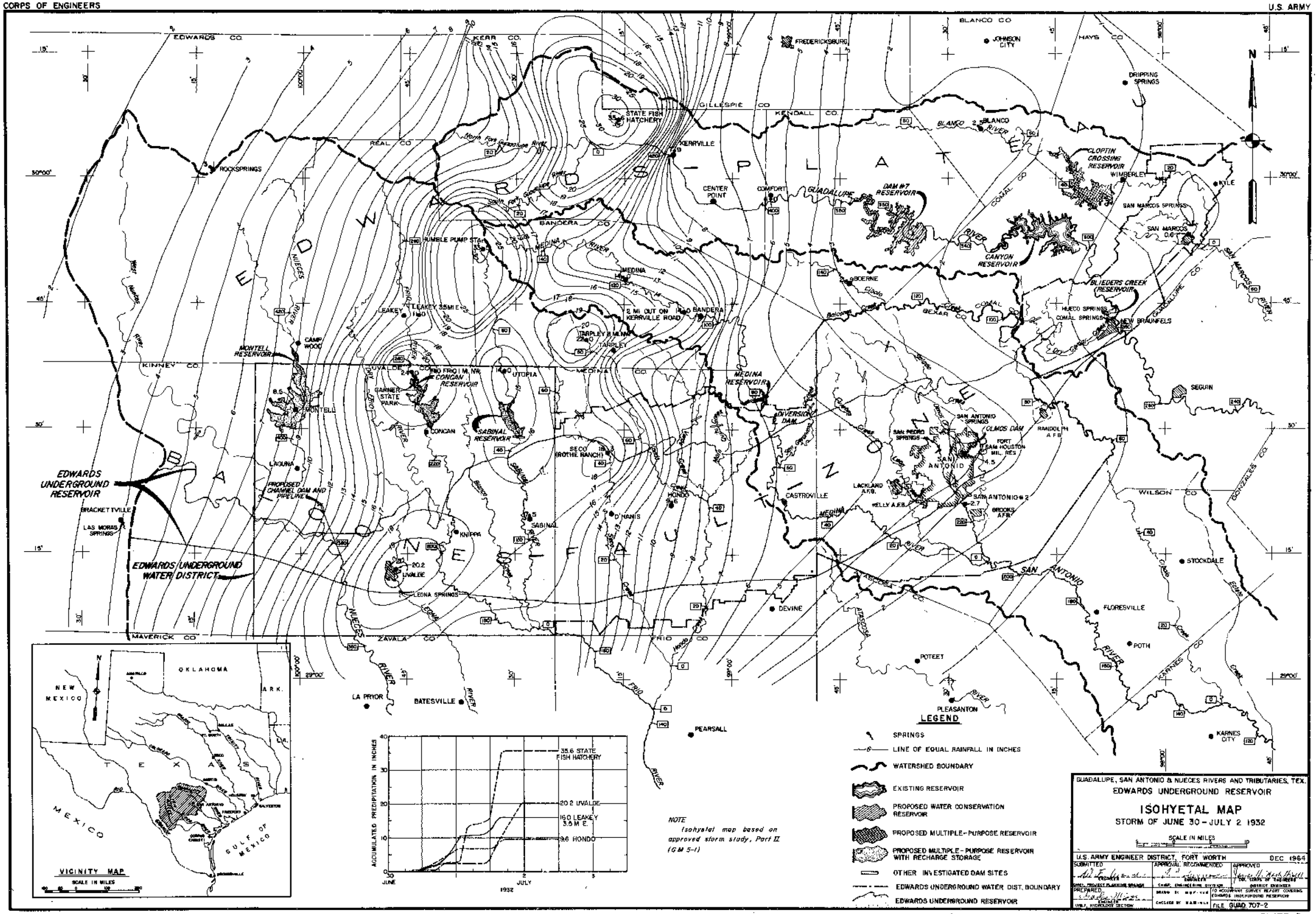
34. STORM OF SEPTEMBER 26-27, 1946.- The center of the storm was located 11 miles southeast of San Antonio at the State Apiculture Farm. The amount of rainfall that was recorded at the State Farm was 17.2 inches. Other rainfall amounts in the vicinity were as follows: San Antonio Nursery, 13.0 inches; San Antonio Airport, 6.9 inches; Kelly AFB, 5.8 inches. Most of the rainfall came within a six to eight hour period. This storm was particularly intense on Calaveras Creek at San Antonio. The isohyetal map and typical mass curves of precipitation are shown on plate 10.

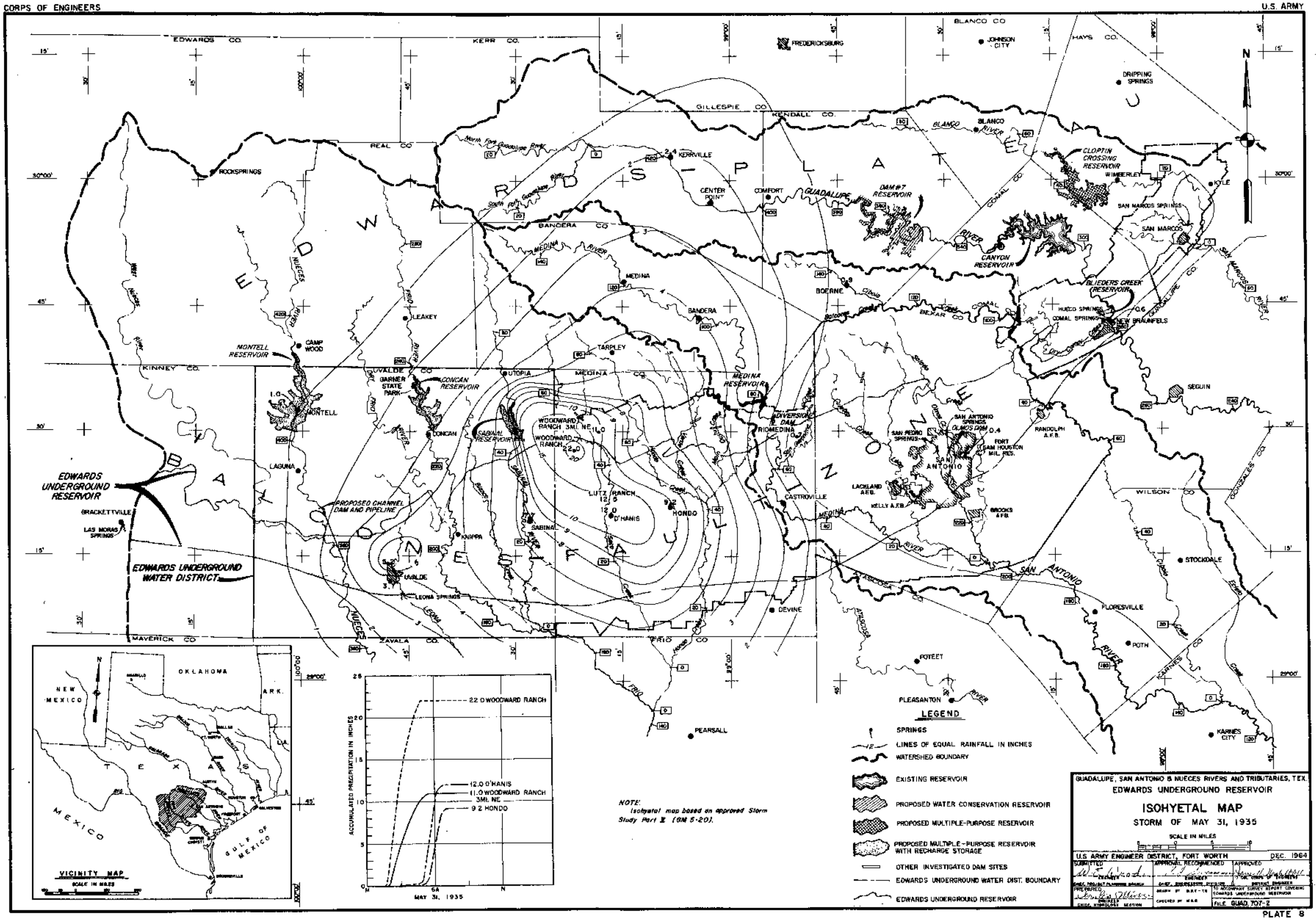
35. STORM OF SEPTEMBER 9-11, 1952.- The storm had two centers within the Edwards Plateau. One of the centers (GS-20) was located just inside the Blanco River watershed approximately four miles southeast of Hye. The amount of rainfall reported at the storm center was 28.8 inches. The other center (F-38) was located approximately seven miles northeast of Comfort. The amount of rainfall reported was 25.1 inches. Some of the other rainfall amounts in the area are as follows: Hye, 26.0 inches; Blanco, 21.1 inches; Boerne, 12.6 inches; San Marcos, 9.7 inches; Kerrville, 8.9 inches; New Braunfels, 8.8 inches. The isohyetal map and typical mass curves of precipitation are shown on plate 11.

36. STORM OF SEPTEMBER 23-24, 1955.- This storm had three distinct centers. Only one of these severe centers was located within the area of study. A 24-inch center (C-1) on the Nueces River at the Edwards-Real County line southeast of Rocksprings, was the principal contributor to the Nueces River flood. Other rainfall amounts in the area are as follows: C-2, 22.0 inches; C-3, 12.0 inches; C-4, 12.0 inches; C-5, 10.2 inches; C-6, 10.0 inches; C-7, 9.0 inches; C-8, 8.0 inches; Crider's Ranch, 5.6 inches; Lynxhaven Ranch, 1.9 inches. This storm produced the maximum stage since at least 1866 on the Nueces River at Laguna. The volume of flow was decreased 82 percent at Three Rivers. Much of the loss occurred before the flood reached Uvalde due to the Balcones Fault Zone which crosses the Nueces River upstream from the Uvalde gage. The isohyetal map and typical mass curves of precipitation are shown on plate 12.

37. FLOODS.- In general, the flooding experienced along the Edwards Plateau is produced by intense storms with relatively limited areal coverage. The storm of June 30-July 2, 1932, was more general in character than any other major storm of record in the vicinity


CORPS OF ENGINEERS
U.S. ARMY
EDWARDS CO.
KERR CO.
GILLESPIE CO.
KENDALL CO.
REAL CO.
BANDERA CO.
KINNEY CO.
UVALDE CO.
MEDINA CO.
BEXAR CO.
COMAL CO.
WILSON CO.
MAVERICK CO.
ZAVALA CO.
FRIO CO.
ATASCOSA CO.
KARNES CO.
GONZALES CO.
HAYS CO.
BLANCO CO.
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
15.0 HENLY
BLANCO
KERRVILLE
CENTER POINT
COMFORT
ROCKSPRINGS
GLOPTIN CROSSING RESERVOIR
WIMBERLEY
KYLE
10.4 FISCHERS STORE
SAN MARCOS SPRINGS
SAN MARCOS
DAM #7 RESERVOIR
SPRING BRANCH
CANYON RESERVOIR
BOERNE
BLIEDERS CREEK RESERVOIR
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
MEDINA
BANDERA
LEAKEY
CAMP WOOD
TARPLEY
MONTELL RESERVOIR
MONTELL
GARNER STATE PARK
CONCAN RESERVOIR
CONCAN
UTOPIA
SABINAL RESERVOIR
MEDINA RESERVOIR
DIVERSION DAM
SEGUIN
SAN ANTONIO SPRINGS
OLMOS DAM
SAN PEDRO SPRINGS
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
SAN ANTONIO
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
CASTROVILLE
LAGUNA
EDWARDS UNDERGROUND RESERVOIR
BRACKETTVILLE
LAS MORAS SPRINGS
PROPOSED CHANNEL DAM AND PIPELINE
HONDO
D'HANIS
KNIPPA
SABINAL
UVALDE
EDWARDS UNDERGROUND WATER DISTRICT
LEONA SPRINGS
DEVINE
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
EDWARDS PLATEAU
BALCONES FAULT ZONE
NEW MEXICO
OKLAHOMA
ARK
LA.
TEXAS
MEXICO
GULF OF MEXICO
VICINITY MAP
ACCUMULATED PRECIPITATION IN INCHES
15.0 HENLY
10.4 FISCHERS STORE
7.2 NEW BRAUNFELS
4.9 BOERNE
MAY, 1929
NOTE: Isohyetal map based on approved storm study, Part II (GM 4-26)
LEGEND
SPRINGS
LINES OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF MAY 25 - 30, 1929
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
FILE: GUAD. 707-2
PLATE 6


LEGEND
SPRINGS
LINE OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
NOTE
Isohyetal map based on approved storm study, Part II (GM 5-1)
ACCUMULATED PRECIPITATION IN INCHES
JUNE
JULY
1932
35.6 STATE FISH HATCHERY
20.2 UVALDE
16.0 LEAKEY 3.5 M E.
9.6 HONDO
VICINITY MAP
SCALE IN MILES
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
EDWARDS PLATEAU
BALCONES FAULT ZONE
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF JUNE 30 - JULY 2 1932
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
FILE GUAD 707-2


EDWARDS PLATEAU
BALCONES FAULT ZONE
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
WOODWARD RANCH 3MI. NE
WOODWARD RANCH
LUTZ RANCH
D'HANIS
HONDO
UVALDE
SAN ANTONIO
NEW BRAUNFELS
SAN MARCOS
KERRVILLE
BANDERA
CASTROVILLE
DEVINE
PEARSALL
VICINITY MAP
NOTE: Isohyetal map based on approved Storm Study Part II (GM 5-20).
22.0 WOODWARD RANCH
12.0 D'HANIS
11.0 WOODWARD RANCH 3MI. NE
9.2 HONDO
ACCUMULATED PRECIPITATION IN INCHES
MAY 31, 1935
LEGEND
SPRINGS
LINES OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF MAY 31, 1935
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE GUAD. 707-2

CORPS OF ENGINEERS

U.S. ARMY

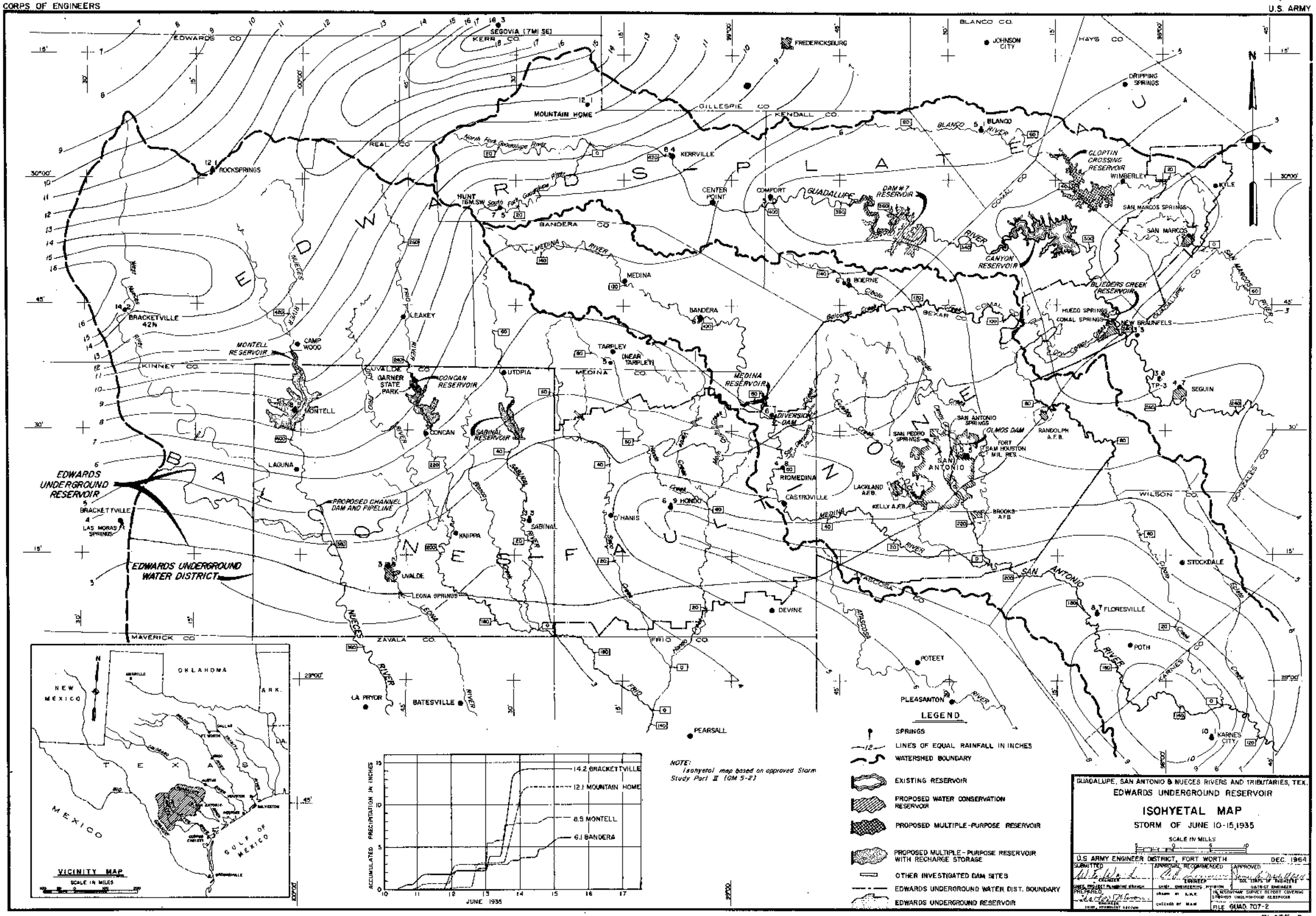
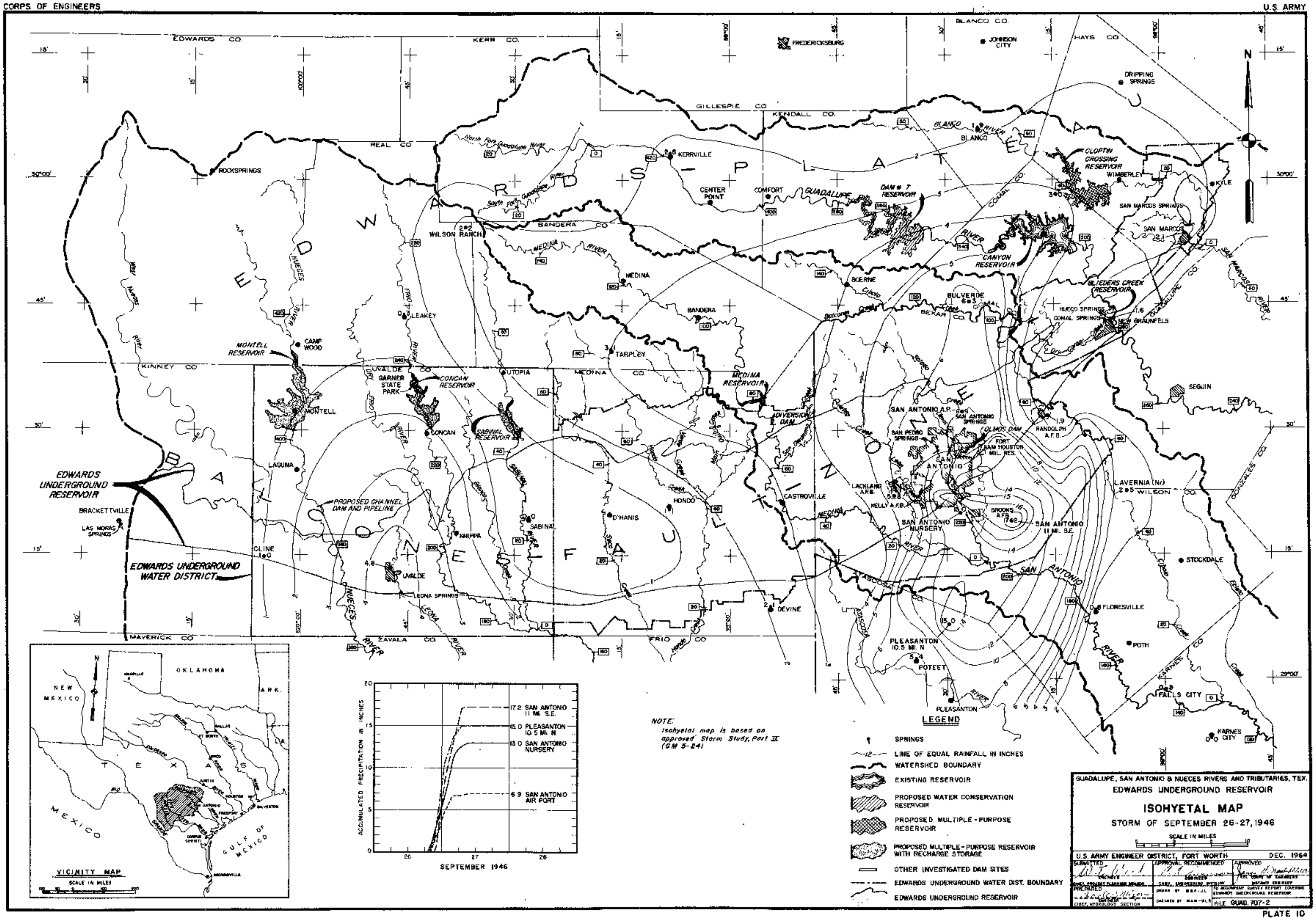
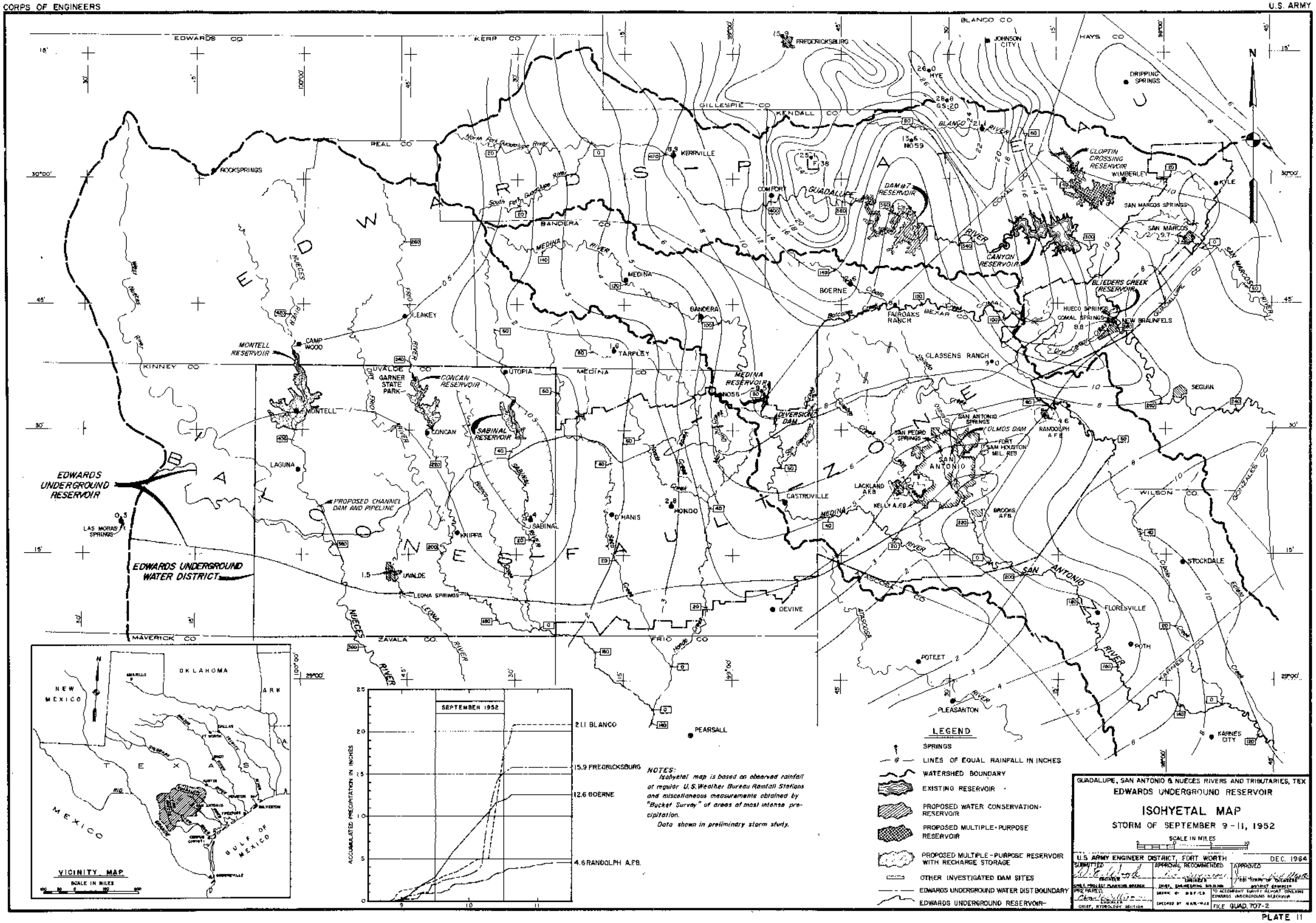


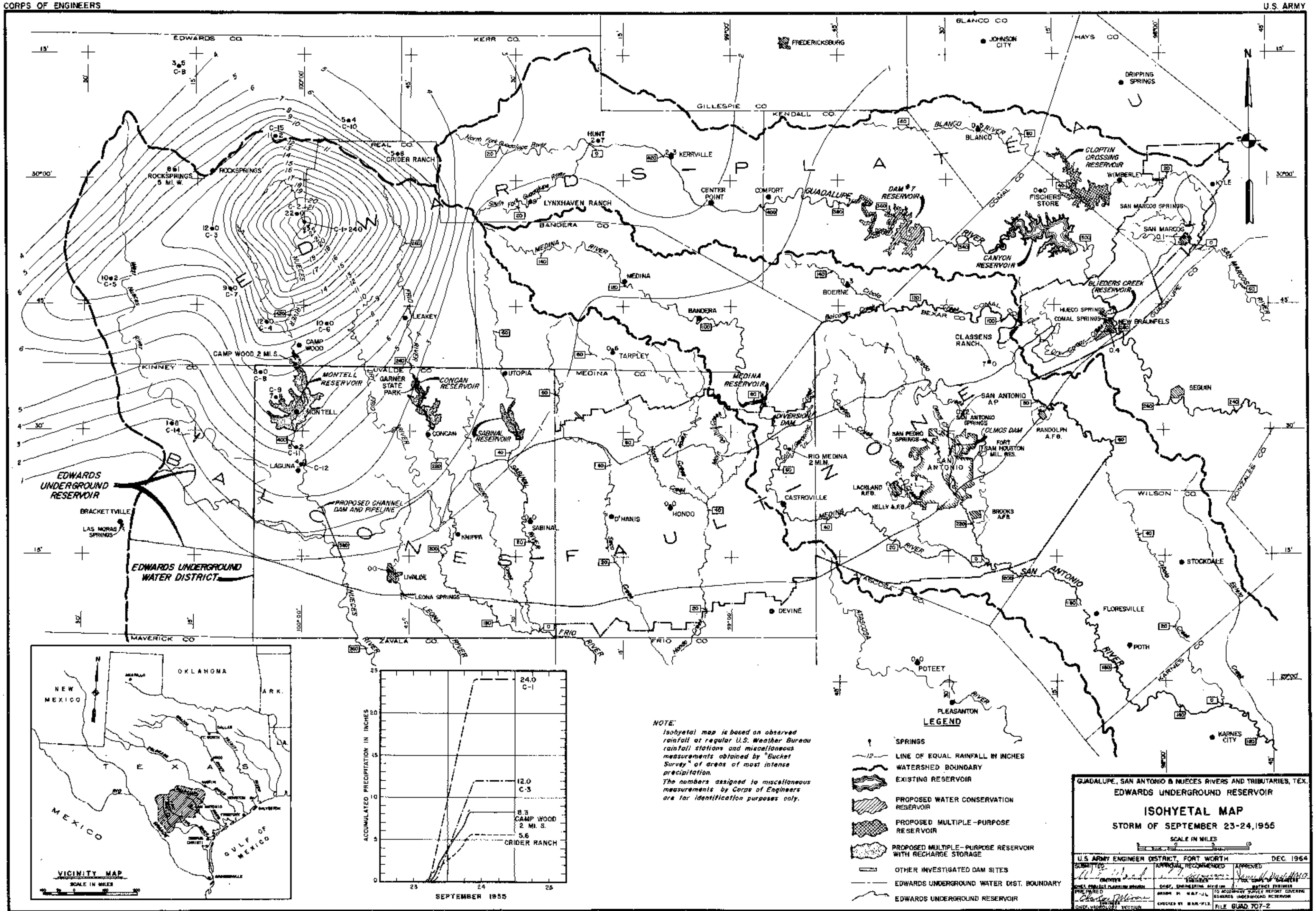
PLATE 9

34


CORPS OF ENGINEERS
U.S. ARMY
EDWARDS PLATEAU
BALCONES FAULT ZONE
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
OLMOS DAM
SAN ANTONIO A.P.
SAN ANTONIO 11 MI. S.E.
PLEASANTON 10.5 MI. N
SAN ANTONIO NURSERY
VICINITY MAP
SCALE IN MILES
SEPTEMBER 1946
ACCUMULATED PRECIPITATION IN INCHES
17.2 SAN ANTONIO 11 MI. S.E.
15.0 PLEASANTON 10.5 MI. N.
13.0 SAN ANTONIO NURSERY
6.9 SAN ANTONIO AIR PORT
NOTE: Isohyetal map is based on approved Storm Study, Part II (GM 5-24)
LEGEND
SPRINGS
LINE OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF SEPTEMBER 26-27, 1946
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
PREPARED
CHIEF, HYDROLOGY SECTION
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2
PLATE 10



CORPS OF ENGINEERS
U.S. ARMY
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF SEPTEMBER 9-11, 1952
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE GUAD. 707-2
PLATE 11
NOTES:
Isohyetal map is based on observed rainfall at regular U.S. Weather Bureau Rainfall Stations and miscellaneous measurements obtained by "Bucket Survey" of areas of most intense precipitation.
Data shown in preliminary storm study.
LEGEND
SPRINGS
LINES OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
SEPTEMBER 1952
ACCUMULATED PRECIPITATION IN INCHES
21.1 BLANCO
15.9 FREDERICKSBURG
12.6 BOERNE
4.6 RANDOLPH A.F.B.
VICINITY MAP
SCALE IN MILES
EDWARDS UNDERGROUND RESERVOIR
EDWARDS UNDERGROUND WATER DISTRICT
BALCONES FAULT ZONE
EDWARDS PLATEAU


EDWARDS CO
KERR CO
GILLESPIE CO
KENDALL CO
BLANCO CO
HAYS CO
REAL CO
BANDERA CO
KINNEY CO
UVALDE CO
MEDINA CO
BEXAR CO
COMAL CO
WILSON CO
GONZALES CO
KARNES CO
MAVERICK CO
ZAVALA CO
FRIO CO
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
HUNT
KERRVILLE
CENTER POINT
COMFORT
ROCKSPRINGS
ROCKSPRINGS 5 MI. W.
CRIDER RANCH
LYNXHAVEN RANCH
WIMBERLEY
FISCHERS STORE
KYLE
SAN MARCOS
SAN MARCOS SPRINGS
CLOPTIN CROSSING RESERVOIR
DAM #7 RESERVOIR
CANYON RESERVOIR
BLIEDERS CREEK RESERVOIR
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
BOERNE
MEDINA
BANDERA
TARPLEY
CLASSENS RANCH
LEAKEY
CAMP WOOD
CAMP WOOD 2 MI.S.
MONTELL RESERVOIR
MONTELL
GARNER STATE PARK
CONCAN RESERVOIR
CONCAN
UTOPIA
SABINAL RESERVOIR
MEDINA RESERVOIR
DIVERSION DAM
SAN ANTONIO AP
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
OLMOS DAM
RANDOLPH A.F.B.
FORT SAM HOUSTON MIL. RES.
SAN ANTONIO
RIO MEDINA 2 MI.N.
CASTROVILLE
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
SEGUIN
STOCKDALE
FLORESVILLE
POTH
KARNES CITY
LAGUNA
EDWARDS UNDERGROUND RESERVOIR
BRACKETTVILLE
LAS MORAS SPRINGS
PROPOSED CHANNEL DAM AND PIPELINE
EDWARDS UNDERGROUND WATER DISTRICT
KNIPPA
SABINAL
D'HANIS
HONDO
UVALDE
LEONA SPRINGS
DEVINE
POTEET
PLEASANTON
EDWARDS PLATEAU
BALCONES FAULT ZONE
NUECES RIVER
FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN ANTONIO RIVER
SAN MARCOS RIVER
ATASCOSA RIVER
LEONA RIVER
North Fork Guadalupe River
South Fork Guadalupe River
Cibolo Creek
30°00'
100°00'
99°00'
98°00'
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK.
TEXAS
MEXICO
GULF OF MEXICO
SCALE IN MILES
ACCUMULATED PRECIPITATION IN INCHES
SEPTEMBER 1955
24.0 C-1
12.0 C-3
8.3 CAMP WOOD 2 MI. S.
5.6 CRIDER RANCH
NOTE:
Isohyetal map is based on observed rainfall at regular U.S. Weather Bureau rainfall stations and miscellaneous measurements obtained by "Bucket Survey" of areas of most intense precipitation.
The numbers assigned to miscellaneous measurements by Corps of Engineers are for identification purposes only.
LEGEND
SPRINGS
LINE OF EQUAL RAINFALL IN INCHES
WATERSHED BOUNDARY
EXISTING RESERVOIR
PROPOSED WATER CONSERVATION RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR
PROPOSED MULTIPLE-PURPOSE RESERVOIR WITH RECHARGE STORAGE
OTHER INVESTIGATED DAM SITES
EDWARDS UNDERGROUND WATER DIST. BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
ISOHYETAL MAP
STORM OF SEPTEMBER 23-24, 1955
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE GUAD 707-2

of the Edwards Plateau. Runoff from this storm produced the maximum known peak discharges in the upper part of the Frio, Sabinal, and Guadalupe River watersheds. Maximum peak discharges are as follows: Frio River at Concan, 162,000 second-feet; Guadalupe River near Comfort, 182,000 second-feet; Sabinal River near Sabinal, an estimated 86,000 second-feet. Several additional intense storms which covered smaller areas were: the storm of May 25-30, 1929 which produced the maximum known peak discharges of 113,000 and 139,000 second-feet on the Blanco River at Wimberley and Kyle, respectively; the storm of May 31, 1935 which produced the maximum known peak discharge of 230,000 second-feet on Seco Creek about 11 miles north of D'Hanis; the storm of June 10-15, 1935 which produced the maximum known peaks of 550,000 second-feet on the West Nueces River near Brackettville and 616,000 second-feet on the Nueces River near Uvalde; the storm of September 26-27, 1946 which produced the maximum known peak discharge of 58,000 second-feet on Calaveras Creek at San Antonio; the storm of September 9-11, 1952 which produced serious flooding on the Blanco River with a peak discharge of 95,000 second-feet at Wimberley; and the storm of September 23-24, 1955 which produced the maximum known peak discharge of 307,000 second-feet on the Nueces River at Laguna. The effect of the Balcones Fault on storms in the area is discussed in the following excerpt from a published report: 1/

> "The escarpment along the Balcones fault zone tends doubtless to increase the rainfall in its vicinity to some extent, because it forces warm moist air from the Gulf to rise, then to expand and cool, thus inducing heavy rainfall. The possible effect of the escarpment may be exaggerated, because whenever intense rains occur in that area, terrific floods are likely to follow, not because the rain was greater in volume or intensity than often occurs in the coastal area, but because of the steepness of the slopes, the shallowness and rocky character of the soil, and the narrow flood plains of the stream channels."

38. Table 15 gives peak discharges and flood volumes of some of the larger floods at selected gages in the upper watersheds of river basins in the vicinity of the Balcones Fault and in the study area.

39. HYPOTHETICAL FLOOD HYDROGRAPHS.- In connection with the determination of flood-control storage requirements, flood volume-duration-frequency studies were made for the reservoirs, based on gages throughout the area, in order to establish the degree of protection that would be afforded by varying amounts of flood-control storage in each project. These studies were developed in accordance with the method set forth in Section VI of "Statistical Methods in

1/ Dalrymple, Tate, and others, "Major Texas Floods of 1936." U. S. Geological Survey Water Supply Paper 816, page 10, Cause of floods.

"Hydrology" by Leo R. Beard, dated January 1962, and recommended for use in ER 1110-2-1450. Data obtained from the volume-duration-frequency curves were used to construct hypothetical hydrographs for floods of selected frequencies at each reservoir.

40. NATURAL RECHARGE CAPACITIES.

a. General.- Analyses of available data pertaining to natural recharge capacities have been made for all streams that cross the recharge zone of the Edwards Reservoir. The amount of data available varied considerably from one location to the next. It was possible to make more detailed analyses for some areas due to the presence of stream gaging records both above and below the outcrop. Most of these gages, however, have been in operation only a short time and the recorded losses are not necessarily indicative of the maximum recharge capacities. Estimates were made for streams without stream gaging records by comparison with the recharge rates for adjacent streams. In addition, use was made of published reports containing estimated recharge rates for certain streams within the Edwards Underground area. Preliminary analyses led to the elimination of some streams from further investigation into the possibilities of recharge reservoir construction. The major reasons for the eliminations were: (1) the estimated natural recharge of a number of the streams represents a large percentage of the runoff; hence, improvement could not increase the recharge significantly; (2) no suitable dam site was available in several areas. The locations of the investigated projects are shown on plate 4. The streams that were investigated in more detail are as follows: Nueces River, Frio River, Sabinal River, Medina River, Guadalupe River, and the Blanco River. Recharge characteristics of these streams are discussed in the following paragraphs.

(1) Nueces River.

(a) The investigation of the recharge capacity of the Nueces River is based on analyses of U. S. Geological Survey gage records. Stream gaging records are available on the Nueces River and the West Nueces River, a tributary to the Nueces River. The Laguna gage on the Nueces River, which is located above the recharge zone, has about 39 years of record. The Brackettville gage on the West Nueces River, which is above the recharge zone, was installed in October 1940, but was discontinued from October 1950 through March 1956. The Uvalde gage on the Nueces River is located below the recharge zone and is approximately 16 miles downstream from the confluence of the Nueces and West Nueces River. As indicated by the gage near Brackettville, Texas, there is seldom any flow in the West Nueces River except in periods of heavy rainfall. By taking into consideration the recorded or estimated flow of the West Nueces River, it is possible to estimate the recharge rate for the Nueces River downstream from the recommended dam site.

TABLE 15

FLOOD DATA

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
West Nueces River near Brackettville - D.A. = 700 sq. mi.				
June 1935	550,000(1)	June 14	-	-
June 16-19, 1958	104,000	June 17	104,400	2.80

(1) Measurement made by U. S. Geological Survey 10 miles above mouth.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Nueces River at Laguna - D.A. = 764 sq. mi.				
June 13-18, 1935	213,000	June 14	277,900	6.82
September 15-19, 1936	114,000	September 16	111,890	2.74
July 13-15, 1939	222,000	July 13	89,000	2.18
September 24-27, 1955	307,000	September 24	153,810	3.77
Nueces River below Uvalde - D.A. = 1,947 sq. mi.				
September 1-4, 1932	207,000	September 1	280,000	2.72(1)
June 13-18, 1935	616,000	June 14	461,700	4.48(1)
July 13-15, 1939	89,000	July 13	57,480	0.55
September 24-27, 1955	189,000	September 24	143,900	1.39
June 17-20, 1958	146,000	June 17	191,100	1.84

(1) Measurement was made at the gage near Uvalde-D.A. = 1,930 sq. mi.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Frio River at Concan - D.A. = 405 sq. mi.				
July 1-6, 1932	162,000	July 1	150,620	6.97
June 13-18, 1935	106,000	June 14	115,140	5.33
September 15-19, 1936	119,000	September 16	44,230	2.05
Frio River near Derby - D.A. = 3,493 sq. mi.				
July 2-8, 1932	230,000	July 4	528,080	2.83
May 29-June 8, 1935	68,300	June 2	261,600	1.40
June 13-22, 1935	50,500	June 16	251,660	1.35
Sabinal River near Sabinal - D.A. = 206 sq. mi.				
May 24-25, 1954	15,800	May 24	5,460	0.50
June 17-19, 1958	55,200	June 17	29,850	2.72
June 25-28, 1959	11,900	June 25	10,950	1.00
Sabinal River at Sabinal-D.A. = 247 sq. mi. (1)				
May 24-26, 1954	15,900	May 24	8,050	0.61
June 17-20, 1958	73,300	June 17	42,230	3.19
June 26-29, 1959	15,900	June 26	11,250	0.85

(1) Gage is located below Balcones fault zone.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Hondo Creek near Tarpley - D.A. = 101 sq. mi.				
May 24-26, 1954	18,600	May 24	2,030	0.39
September 22-24, 1957	25,300	September 22	6,900	1.28
June 17-20, 1958	69,800	June 17	26,400	4.90
Hondo Creek near Hondo - D.A. = 132 sq. mi. (1)				
May 24-26, 1954	13,700	May 24	2,600	0.37
September 22-24, 1957	20,500	September 22	6,810	0.97
June 17-20, 1958	71,700	June 17	22,980	3.26

(1) Gage is located below Balcones fault zone.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Seco Creek near Utopia - D.A. = 53 sq. mi.				
September 22-25, 1957	12,100	September 22	3,340	1.18
June 17-20, 1958	52,600	June 17	13,770	4.87
Seco Creek near D'Hanis - D.A. = 87 sq. mi. (1)				
May, 1935	230,000(2)	May 31	-	-
September 22-24, 1957	12,400	September 22	3,750	0.81
June 17-19, 1958	72,000	June 17	20,020	4.32

(1) Gage located below Balcones fault zone.
(2) Measurement made by U. S. Geological Survey 11 miles above D'Hanis)

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Medina River near Pipe Creek - D.A. = 474 sq. mi.				
July 1-5, 1932	64,000	July 1	81,880	3.24
July 24, 1935	40,400(1)	July 24	-	-
June 17-19, 1958	37,100	June 17	30,660	1.21

(1) Station abandoned July 25.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Guadalupe River at Comfort - D.A. = 836 sq. mi.				
July 1-3, 1932	182,000	July 1	136,070	3.35(1)
May 25-28, 1944	59,400	May 26	49,030	1.10
September 10-12, 1952	38,600	September 10	19,840	0.44
October 4-7, 1959	93,200	October 4	56,900	1.28

(1) Measurement was made at gage near Comfort - D.A. = 762 sq. mi.
Note: Gage was not operating during 1935 flood.

Date of flood	Peak discharge (cfs)	Date of peak	Flood volume passing gage (acre-feet)	Flood volume passing gage (inches)
Guadalupe River near Spring Branch - D.A. = 1,282 sq. mi.				
July 2-4, 1932	121,000	July 3	194,580	2.85
June 13-17, 1935	114,000	June 15	179,520	2.63
May 25-29, 1944	28,000	May 27	62,940	0.92
September 10-13, 1952	66,900	September 11	119,190	1.74
October 4-8, 1959	42,500	October 5	68,270	1.00
Blanco River at Wimberley - D.A. = 353 sq. mi.				
May 28-31, 1929	113,000	May 28	84,630	4.50
September 11-14, 1952	95,000	September 11	77,840	4.13
April 24-26, 1957	68,600	April 24	27,990	1.49
May 2-5, 1958	96,400	May 2	43,700	2.36

(b) During a 5-day period from August 31 to September 5, 1942, the average daily infiltration rate varied from over 300 second-feet to over 1600 second-feet. On October 20, 1962, the average daily flow at the Laguna gage was 901 second-feet, with a peak discharge of 3210 second-feet. All of this flow was lost to the underground reservoir in crossing the recharge zone. The above recharge values are examples of the infiltration that has been experienced in the Nueces River channel below the recommended dam site.

(2) Frio River.

(a) Stream gaging records are available on the Frio River and Dry Frio River, above the recharge zone. The Concan gage on the Frio River, which is located above this zone, has about 39 years of record. The Reagan Wells gage on the Dry Frio River, however, was not installed until September 1952. The Dry Frio River enters the Frio River a short distance downstream from the lower edge of the recharge zone. Approximately five miles downstream from the confluence of the Dry Frio with the Frio River the Geological Survey installed a stream gage on the Frio River near Uvalde. By use of these gages it was possible to estimate the recharge rate for the Frio River.

(b) On July 17, 1955, the average daily flow at the Concan gage was 447 second-feet, with a peak discharge of 2670 second-feet; all of this flow was lost to the Udwards Underground Reservoir. An average daily flow of 728 second-feet, having a peak of 3500 second-feet, was lost to the underground on October 20, 1962. The above losses are the only examples of high rates of recharge since the gage has been installed below the recharge zone on the Frio River.

(3) Sabinal River.

(a) Stream gaging records are available above the recharge zone since October 1942, and below the recharge zone since September 1952. There are no large tributaries entering the Sabinal River between the gages; therefore, the recharge was estimated to be the difference in the amount of flow passing the two gages.

(b) The losses on the Sabinal River varied from 500 second-feet to 300 second-feet for a five day period from July 16 through July 20, 1960. On May 6, 1963, the average daily flow was 406 second-feet, having a peak of 1010 second-feet; all of this flow was lost to the underground. The recommended dam site is located within the loss area; therefore, it is expected that the recharge rate will increase due to the large area of exposed limestone that is within the reservoir storage limits.

(4) Medina River.

(a) The two major loss areas in the Medina River Basin are the Medina Reservoir, and the small diversion dam that is located approximately four miles downstream from the main reservoir. As stated in a published report: 1/

> "The two components which make up this loss have different characteristics. The loss on the main reservoir would be expected to vary with the stage of the water in the reservoir, whereas the loss from the diversion reservoir is more or less a constant, continuing whenever the reservor is being used, because it operates with very little variation in head. . . .
>
> "On a falling stage the combined losses in the two reservoirs vary from about 50 second-feet (whenever there is more than 30,000 acre-feet in storage) to something in excess of 120 second-feet when the reservoir is full. When the stage is rising the losses vary from about 90 second-feet to more than 165 second-feet.
>
> "As indicated above, the losses from the diversion reservoir and the channel downstream are independent of stage in the main reservoir, and are more or less constant as long as water is being supplied to the canal. Without additional information it was assumed that this loss would be a constant . . . and would amount to about 25 second-feet."

(b) It is noted that the above data and conclusions were reviewed and adopted by Guyton in a report dated 1958. 2/ In the 1958 report, several additional years of record were evaluated, and found to generally substantiate the original findings. This office also reviewed the original computations, examined the latest available records and found Lowry's original computations to be satisfactory.

(5) Guadalupe River.

> "The Guadalupe River, in contrast to most of the other streams crossing the Balcones fault zone, apparently does not lose significant quantities of water to the Edwards limestone. . . . Investigations to determine seepage losses have

1/ Lowry, R. L., 1953 "Hydrologic Report Medina River Above the Applewhite Dam Site." Consulting Engineer's Report to San Antonio City Water Board.

2/ William T. Guyton and Associates, March 1958, "Leakage from Medina Lake, Medina County, Texas."

"failed to disclose losses greater than those that might be expected from evapo-transpiration. However, there are minor losses and gains in various reaches of the river . . . ." 3/

(6) Blanco River.

"Records of the discharge of the Blanco River at Wimberley, which is above the outcrop of the Edwards, are available for the period since June 1928. No continuous records of discharge are available below the outcrop. Discharge measurements to determine seepage losses or gains indicate that, with discharge up to approximately 200 cfs at the gage, the loss in crossing the outcrop of the Edwards limestone is about 15 cfs. Therefore, the limit of infiltration in this section has been set at 15 cfs regardless of flow above 200 cfs at the gage. All flows up to 15 cfs are assumed to be recharge to the ground water reservoir. . . ." 3/

b. Recommended Releases for Recharge.- The reservoirs considered for the improvement of the recharge of the underground are Montell, Concan, and Sabinal Reservoirs. The storage requirements for these reservoirs were determined based on various release rates covering reasonable ranges indicated by the gage records. It was found that regardless of the release rate selected, there was only a small difference in the storage requirements. This was due primarily to the normally short duration of the surface runoff in this area. The release rates which have been adopted for this study are values which approach the maximum average daily losses that have been experienced. The recommended rates for Montell, Concan, and Sabinal Reservoirs are 1,000 second-feet, 750 second-feet and 500 second-feet, respectively. It is possible that these rates may have to be adjusted after experience gained from the operation of the reservoirs indicates more closely the actual recharge rates.

41. CHANNEL CAPACITIES.- Minimum channel capacities downstream from the Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs are shown on table 16.

3/ Petitt, B. M., Jr., and George, W. O., 1956 U. S. Geological Survey, "Ground Water Resources of the San Antonio Area, Texas, A Progress Report on Current Studies," Texas Board of Water Engineers Bulletin 5608, Volume I.

TABLE 16

CHANNEL CAPACITIES

Stream	Location	Minimum channel capacities (cfs)
	NUECES RIVER BASIN	
Nueces	Laguna	5,000
	Nr Uvalde	64,000
	Nr Cinonia (discontinued gage-above mouth of Turkey Creek)	15,000
	Nr Asherton	20,000
	Cotulla	5,000
	Nr Tilden	5,000
Frio	Concan	7,000
Sabinal	Nr Sabinal	3,000
Frio	Derby	7,000
	Calliham	10,000
Nueces	Nr Three Rivers	5,000
	GUADALUPE RIVER BASIN	
Blanco	Wimberley	15,000(1)
	Nr Kyle	15,000(2)
San Marcos	Luling	14,000
	Ottine	12,000
Guadalupe	Gonzales	15,000
	Nr Cuero	20,000
	Victoria	12,000

(1) Channel capacity is restricted to approximately 5,000 second-feet by low water crossings on County roads.

(2) Channel capacity is restricted to approximately 6,000 second-feet by low water crossings on County roads.

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CORPS OF ENGINEERS

U.S. ARMY

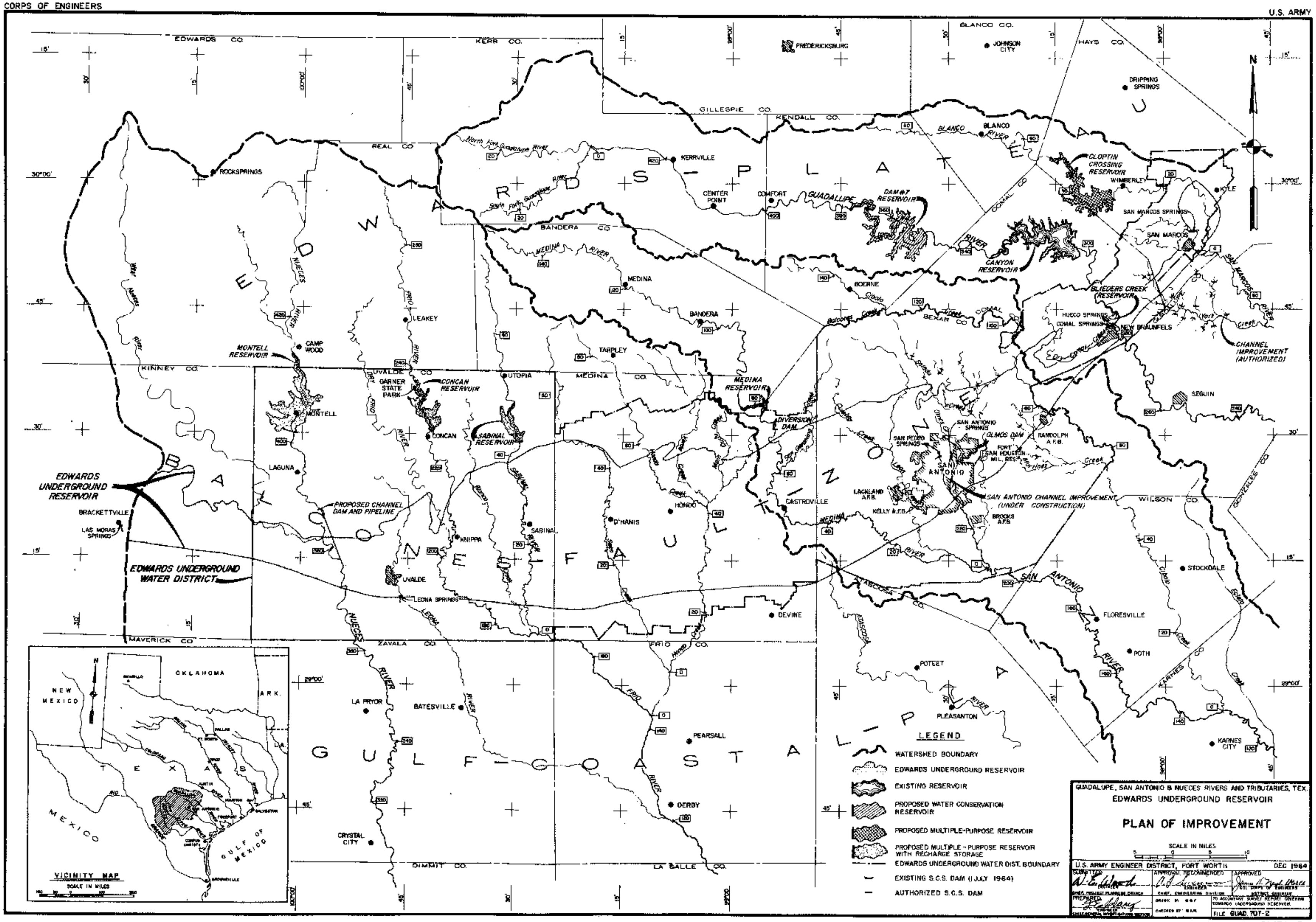

PLATE 13

42. EXISTING AND AUTHORIZED FEDERAL PROJECTS.- The existing and authorized Federal projects in the study area are those of the Corps of Engineers and the Soil Conservation Service. These projects are discussed in paragraph 8 and located on plate 13.

43. EXISTING NON-FEDERAL RESERVOIRS.- The existing non-Federal reservoirs in the study area are discussed in paragraph 9 and located on plate 13.

44. RECOMMENDED PLAN.- The recommended plan will provide controlled recharge storage for the underground reservoir, additional water supply storage and recreation facilities for the people of the Edwards Reservoir area, and flood protection for the downstream areas of the Nueces and Guadalupe River Basins. The storage allocations for the reservoirs are given in table 17. Location of the recommended reservoirs is shown on plate 13. Reservoirs recommended in the plan of improvement are as follows:

a. For authorization and construction by the Federal Government:

(1) Montell Reservoir on the Nueces River for flood-control, water supply, recharge, and for recreation and fish and wildlife purposes, including a channel dam and a pipeline for water supply to downstream areas of the Nueces River Basin. Detailed pertinent data are shown in table 18.

(2) Concan Reservoir on the Frio River for flood-control, recharge, and recreation purposes. Detailed pertinent data are shown in table 19.

(3) Sabinal Reservoir on the Sabinal River for flood-control, recharge, and recreation purposes. Detailed pertinent data are shown in table 20.

(4) Cloptin Crossing Reservoir on the Blanco River for flood-control, water conservation, recreation, and fish and wildlife purposes. Detailed pertinent data are shown in table 21.

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

45. AREA AND CAPACITY OF THE RESERVOIRS.- The area and capacity of the reservoirs investigated for this study were determined from available topographic maps of the reservoir sites. The topographic maps were planimetered and the area at and below each mapped contour was plotted versus elevation to form area-elevation curves. Areas were

picked from these curves at 1-foot intervals and capacities were computed therefrom by the average-end area method. Tabulations of initial areas and capacities are given in tables 22 through 26 for Montell, Concan, Sabinal, Dam No. 7, and Cloptin Crossing Reservoirs.

46. DETERMINATION OF RESERVOIR INFLOWS.- Monthly flows were determined at the existing and investigated reservoir sites in the Edwards Reservoir area for periods including a reasonably representative cycle of floods and runoff deficiency in the vicinity of the reservoirs. The monthly flows were based on: (1) existing conditions of runoff, generally determined from observed records at stream-gaging stations, and (2) runoff under 2025 conditions of watershed development. Because of the small consumptive use of surface water in the area and because total surface reservoir capacity in the basin was very small prior to 1962, it was considered that historical runoff was the same as runoff under existing conditions of watershed development. It was, however, necessary to adjust existing flows to 2025 conditions for water supply studies. The United States Study Commission - Texas had previously determined 2010 flows at the Canyon Dam site on the Guadalupe River and at the Wimberley Dam site (approximately 10 miles downstream from Cloptin Crossing) on the Blanco River for the period 1941-1957. The factors adopted by the USSC-T for the conversion of existing to 2010 conditions runoff were based upon thorough studies of future watershed development. The methods and procedures used were examined, found to be acceptable, and the factors adopted for use in this report. Since the U. S. Study Commission assumed that the watershed development for these basins would be substantially complete by 2010, these conversion factors, relating natural to 2010 runoff, also relate natural to 2025 runoff. Because of the proximity of the dam sites, the factors developed for Canyon and Wimberley Dam sites were considered applicable to Dam No. 7 and Cloptin Crossing Dam sites. Factors for the conversion of natural to 2025 flow for the period prior to 1941 and subsequent to 1957 were determined in a manner similar to that for the 1941-1957 period.

47. The report of the U. S. Study Commission - Texas did not recommend construction of reservoirs above the Balcones Fault Zone in the Nueces River Basin and consequently studies for the report did not determine whether anticipated watershed development would reduce future runoff appreciably from that area. The studies of future conditions depletion of runoff were accomplished for the U. S. Study Commission - Texas by the U. S. Bureau of Reclamation and were based upon procedures which that agency had developed in connection with its report on "Gulf Basins Project, Texas."

48. These procedures and a discussion of them is presented in Annex (C-8) of the above report titled "Land Treatment, Pond and Minor Reservoir and Floodwater Retarding Structure Depletions," dated August 1958. According to the introduction to Annex (C-8),

TABLE 17

EXISTING AND RECOMMENDED RESERVOIRS - EDWARDS UNDERGROUND RESERVOIR AREA

Reservoir	Stream	River mile	Contributing drainage area (sq. mi.)	Storage capacity (acre-feet) Sediment	Conservation	F-C	Total	2025 Yield (cfs)
				FEDERAL PROJECTS				
Montell	Nueces	401.6	707	12,000	1,000	239,300(1)	252,300	6
Concan	Frio	226.2	391	7,800	0	141,200(1)	149,000	0
Sabinal	Sabinal	42.3	210	4,200	0	89,100(1)	93,300	0
Canyon	Guadalupe	303.0	1,425	28,100	366,400	346,400	740,900	133
Canyon w/Dam 7	Guadalupe	303.0	301(2)	10,300	378,900	351,700	740,900	67
Cloptin Crossing	Blanco	32.5	307	9,200	274,900	119,900	404,000	59
				LOCAL INTERESTS PROJECTS				
Dam 7	Guadalupe	351.3	1,124	17,500	640,500	-	658,000	130

(1) Dual-purpose storage (flood control and recharge).

(2) Local area below Dam 7.

TABLE 18

MONTELL RESERVOIR
(RECOMMENDED)

LOCATION:
R.M. 401.6 on Nueces River in Uvalde County, and about 2.5 mi. south of Montell; about 11.5 mi. south of Camp Wood, Texas

DRAINAGE AREA: 707 sq. mi.

DAM:

Type:	Rock fill w/spwy near left abutment
Length:	7,360 ft.
Max. height:	158 ft.
Top width:	30 ft.

SPILLWAY:

Crest:	1331.0 ft. msl
Length:	960.0 ft.
Type:	Broadcrested
Control:	None

INFLOW:

Spillway design flood peak, cfs	893,900
Spillway design flood volume, ac-ft	821,300
Spillway design flood runoff, inches	21.78

OUTFLOW: (El. 1366.0)

Total routed peak outflow, cfs	581,000
Spillway	570,600
Outlet works	10,400

OUTLET WORKS:

Type:	1 gate controlled conduit
Dimension:	15' diameter
Control:	3 - 5'8" x 12'0" tractor-type gates
Invert:	1216.0 ft. msl

POWER FEATURES:
None

RESERVOIR DATA

Features	Elev feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac-ft)	Reservoir capacity: Runoff (inches)	Reservoir capacity: Incremental (ac-ft)	Spillway capacity (cfs)	Outlet works capacity (cfs)
Top of dam	1371.0						
Maximum water surface	1366.0	10,180	533,100	14.14		570,600	10,400(2)
Flood control pool	1331.0	6,200	252,300	6.69	239,300	0	10,350
Spillway crest	1331.0	6,200	252,300	6.69		0	10,350
Conservation pool	1237.0	260	2,200	0.06	1,000	0	3,400
Sediment reserve					12,000(1)		
Total storage					252,300		
Maximum tailwater	1257.4						
Streambed	1216.0						

(1) Sediment distributed as follows:
1,200 ac-ft below el. 1237.0
10,800 ac-ft between el. 1237.0 and 1331.0

(2) O/W submerged by tailwater

TABLE 19

CONCAN RESERVOIR
(RECOMMENDED)

LOCATION:
R.M. 226.2 on Frio River in Uvalde County, and about 1.0 mi. northeast of Concan, Tex.

DRAINAGE AREA: 391.0 sq. mi.

DAM:

Type:	Rock fill w/spwy near right abutment
Length:	2,955 ft.
Max. height:	164.0 ft.
Top width:	30 ft.

SPILLWAY:

Crest:	1366.5 ft msl
Length:	1030 ft.
Type:	Broadcrested
Control:	None

INFLOW:

Spillway design flood peak, cfs	592,500
Spillway design flood volume, ac-ft	489,400
Spillway design flood runoff, inches	23.47

OUTFLOW: (El. 1394.2)

Total routed peak outflow, cfs	433,000
Spillway	425,300
Outlet works	7,700

OUTLET WORKS:

Type:	1 gate-controlled conduit
Dimension:	13' diameter
Control:	2 - 6' x 13' Tractor-type gates
Invert:	1240.0 ft. msl

POWER FEATURES:
None

RESERVOIR DATA

Features	Elev feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac-ft)	Reservoir capacity: Runoff (inches)	Reservoir capacity: Incremental (ac-ft)	Spillway capacity (cfs)	Outlet works capacity (cfs)
Top of dam	1399.5						
Maximum water surface	1394.2	5,670	280,600	13.46		425,300	7,700(1)
Flood control pool	1366.5	3,830	149,000	7.15	141,200	0	8,000
Spillway crest	1366.5	3,830	149,000	7.15		0	8,000
Sediment reserve					7,800		
Total storage					149,000		
Maximum tailwater	1283.3						
Streambed	1240.0						

(1) O/W submerged by tailwater.

TABLE 20

SABINAL RESERVOIR
(RECOMMENDED)

LOCATION:
R.M. 42.3 on Sabinal River in Uvalde County and about 11.0 mi. north of Sabinal, Texas

DRAINAGE AREA: 210 sq. mi.

DAM:

Type:	Rock fill w/gated spwy in river channel
Length:	2,150 ft.
Max. height:	114 ft.
Top width:	30 ft.

SPILLWAY:

Crest:	1196.5 ft. msl
Length:	240 ft. net @ crest
Type:	Ogee
Control:	6 - 40' x 30' tainter gates

INFLOW:

Spillway design flood peak, cfs	381,800
Spillway design flood volume, ac-ft	249,000
Spillway design flood runoff, inches	22.23

OUTFLOW: (El. 1238.8)

Total routed peak outflow, cfs	270,600
Spillway	270,600
Outlet works	0

OUTLET WORKS:

Type:	2 sluices
Dimension:	3' x 6'
Control:	2 - 3' x 6' slide gates
Invert:	1130.0 ft. msl

POWER FEATURES:
None

RESERVOIR DATA

Features	Elev feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac-ft)	Runoff (inches)	Incremental (ac-ft)	Spillway capacity (cfs)	Outlet works capacity (cfs)
Top of dam	1244.0						
Maximum water surface	1238.8	3,860	135,200	12.07		270,600	0(1)
Flood control pool(2)	1226.5	2,990	93,300	8.33	89,100	156,200	1,730
Spillway crest	1196.5	1,320	30,100	2.69		0	1,420
Sediment reserve					4,200		
Total storage					93,300		
Maximum tailwater	1179.0						
Streambed	1130.0						

(1) Outlet works inoperative during routing of spillway design flood
(2) Also top of gates

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TABLE 21
CLOPTIN CROSSING RESERVOIR
(RECOMMENDED)

LOCATION:
R.M. 32.5 on the Blanco River about 2.5 mi. S.W. Wimberley, Texas, in Hays County

DRAINAGE AREA: 307 sq. mi.

DAM:

Type:	Rolled earth fill w/spwy in saddle near left abutment.
Length:	8,280 ft.
Max. height:	200 ft.
Top width:	30.0 ft.

SPILLWAY:

Crest:	998.0 ft. msl
Length:	760.0 ft.
Type:	Broadcrested
Control:	None

INFLOW:

Spillway design flood peak, cfs	414,900
Spillway design flood volume, ac-ft	353,000
Spillway design flood runoff, in.	21.56

OUTFLOW: (El. 1017.5)

Total routed peak outflow, cfs	196,400
Spillway	187,200
Outlet works	9,200

OUTLET WORKS:

Type:	1 gate controlled conduit
Dimension:	13' diameter
Invert:	855.0 ft. msl
Control:	2 - 6'0" x 13'0" (tractor-type gates)

POWER FEATURES:
None

RESERVOIR DATA

Feature	Elev. feet msl	Reservoir area (acres)	Reservoir capacity: Accumulative (ac-ft)	Reservoir capacity: Runoff (inches)	Reservoir capacity: Incremental (ac-ft)	Spillway capacity (cfs)	Outlet works capacity (cfs)
Top of Dam	1023.0						
Maximum water surface	1017.5	9,600	573,000	35.00		187,200	9,200
Flood control pool	998.0	7,730	404,000	24.67	119,900	0	8,600
Spillway crest	998.0	7,730	404,000	24.67		0	8,600
Conservation pool	980.5	6,060	283,400	17.31	274,900	0	8,000
Sediment reserve					9,200*		
Total storage					404,000		
Maximum tailwater	868.8						
Streambed	823.0						

*Sediment distributed as follows: 8,500 ac-ft below El. 980.5; 700 ac-ft between El. 980.5 and El. 998.0.

TABLE 22

EDWARDS UNDERGROUND RESERVOIR
NUECES RIVER
MONTELL RESERVOIR
R. M. 401.6
AREA AND CAPACITY DATA

AREA - ACRES

El	0	1	2	3	4	5	6	7	8	9
1210							0	2	5	9
1220	13	20	30	42	54	68	84	102	117	134
1230	153	168	183	196	212	226	241	256	273	292
1240	314	342	370	400	429	462	494	526	559	591
1250	623	656	687	720	752	785	818	853	887	924
1260	962	1,004	1,049	1,097	1,147	1,200	1,253	1,308	1,364	1,419
1270	1,476	1,528	1,588	1,649	1,712	1,774	1,842	1,908	1,973	2,042
1280	2,109	2,176	2,246	2,314	2,386	2,456	2,526	2,598	2,672	2,746
1290	2,819	2,892	2,964	3,038	3,114	3,190	3,266	3,344	3,422	3,502
1300	3,578	3,653	3,728	3,803	3,877	3,953	4,029	4,106	4,184	4,263
1310	4,343	4,427	4,513	4,603	4,694	4,788	4,886	4,982	5,076	5,164
1320	5,251	5,338	5,422	5,504	5,586	5,670	5,756	5,842	5,927	6,014
1330	6,098	6,196	6,292	6,392	6,492	6,593	6,693	6,794	6,898	7,004
1340	7,108	7,206	7,300	7,396	7,488	7,580	7,674	7,770	7,866	7,973
1350	8,083	8,186	8,298	8,416	8,536	8,658	8,784	8,914	9,044	9,174
1360	9,323	9,454	9,595	9,737	9,885	10,032	10,180	10,330	10,475	10,616
1370	10,762	10,904	11,045	11,186	11,325	11,457	11,593	11,731	11,869	12,007
1380	12,154	12,296	12,440	12,584	12,728	12,868	13,008	13,150	13,298	13,451
1390	13,608	13,778	13,954	14,127	14,306	14,488	14,670	14,852	15,034	15,216
1400	15,398	15,600	15,790	15,980	16,180	16,380	16,590	16,800	17,010	17,200
1410	17,420	17,640	17,860	18,080	18,300	18,530	18,750	18,980	19,210	19,440
1420	19,670	19,910	20,150	20,390	20,640	20,890	21,150	21,420	21,700	21,980
1430	22,260	22,540	22,830	23,120	23,420	23,710	24,010	24,310	24,610	24,910
1440	25,197									

CAPACITY - ACRE-FEET

El	0	1	2	3	4	5	6	7	8	9
1210							0	1	5	12
1220	23	39	64	100	148	209	285	378	488	614
1230	758	918	1,094	1,284	1,488	1,707	1,941	2,189	2,453	2,735
1240	3,038	3,366	3,722	4,107	4,521	4,967	5,445	5,955	6,497	7,072
1250	7,679	8,319	8,991	9,695	10,431	11,199	12,001	12,837	13,707	14,613
1260	15,556	16,539	17,565	18,638	19,760	20,934	22,160	23,440	24,776	26,168
1270	27,616	29,118	30,676	32,294	33,974	35,717	37,525	39,400	41,340	43,348
1280	45,424	47,566	49,777	52,057	54,407	56,828	59,319	61,881	64,516	67,225
1290	70,007	72,803	75,791	78,792	81,868	85,020	88,248	91,553	94,936	98,398
1300	101,938	105,554	109,244	113,010	116,850	120,765	124,756	128,824	132,969	137,193
1310	141,496	145,881	150,351	154,909	159,557	164,298	169,135	174,069	179,098	184,218
1320	189,426	194,720	200,100	205,563	211,108	216,736	222,449	228,248	234,132	240,102
1330	246,158	252,305	258,549	264,891	271,333	277,875	284,518	291,262	298,108	305,059
1340	312,115	319,272	326,525	333,873	341,315	348,849	356,476	364,198	372,016	379,936
1350	387,964	396,098	404,340	412,697	421,173	429,770	438,491	447,340	456,319	465,428
1360	474,676	484,064	493,588	503,254	513,065	523,023	533,129	543,384	553,786	564,332
1370	575,021	585,854	596,828	607,944	619,200	630,591	642,116	653,778	665,578	677,516
1380	689,596	701,821	714,189	726,701	739,357	752,155	765,093	778,172	791,396	804,770
1390	818,299	831,992	845,858	859,898	874,114	888,511	903,090	917,851	932,794	947,919
1400	963,226	978,725	994,420	1,010,305	1,026,385	1,042,665	1,059,150	1,075,845	1,092,750	1,109,865
1410	1,127,185	1,144,715	1,162,465	1,180,435	1,198,625	1,217,040	1,235,680	1,254,545	1,273,640	1,292,965
1420	1,312,520	1,332,310	1,352,340	1,372,610	1,393,125	1,413,890	1,434,910	1,456,195	1,477,755	1,499,595
1430	1,521,715	1,544,115	1,566,800	1,589,775	1,613,045	1,636,610	1,660,470	1,684,630	1,709,090	1,733,850
1440	1,758,904									

D.A. = 707 sq. mi., determined by subtracting area between Laguna Gage and Montell Dam Site from D. A. at Laguna Gage. (Delineated on Quads. Barksdale, Davenport Hill, Turkey Mountain, and York Hollow; scale 1:62,500).

TABLE 23

EDWARDS UNDERGROUND RESERVOIR
CONCAN RESERVOIR
R.M. 226.2 - Frio River
DRAINAGE AREA 391 SQ. MI.
AREA AND CAPACITY CURVES

AREA (ACRES)

Elev.	0	1	2	3	4	5	6	7	8	9
1240	0	1	2	4	6	8	10	15	18	19
1250	20	23	25	30	36	37	40	42	45	50
1260	57	60	70	80	90	100	110	125	140	150
1270	165	175	185	203	216	228	243	265	271	283
1280	302	312	328	345	358	374	392	408	426	444
1290	463	482	501	522	544	564	586	608	630	654
1300	675	705	732	762	790	821	852	883	914	945
1310	976	1,010	1,040	1,073	1,108	1,141	1,176	1,210	1,245	1,278
1320	1,315	1,355	1,400	1,441	1,486	1,530	1,580	1,626	1,678	1,727
1330	1,780	1,827	1,878	1,927	1,980	2,031	2,082	2,136	2,187	2,240
1340	2,290	2,350	2,400	2,452	2,508	2,558	2,614	2,672	2,726	2,781
1350	2,836	2,890	2,948	3,004	3,062	3,120	3,177	3,236	3,294	3,355
1360	3,414	3,474	3,540	3,603	3,671	3,736	3,798	3,860	3,928	3,993
1370	4,060	4,120	4,190	4,259	4,324	4,393	4,463	4,532	4,600	4,668
1380	4,740	4,803	4,866	4,930	4,994	5,060	5,125	5,190	5,258	5,325
1390	5,393	5,460	5,526	5,593	5,653	5,730	5,800	5,868	5,938	6,008
1400	6,083	6,150	6,223	6,300	6,380	6,461	6,543	6,625	6,710	6,797
1410	6,880	6,970	7,054	7,142	7,228	7,320	7,412	7,500	7,592	7,684
1420	7,747	7,825	7,900	7,975	8,050	8,125	8,205	8,285	8,365	8,445
1430	8,525	8,605	8,690	8,775	8,855	8,940	9,025	9,115	9,205	9,295
1440	9,384	9,475	9,570	9,665	9,755	9,845	9,935	10,030	10,125	10,215
1450	10,305	10,395	10,485	10,575	10,670	10,760	10,850	10,945	11,035	11,125
1460	11,218									

CAPACITY (ACRE-FEET)

Elev.	0	1	2	3	4	5	6	7	8	9
1240	0	1	3	6	11	18	27	40	57	76
1250	96	118	142	170	203	240	279	320	364	412
1260	466	525	590	665	750	845	950	1,068	1,201	1,346
1270	1,504	1,674	1,854	2,048	2,258	2,480	2,716	2,970	3,238	3,515
1280	3,808	4,115	4,435	4,772	5,124	5,490	5,873	6,273	6,690	7,125
1290	7,579	8,052	8,544	9,056	9,589	10,143	10,718	11,315	11,934	12,576
1300	13,241	13,931	14,650	15,397	16,173	16,979	17,816	18,684	19,583	20,513
1310	21,474	22,467	23,492	24,549	25,640	26,765	27,924	29,117	30,345	31,607
1320	32,904	34,239	35,617	37,038	38,502	40,010	41,565	43,168	44,820	46,523
1330	48,277	50,081	51,934	53,837	55,791	57,797	59,854	61,963	64,125	66,339
1340	68,604	70,924	73,299	75,725	78,205	80,738	83,324	85,967	88,666	91,420
1350	94,229	97,092	100,011	102,987	106,020	109,111	112,260	115,467	118,732	122,057
1360	125,442	128,886	132,393	135,965	139,602	143,306	147,073	150,902	154,796	158,757
1370	162,784	166,874	171,029	175,254	179,546	183,905	188,333	192,831	197,397	202,031
1380	206,735	211,507	216,342	221,240	226,202	231,229	236,322	241,480	246,704	251,996
1390	257,355	262,782	268,275	273,835	279,458	285,150	290,915	296,749	302,652	308,625
1400	314,671	320,788	326,975	333,237	339,577	345,998	352,500	359,084	365,752	372,506
1410	379,345	386,270	393,282	400,380	407,565	414,839	422,205	429,661	437,207	444,845
1420	452,561	460,347	468,209	476,147	484,159	492,247	500,412	508,657	516,982	525,387
1430	533,872	542,437	551,085	559,817	568,632	577,530	586,512	595,582	604,742	613,992
1440	623,332	632,762	642,284	651,902	661,612	671,412	681,302	691,284	701,362	711,532
1450	721,791	732,141	742,581	753,111	763,733	774,448	785,253	796,151	807,141	818,221
1460	829,393									

D.A. = 391 sq. mi., determined by subtracting D.A. between site at R.M. 225.0 and site at R.M. 226.2 from area determined by U.S.G.S. for site at R.M. 225.0. Reservoir area determined from A.M.S. Quadrangle "Magers Crossing, Texas," scale 1:24,000.

TABLE 24

EDWARDS UNDERGROUND RESERVOIR
SABINAL DAM SITE
Sabinal R. M. 42.3
AREA AND CAPACITY CURVES

Area - Acres

Elev.(ft)	0	1	2	3	4	5	6	7	8	9
1130	0	7	14	21	28	35	42	49	56	63
1140	70	78	86	94	102	110	119	128	137	146
1150	155	165	176	188	201	215	230	246	263	281
1160	300	319	338	357	376	395	414	433	452	471
1170	490	510	530	552	574	596	620	644	668	694
1180	720	748	778	810	844	878	914	950	986	1,022
1190	1,060	1,098	1,136	1,176	1,216	1,256	1,298	1,340	1,384	1,428
1200	1,473	1,520	1,568	1,618	1,668	1,720	1,774	1,830	1,886	1,942
1210	2,000	2,058	2,116	2,174	2,232	2,290	2,350	2,410	2,470	2,530
1220	2,590	2,650	2,710	2,770	2,832	2,894	2,956	3,018	3,082	3,146
1230	3,210	3,278	3,346	3,416	3,488	3,562	3,638	3,716	3,794	3,872
1240	3,950	4,028	4,106	4,184	4,262	4,340	4,419	4,499	4,579	4,659
1250	4,739	4,822	4,906	4,992	5,080	5,168	5,256	5,346	5,436	5,528
1260	5,620	5,712	5,804	5,898	5,992	6,086	6,182	6,278	6,374	6,472
1270	6,570	6,668	6,766	6,864	6,962	7,060	7,160	7,260	7,360	7,460
1280	7,560	7,660	7,760	7,860	7,962	8,064	8,166	8,268	8,372	8,476
1290	8,580	8,684	8,788	8,892	8,998	9,104	9,210	9,318	9,426	9,534
1300	9,644	9,740	9,840	9,940	10,040	10,140	10,240	10,340	10,440	10,540
1310	10,640	10,742	10,844	10,948	11,052	11,160	11,268	11,376	11,484	11,592
1320	11,700	11,808	11,916	12,024	12,132	12,240	12,348	12,456	12,564	12,672
1330	12,780	12,890	13,000	13,110	13,222	13,334	13,446	13,558	13,672	13,786
1340	13,900	14,014	14,130	14,246	14,362	14,480	14,598	14,716	14,834	14,954
1350	15,074									

Capacity - Acre-feet

Elev.(ft)	0	1	2	3	4	5	6	7	8	9
1130	0	3	14	31	56	87	126	171	224	283
1140	350	424	506	596	694	800	914	1,038	1,170	1,312
1150	1,462	1,622	1,792	1,974	2,169	2,377	2,599	2,837	3,091	3,363
1160	3,654	3,963	4,292	4,639	5,006	5,391	5,796	6,219	6,661	7,123
1170	7,604	8,104	8,624	9,165	9,728	10,313	10,921	11,553	12,209	12,890
1180	13,597	14,331	15,094	15,888	16,715	17,576	18,472	19,404	20,372	21,376
1190	22,417	23,496	24,613	25,769	26,965	28,201	29,478	30,797	32,159	33,565
1200	35,015	36,511	38,055	39,648	41,291	42,985	44,732	46,534	48,392	50,306
1210	52,277	54,306	56,393	58,538	60,741	63,002	65,322	67,702	70,142	72,642
1220	75,202	77,822	80,502	83,242	86,043	88,906	91,831	94,818	97,868	100,982
1230	104,160	107,404	110,716	114,097	117,549	121,074	124,674	128,351	132,106	135,939
1240	139,850	143,839	147,906	152,051	156,274	160,575	164,954	169,413	173,952	178,571
1250	183,270	188,050	192,914	197,863	202,899	208,023	213,235	218,536	223,927	229,409
1260	234,983	240,649	246,407	252,258	258,203	264,242	270,376	276,606	282,932	289,355
1270	295,876	302,495	309,212	316,027	322,940	329,951	337,061	344,271	351,581	358,991
1280	366,501	374,111	381,821	389,631	397,542	405,555	413,670	421,887	430,207	438,631
1290	447,159	455,791	464,527	473,367	482,312	491,363	500,520	509,784	519,156	528,636
1300	538,225	547,917	557,707	567,597	577,587	587,677	597,867	608,157	618,547	629,037
1310	639,627	650,318	661,111	672,007	683,007	694,113	705,327	716,649	728,079	739,617
1320	751,263	763,017	774,879	786,849	798,927	811,113	823,407	835,809	848,319	860,937
1330	873,663	886,498	899,443	912,498	925,664	938,942	952,332	965,834	979,449	993,178
1340	1,007,021	1,020,978	1,035,050	1,049,238	1,063,542	1,077,963	1,092,502	1,107,159	1,121,934	1,136,828
1350	1,151,842									

Drainage Area = 210 sq. mi., determined by adding the drainage area between original site and site at R.M. 42.3 to the drainage area at the original site as determined by the USSC-T. Reservoir areas determined from A.M.S. map "SAN ANTONIO, TEXAS", scale 1:250,000.

TABLE 25

EDWARDS UNDERGROUND RESERVOIR
DAM #7 RESERVOIR
R.M. 351.3 Guadalupe River
AREA AND CAPACITY CURVES

Area - Acres

Elev.(ft)	0	1	2	3	4	5	6	7	8	9
1050			0	1	3	4	6	8	10	12
1060	15	18	21	23	26	29	32	36	40	44
1070	49	53	57	61	66	71	76	82	88	94
1080	101	108	117	126	135	144	153	163	173	183
1090	193	204	214	224	235	246	257	268	279	291
1100	303	315	327	340	353	367	381	395	409	423
1110	438	454	470	487	504	522	542	563	585	608
1120	631	655	680	706	733	761	789	818	846	875
1130	904	933	964	995	1,026	1,057	1,088	1,120	1,151	1,183
1140	1,215	1,252	1,291	1,330	1,370	1,410	1,450	1,490	1,531	1,572
1150	1,614	1,657	1,700	1,743	1,787	1,833	1,880	1,928	1,976	2,023
1160	2,070	2,124	2,180	2,240	2,302	2,367	2,436	2,507	2,580	2,656
1170	2,732	2,808	2,885	2,963	3,043	3,124	3,205	3,286	3,368	3,451
1180	3,534	3,632	3,730	3,828	3,925	4,020	4,120	4,220	4,326	4,430
1190	4,538	4,645	4,750	4,855	4,960	5,070	5,175	5,285	5,400	5,520
1200	5,638	5,770	5,910	6,050	6,195	6,350	6,500	6,655	6,815	6,975
1210	7,145	7,310	7,475	7,645	7,815	7,985	8,155	8,325	8,500	8,670
1220	8,844	9,015	9,190	9,360	9,535	9,710	9,890	10,070	10,245	10,425
1230	10,605	10,785	10,965	11,145	11,325	11,510	11,695	11,880	12,060	12,245
1240	12,431	12,615	12,800	12,985	13,170	13,355	13,545	13,735	13,925	14,115
1250	14,310	14,505	14,700	14,895	15,090	15,290	15,495	15,705	15,915	16,130
1260	16,346	16,560	16,780	17,000	17,216	17,460	17,700	17,930	18,170	18,410
1270	18,660	18,930	19,210	19,490	19,790	20,100	20,420	20,760	21,130	21,550
1280	22,030									

Capacity - Acre-feet

Elev.(ft)	0	1	2	3	4	5	6	7	8	9
1050			0	0	2	6	11	18	27	38
1060	52	68	88	110	134	162	192	226	264	306
1070	352	403	458	517	581	649	723	802	887	978
1080	1,076	1,180	1,292	1,414	1,544	1,684	1,832	1,990	2,158	2,336
1090	2,524	2,722	2,931	3,150	3,380	3,620	3,872	4,134	4,408	4,693
1100	4,990	5,299	5,620	5,954	6,300	6,660	7,034	7,422	7,824	8,240
1110	8,670	9,116	9,578	10,056	10,552	11,065	11,597	12,149	12,723	13,319
1120	13,939	14,582	15,250	15,943	16,663	17,410	18,185	18,989	19,821	20,681
1130	21,571	22,489	23,437	24,417	25,427	26,469	27,541	28,645	29,781	30,948
1140	32,147	33,381	34,653	35,963	37,313	38,703	40,133	41,603	43,113	44,665
1150	46,258	47,894	49,572	51,294	53,059	54,869	56,725	58,629	60,581	62,581
1160	64,627	66,724	68,876	71,086	73,357	75,691	78,093	80,565	83,109	85,727
1170	88,421	91,191	94,037	96,961	99,964	103,048	106,212	109,458	112,785	116,195
1180	119,687	123,270	126,951	130,730	134,606	138,578	142,648	146,818	151,091	155,469
1190	159,953	164,545	169,243	174,045	178,953	183,968	189,090	194,320	199,662	205,122
1200	210,701	216,405	222,245	228,225	234,347	240,619	247,044	253,622	260,357	267,252
1210	274,312	281,540	288,932	296,492	304,222	312,122	320,192	328,432	336,844	345,429
1220	354,186	363,116	372,218	381,493	390,941	400,563	410,363	420,343	430,501	440,836
1230	451,351	462,046	472,921	483,976	495,211	506,629	518,231	530,017	541,987	554,139
1240	566,477	579,000	591,708	604,600	617,678	630,940	644,390	658,030	671,860	685,880
1250	700,092	714,500	729,102	743,900	758,892	774,082	789,474	805,074	820,884	836,906
1260	853,144	869,597	886,267	903,157	920,265	937,603	955,183	972,998	991,048	1,009,338
1270	1,027,873	1,046,668	1,065,738	1,085,088	1,104,728	1,124,673	1,144,933	1,165,523	1,186,468	1,207,808
1280	1,229,598									

Drainage Area = 1,124 sq. mi., as determined by USSC-T and Consulting Engineer for Guadalupe-Blanco River Authority. Reservoir area determined from A.M.S. Quadrangle, "Boerne, Texas", scale 1:62,500.

TABLE 26

EDWARDS UNDERGROUND RESERVOIR
CLOPTIN CROSSING RESERVOIR
BLANCO RIVER - Mile 32.5
AREA AND CAPACITY CURVES

AREA (ACRES)

Elev.	0	1	2	3	4	5	6	7	8	9
820				0	10	12	15	17	20	22
830	25	27	28	29	30	32	34	35	36	38
840	40	42	47	50	56	60	66	70	76	82
850	84	86	90	99	104	112	121	124	131	134
860	145	158	168	180	195	209	224	240	250	258
870	263	275	287	299	312	326	341	356	372	391
880	410	431	454	477	501	527	552	578	605	632
890	659	687	715	744	773	803	833	864	897	932
900	970	1,013	1,057	1,102	1,147	1,194	1,242	1,290	1,340	1,391
910	1,440	1,491	1,542	1,592	1,644	1,697	1,752	1,807	1,862	1,915
920	1,967	2,018	2,071	2,122	2,174	2,225	2,275	2,325	2,376	2,428
930	2,480	2,554	2,625	2,693	2,762	2,826	2,890	2,954	3,018	3,082
940	3,146	3,211	3,277	3,341	3,403	3,465	3,524	3,583	3,642	3,704
950	3,770	3,838	3,909	3,980	4,051	4,122	4,193	4,264	4,336	4,407
960	4,478	4,546	4,614	4,684	4,755	4,827	4,900	4,972	5,045	5,119
970	5,196	5,272	5,350	5,430	5,510	5,589	5,672	5,757	5,839	5,924
980	6,013	6,110	6,203	6,297	6,392	6,486	6,581	6,675	6,770	6,865
990	6,960	7,057	7,152	7,248	7,343	7,439	7,536	7,632	7,728	7,824
1000	7,920	8,016	8,112	8,208	8,304	8,400	8,496	8,592	8,688	8,784
1010	8,880	8,976	9,072	9,168	9,264	9,360	9,456	9,552	9,648	9,744
1020	9,840									

CAPACITY (ACRE-FEET)

Elev.	0	1	2	3	4	5	6	7	8	9
820				0	2	17	36	56	78	101
830	125	151	179	207	236	267	300	334	370	407
840	446	487	532	580	633	691	754	821	894	973
850	1,056	1,141	1,229	1,323	1,425	1,533	1,649	1,771	1,899	2,032
860	2,171	2,323	2,483	2,665	2,843	3,045	3,263	3,494	3,739	3,998
870	4,255	4,525	4,806	5,099	5,404	5,723	6,056	6,405	6,769	7,151
880	7,551	7,972	8,414	8,879	9,368	9,883	10,422	10,987	11,578	12,197
890	12,843	13,516	14,217	14,946	15,704	16,493	17,310	18,159	19,039	19,954
900	20,905	21,896	22,931	24,011	25,136	26,306	27,524	28,790	30,105	31,471
910	32,886	34,352	35,868	37,435	39,053	40,723	42,448	44,228	46,062	47,951
920	49,892	51,884	53,929	56,025	58,173	60,372	62,623	64,922	67,273	69,675
930	72,129	74,646	77,235	79,894	82,622	85,416	88,274	91,196	94,182	97,232
940	100,346	103,525	106,768	110,077	113,450	116,883	120,378	123,932	127,544	131,217
950	134,954	138,758	142,631	146,576	150,592	154,678	158,835	163,064	167,364	171,736
960	176,178	180,690	185,270	189,919	194,639	199,430	204,293	209,229	214,237	219,320
970	224,477	229,711	235,022	240,412	245,882	251,431	257,062	262,776	268,575	274,456
980	280,424	286,486	292,643	298,892	305,237	311,676	318,209	324,837	331,560	338,377
990	345,290	352,299	359,404	366,604	373,900	381,291	388,778	396,362	404,042	411,818
1,000	419,690	427,658	435,722	443,682	452,138	460,490	468,938	477,482	486,122	494,858
1,010	503,690	512,618	521,642	530,762	539,978	549,290	558,698	568,202	577,802	587,498
1,020	597,290									

D.A. = 307 sq. mi., determined from A.M.S. maps "SAN ANTONIO, TEXAS" and "LLANO, TEXAS", scale 1:250,000.
Reservoir area determined from Corps of Engineers, FWD, field survey topography map.

". . . The runoff reductions were computed by reasonable methods from available data. However, as will be apparent from later exposition, available data are inadequate to permit an accurate estimate of either past or future effects of land use, land treatment, and minor reservoirs upon runoff. Consequently, the computed depletions should be viewed as a generous allowance for depletions which available data indicates might happen or might have happened rather than as a precise determination of what will happen, or has happened. Future evaluation procedures may indicate smaller depletions."

Annex (C-8) indicates considerable coordination with the Soil Conservation Service, the Agricultural Stabilization and Conservation Service, and the Texas Forest Service. The 1954 census of agriculture published by the Department of Agriculture was also used extensively as were data collected at the Agricultural Experiment Station at Riesel and Spur, Texas, and at Guthrie, Oklahoma.

49. Although Annex (C-8) does not estimate future depletions for the area in the upper Nueces River Basin, the procedures it presents allow the estimation of such future depletions for the drainage area above Montell, Concan, and Sabinal Reservoirs. Our interpretation of these procedures and their application results in the finding that only very small reductions in future runoff will take place, and that for all practical purposes, existing conditions data, historical data and future (2025) conditions data may be regarded as the same for these three reservoirs. Monthly and annual values of estimated 2025 inflow for Montell, Concan, Sabinal, Dam No. 7, and Cloptin Crossing Reservoirs are given in tables 27 through 31.

50. SEDIMENT CONTRIBUTING AREA.- All of the reservoir sites studied for this report are located in the Edwards Plateau area above the Balcones Fault zone. The following description of the area is quoted from Bulletin 5912: 1/

"The Edwards Plateau is a high limestone plain in southwest Texas covering an area of about 22,000,000 acres. On the northwest it merges with slightly higher areas of the High Plains, and on the northeast joins the lower lying Rolling Plains in a series of rock escarpments. On the east, it merges with the Grand Prairie with little change in elevation. On the southeast and south the plateau terminates in steep rock slopes of the Balcones Escarpment, descending to the level of the Blackland Prairies and Rio Grande Plain. Annual

1/ "Inventory and use of Sedimentation Data in Texas," prepared by the Soil Conservation Service, USDA, for the Texas Board of Water Engineers (now the Texas Water Commission) January 1959.

"rainfall decreases from 32 inches in the eastern section to 16 inches in the western section. Elevation ranges from 2,000 to 4,000 feet above mean sea level. Locally there are some nearly level divides and smooth valleys, but generally the area is made up of hilly, broken, and rough lands. Limestone sinks are a feature of the nearly level divides, and these areas are noncontributing so far as sediment is concerned. The Edwards Plateau is dominantly range land and is used almost exclusively for the raising of livestock. Some cultivation is found on the nearly level divides where deeper soils have developed in the eastern one-third of the area, but less than 5 percent of the total area is in cultivation."

Over almost the entire area the surface consists of thin limestone based soil. In places it is open prairie but most of the surface is covered with a medium to thick growth of cedar, small oak, and mesquite with a varying growth of prickly pear and a consistent range of grass and weeds.

51. SEDIMENT PRODUCTION RATES.- Annual sedimentation production rates are generally considered to be low in the Edwards Plateau area. Many of the streams are springfed and clear flowing except in times of flood when flood plain scour and streambank erosion occurs. Estimates based on Bulletin 5912 indicate that the average annual rate of sediment production in the Edwards Plateau area varies from 0.065 to 0.038 acre-foot per square mile for drainage areas from 100 to 10,000 square miles, respectively. Due to the paucity of general sedimentation data for this area and the lack of suspended samples during extremely high flash floods, the rates recommended in Bulletin 5912 have been increased. The 100-year sediment volumes and the estimated distribution of the sediment in the reservoirs studied are shown in table 32.

52. STORAGE REQUIREMENTS.

a. General.

(1) To determine the most effective and efficient means of recharge to the underground reservoir several plans of operation were tested. Of the several investigated plans the immediate recharge of stored flood water was determined to be the most effective in areas of high natural recharge to the Edwards Reservoir. Under this plan, releases from the reservoirs were limited to the estimated recharge rates for the streams below the proposed dam sites. The estimated recharge rates for the Nueces, Frio, and Sabinal Rivers are 1,000 second-feet, 750 second-feet, and 500 second-feet, respectively. It is noted that the recommended releases are considerably less than the minimum downstream channel capacities shown in table 16. Under this plan, the surface reservoirs would be empty approximately 95 percent of the time;

TABLE 27

ESTIMATED MONTHLY AND ANNUAL FLOWS IN 1000 ACRE-FEET AT MONTELL DAM SITE - 2025 CONDITIONS

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
1924	8.4	6.3	7.2	7.8	5.1	4.1	2.2	0.9	0.7	0.8	1.0	1.4	45.9
1925	1.8	2.2	2.3	1.8	36.4	13.1	4.5	2.1	2.3	14.1	8.9	5.2	94.7
1926	3.9	3.4	3.8	4.1	6.1	2.6	30.2	7.3	2.7	1.7	2.1	3.2	71.1
1927	3.5	8.4	6.8	7.8	3.4	3.9	3.8	1.6	0.8	13.8	3.0	2.5	59.3
1928	2.5	2.5	2.3	2.1	3.7	9.5	1.5	3.3	1.0	3.1	2.4	2.1	36.0
1929	1.8	1.6	1.7	1.6	16.5	6.3	6.3	2.0	1.8	1.1	1.0	2.0	43.7
1930	2.1	2.0	1.9	1.5	2.1	48.8	4.7	1.4	1.1	33.7	6.8	5.8	111.9
1931	5.9	11.2	9.1	9.9	24.5	8.8	14.7	9.7	4.8	3.6	3.5	3.8	109.5
1932	3.7	3.2	4.7	4.5	5.6	2.9	45.3	13.9	111.0	21.0	11.6	8.4	235.8
1933	7.3	5.8	5.5	4.3	3.6	2.9	1.6	1.0	1.1	1.3	1.3	1.7	37.4
1934	1.8	1.8	2.1	2.6	3.2	1.5	0.9	0.6	0.5	0.5	0.5	0.6	16.6
1935	0.8	1.0	1.2	1.3	49.4	297.7	22.3	12.8	21.1	9.3	6.6	6.7	430.2
1936	5.7	4.6	5.0	4.3	4.6	7.1	8.5	3.7	124.2	22.6	15.3	10.1	215.7
1937	7.2	5.2	6.5	5.3	3.7	4.5	2.8	1.9	1.3	1.6	2.2	15.2	57.4
1938	12.6	7.1	5.6	6.9	7.2	3.8	8.8	5.0	2.8	2.7	2.3	2.4	67.2
1939	3.1	2.6	2.7	2.3	2.0	1.5	89.9	8.1	4.2	21.4	4.3	4.5	146.6
1940	3.9	4.1	3.9	4.9	9.6	5.7	3.9	3.0	2.4	1.9	2.2	3.3	48.8
1941	3.2	3.3	4.2	6.9	13.7	7.2	8.0	4.6	4.5	13.6	6.3	4.8	80.3
1942	3.9	3.0	3.0	3.1	5.4	3.0	2.3	3.3	22.8	22.7	9.6	6.6	88.7
1943	4.5	3.5	3.7	4.3	3.9	6.5	3.0	1.9	1.7	2.0	2.2	2.9	40.1
1944	4.5	4.8	7.0	5.9	4.5	3.7	2.1	1.8	11.7	5.6	3.5	3.8	58.9
1945	7.8	5.2	5.0	5.0	3.1	1.8	1.3	1.1	0.8	4.7	3.3	3.0	42.1
1946	3.1	2.9	2.6	2.3	4.0	7.4	3.2	1.3	1.5	22.3	6.5	4.5	61.6
1947	7.5	7.3	6.5	4.9	7.0	8.5	7.8	3.6	2.2	1.8	1.7	2.1	60.9
1948	2.3	2.5	2.6	2.3	2.2	2.7	14.3	1.9	1.2	1.4	1.5	1.6	36.5
1949	1.9	59.6	18.3	9.7	11.0	7.0	4.5	26.0	10.7	8.3	6.8	5.8	169.6
1950	5.4	4.7	4.3	3.4	4.2	5.0	3.8	2.8	2.6	2.7	2.3	2.6	43.8
1951	2.3	2.0	2.5	2.7	2.1	1.7	1.2	0.9	0.6	0.5	0.6	0.8	17.9
1952	1.0	1.1	1.4	4.4	6.2	2.4	1.2	0.8	0.6	0.4	0.4	0.5	20.4
1953	0.8	1.1	1.6	1.7	1.0	0.7	0.5	0.4	6.4	2.8	2.1	1.7	20.8
1954	1.5	1.3	1.2	2.0	10.1	20.5	9.5	2.9	1.5	1.6	1.3	1.3	54.7
1955	1.5	1.5	1.8	1.4	1.2	1.0	3.4	1.9	146.8	9.9	5.8	3.6	179.8
1956	2.8	2.3	2.2	1.7	1.5	1.0	0.8	0.5	0.5	0.6	0.3	0.3	14.5
1957	0.3	0.3	0.4	4.4	9.8	15.7	3.7	1.8	1.8	6.5	6.6	6.5	57.8
1958	6.7	9.6	16.2	8.2	8.8	60.1	17.9	8.5	50.2	28.5	23.2	14.5	252.4
1959	9.6	7.6	7.1	5.8	7.4	23.9	22.0	11.1	11.2	26.2	9.2	7.9	149.0
1960	7.8	8.0	7.6	6.0	5.2	3.4	5.7	16.5	8.2	13.3	15.2	11.7	108.6
1961	10.8	11.8	9.8	7.3	5.6	10.7	18.8	12.8	7.8	11.3	9.6	7.4	123.7
1962	6.0	4.7	4.6	4.2	3.3	5.2	2.4	1.5	1.3	--	--	--	(33.2)
Total	171.2	221.1	185.9	170.6	307.9	623.8	389.3	186.2	580.4	340.9	193.0	172.8	3,543.1
Average	4.4	5.7	4.8	4.4	7.9	16.0	10.0	4.8	14.9	9.0	5.0	4.5	91.4

TABLE 28

ESTIMATED MONTHLY AND ANNUAL FLOWS IN 1000 ACRE-FEET AT CONCAN DAM SITE - 2025 CONDITIONS

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
1924	7.0	5.3	7.4	8.3	9.4	6.0	2.7	1.3	1.5	1.5	1.6	1.7	53.7
1925	1.7	1.9	2.0	1.8	4.7	2.6	1.2	1.1	1.6	4.3	3.1	2.8	28.8
1926	2.7	2.3	2.7	3.2	2.7	2.0	26.4	5.2	3.1	3.2	2.3	3.1	58.9
1927	2.9	8.8	9.2	6.6	4.7	3.7	3.2	2.1	1.5	2.5	1.8	1.9	48.9
1928	1.9	1.9	2.0	1.8	2.2	1.9	0.9	2.5	1.4	2.1	1.4	1.5	21.5
1929	1.5	1.1	1.2	1.0	4.0	2.7	3.9	1.1	1.3	1.2	1.0	2.1	22.1
1930	2.2	2.1	1.9	1.6	2.2	32.7	4.9	1.5	1.2	30.2	5.7	5.0	91.2
1931	6.5	10.6	9.6	12.5	25.1	8.9	25.8	8.7	4.5	7.6	4.1	4.4	128.3
1932	4.6	5.1	7.5	5.6	7.5	4.4	168.0	12.1	65.9	21.5	10.2	7.9	320.3
1933	8.0	5.8	5.5	4.4	4.2	3.4	2.3	2.1	2.2	1.9	2.0	2.1	43.9
1934	2.5	2.1	2.3	3.7	3.9	1.4	1.0	0.9	0.6	0.6	0.7	1.2	20.9
1935	1.5	1.5	1.5	1.8	61.8	141.8	33.6	14.3	28.2	10.2	6.8	7.6	310.6
1936	6.7	5.4	5.2	5.2	5.7	5.5	5.3	3.4	76.6	23.5	15.5	9.8	167.8
1937	7.6	5.9	7.0	5.3	4.0	5.0	3.0	2.0	1.7	2.1	2.5	6.0	52.1
1938	8.0	6.2	5.9	5.5	6.3	4.1	3.1	2.4	1.8	1.7	1.4	1.8	48.2
1939	2.5	2.3	2.3	1.8	1.4	1.1	22.2	5.4	2.4	3.8	2.9	2.7	50.8
1940	2.5	2.8	2.7	4.3	6.7	5.3	6.4	2.8	2.1	1.8	2.4	3.9	43.7
1941	3.5	4.1	5.2	14.5	20.0	8.6	5.8	9.2	11.2	13.0	9.2	6.7	111.0
1942	5.0	4.0	3.8	5.5	7.1	3.8	3.3	3.3	9.6	8.7	6.3	4.8	65.2
1943	4.0	3.0	3.2	3.4	2.9	3.3	2.4	1.3	1.5	1.8	1.7	2.4	30.9
1944	3.0	2.9	5.4	4.5	6.2	7.1	3.6	4.4	5.4	4.5	3.2	3.9	54.1
1945	8.1	6.4	6.1	6.8	5.7	3.1	2.0	1.2	0.9	3.6	2.7	3.1	49.7
1946	2.7	2.6	2.4	2.2	3.0	2.1	1.7	0.8	1.6	16.6	6.1	4.1	45.9
1947	6.3	5.4	5.0	5.0	5.9	9.4	6.4	3.3	2.2	1.9	2.1	2.6	55.5
1948	2.4	2.4	2.4	1.9	1.7	1.8	1.7	0.8	0.8	1.1	1.2	1.4	19.6
1949	1.7	26.8	10.6	7.9	6.8	4.9	3.1	3.0	3.2	3.6	3.1	3.2	77.9
1950	3.3	3.1	3.3	2.8	2.9	2.5	1.7	1.4	1.3	1.4	1.1	1.5	26.3
1951	1.2	1.4	2.2	2.2	7.3	2.5	0.8	0.4	2.2	7.0	0.9	1.2	29.3
1952	1.2	1.1	1.4	1.8	2.5	1.6	0.7	0.2	0.1	0.1	0.4	1.2	12.3
1953	1.7	1.3	1.2	0.9	0.4	0.1	0.1	0.2	0.8	1.2	1.2	1.2	10.3
1954	1.0	0.8	0.7	0.6	10.3	3.4	2.6	1.1	0.5	0.3	0.4	0.5	22.2
1955	0.8	0.9	1.0	0.6	2.5	0.8	2.2	0.8	1.9	1.1	0.9	0.9	14.4
1956	0.8	0.7	0.7	0.5	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3.2
1957	0.1	0.4	1.6	10.2	5.4	8.1	1.9	0.7	1.3	6.5	5.9	4.9	47.0
1958	5.5	8.3	12.5	6.4	5.5	30.2	12.4	8.2	44.0	23.9	22.5	11.7	191.1
1959	7.9	5.5	5.0	4.9	5.2	22.2	14.1	7.4	5.6	15.0	7.7	6.3	106.8
1960	6.2	5.8	5.7	4.9	4.2	2.8	5.4	12.6	7.0	7.6	10.1	11.7	84.0
1961	10.1	12.6	10.7	7.4	5.4	12.6	10.7	8.7	5.6	6.2	5.3	4.7	100.0
1962	4.2	3.3	3.1	3.3	3.1	5.0	1.7	0.8	0.8	--	--	--	(25.3)
Total	151.0	173.9	169.1	172.6	270.8	368.5	398.3	138.7	305.1	244.8	157.4	143.5	2,693.7
Average	3.9	4.5	4.3	4.4	6.9	9.5	10.2	3.6	7.8	6.4	4.2	3.8	69.5

TABLE 29

ESTIMATED MONTHLY AND ANNUAL FLOWS IN 1000 ACRE-FEET AT SABINAL DAM SITE - 2025 CONDITIONS

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
1934	0.8	0.7	0.7	1.1	1.2	0.4	0.3	0.3	0.2	0.2	0.2	0.4	6.5
1935	1.1	1.2	1.1	1.4	46.8	107.3	25.4	10.8	21.3	7.7	5.1	5.8	235.0
1936	4.7	3.8	3.7	3.7	4.0	3.8	3.8	2.3	54.3	16.6	11.0	7.0	118.7
1937	3.6	2.8	3.3	2.5	1.9	2.4	1.4	1.0	0.8	1.0	1.2	2.8	24.7
1938	3.6	2.8	2.7	2.5	2.9	1.9	1.4	1.1	0.8	0.8	0.7	0.8	22.0
1939	1.2	1.1	1.1	0.9	0.7	0.5	10.5	2.6	1.1	1.8	1.4	1.3	24.2
1940	1.1	1.2	1.2	1.8	2.8	2.3	2.7	1.2	0.9	0.7	1.0	1.7	18.6
1941	2.3	2.6	3.4	9.5	13.0	5.6	3.8	5.9	7.3	8.4	6.0	4.3	72.1
1942	2.7	2.3	2.1	3.0	3.9	2.2	1.8	1.8	5.2	5.1	2.5	1.8	34.4
1943	1.3	0.9	1.0	1.8	0.9	2.2	1.7	0.4	0.2	0.2	0.2	0.3	11.1
1944	0.8	1.3	4.4	2.8	2.8	3.8	1.7	2.5	1.3	1.0	0.8	1.6	24.8
1945	6.1	3.6	5.2	6.3	3.4	1.7	0.8	0.3	0.6	1.0	0.7	1.0	30.7
1946	0.7	0.7	0.6	1.0	1.2	0.7	0.3	0.0	1.9	4.9	2.8	1.7	16.5
1947	2.2	2.0	1.8	1.7	1.9	4.0	1.6	0.7	0.3	0.1	0.1	0.2	16.6
1948	0.3	0.4	0.4	0.2	0.0	0.3	0.1	0.0	0.3	0.3	0.0	0.1	2.4
1949	0.3	5.4	3.8	5.5	4.9	2.9	1.5	1.4	1.3	1.8	1.3	1.1	31.2
1950	1.3	1.5	1.6	1.2	1.2	1.8	0.9	0.2	0.1	0.0	0.0	0.1	9.9
1951	0.1	0.1	0.2	0.3	5.0	1.3	0.2	0.0	0.0	0.0	0.0	0.0	7.2
1952	0.0	0.0	0.0	0.3	1.5	1.2	0.2	0.0	0.0	0.0	0.0	0.0	3.2
1953	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.3	1.2	0.6	0.5	3.0
1954	0.2	0.1	0.0	0.0	5.7	1.0	0.6	0.1	0.0	0.0	0.0	0.0	7.7
1955	0.0	0.0	0.0	0.0	0.3	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.5
1956	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	1.1
1957	0.0	0.0	1.4	6.1	2.6	5.6	0.5	0.0	5.2	4.0	4.1	3.7	33.2
1958	5.9	8.8	15.7	6.0	5.7	42.6	9.5	3.7	15.3	18.4	19.1	8.0	158.7
1959	4.5	2.8	2.2	2.6	2.0	13.1	9.2	3.8	2.2	7.6	4.9	4.0	58.9
1960	4.1	3.6	3.0	2.5	2.7	1.0	5.9	11.8	3.7	5.4	5.6	6.4	55.7
1961	5.8	9.9	7.5	4.0	2.7	9.7	5.4	3.6	1.6	2.2	1.2	1.2	54.8
1962	1.0	0.7	0.5	0.7	0.5	0.4	0.0	0.0	0.0	--	--	--	(3.8)
Total	55.8	60.5	68.7	69.4	122.2	219.7	92.5	55.5	126.2	90.4	70.5	55.8	1087.2
Average	1.9	2.1	2.4	2.4	4.2	7.6	3.2	1.9	4.3	3.2	2.5	2.0	37.7

TABLE 30

ESTIMATED MONTHLY AND ANNUAL FLOWS IN 1000 ACRE-FEET AT DAM NO. 7 SITE - 2025 CONDITIONS

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
1924	21.8	22.0	33.5	28.6	41.7	24.4	8.7	4.2	5.9	4.1	4.4	5.0	204.3
1925	4.6	3.7	3.5	3.0	3.7	1.6	1.1	1.5	2.2	15.2	9.4	4.2	53.7
1926	4.6	3.4	7.6	38.4	20.3	8.2	11.8	4.5	2.7	3.5	5.5	6.8	117.3
1927	4.8	14.0	21.6	18.0	10.0	20.3	5.4	2.4	2.5	5.5	2.9	3.5	110.9
1928	3.7	4.4	7.2	3.0	3.6	6.0	1.4	1.0	1.5	2.0	1.8	2.2	37.8
1929	2.3	2.2	3.0	4.2	61.1	12.0	22.9	2.7	2.1	1.7	2.4	3.6	120.2
1930	3.0	3.0	2.9	2.3	21.3	20.1	3.6	1.1	0.9	45.0	8.6	7.8	119.6
1931	15.6	26.2	24.6	35.5	48.0	13.9	13.4	6.7	3.3	3.0	4.2	5.3	199.7
1932	8.3	8.0	18.2	12.0	13.5	5.3	197.6	10.8	32.2	13.7	9.0	10.8	339.4
1933	18.1	10.9	11.9	9.2	12.0	6.0	3.4	2.6	2.7	2.5	2.7	3.2	85.2
1934	5.9	4.1	6.3	11.3	5.0	1.8	4.0	1.1	1.2	1.0	1.5	2.1	45.3
1935	2.1	4.1	2.7	2.9	49.8	206.5	22.7	8.7	50.8	18.0	12.3	18.7	399.3
1936	13.9	10.0	10.6	7.7	37.9	48.8	64.7	11.5	209.4	60.4	34.2	28.3	537.4
1937	23.7	17.7	20.9	14.5	9.5	31.4	7.5	3.7	3.9	4.8	4.5	11.8	153.9
1938	25.3	14.7	11.9	20.5	19.2	8.3	4.7	2.7	3.0	2.5	2.7	2.9	118.5
1939	5.2	3.4	3.4	3.2	3.8	1.1	7.7	2.8	1.1	11.7	3.2	3.4	50.0
1940	3.5	4.7	7.7	18.6	13.7	16.5	9.0	4.3	2.5	3.6	10.8	33.4	128.3
1941	12.2	60.8	54.8	77.0	96.2	29.8	20.0	9.5	13.8	21.8	11.2	9.7	416.8
1942	7.8	6.6	6.4	32.6	43.3	11.9	7.4	5.4	19.0	25.0	14.2	12.0	191.6
1943	10.6	7.6	8.2	9.2	6.4	14.6	7.2	2.4	4.4	3.7	3.2	4.6	82.1
1944	7.8	12.0	26.4	15.0	87.8	32.6	10.0	15.0	16.0	13.6	9.0	25.4	270.6
1945	38.8	36.4	50.6	37.2	16.0	9.6	8.0	5.0	12.6	17.4	8.0	20.2	259.8
1946	12.4	14.6	16.2	12.4	25.6	11.8	4.6	2.8	11.8	20.4	38.4	23.4	194.4
1947	50.4	28.6	22.6	21.0	18.0	22.4	8.8	4.8	3.0	2.9	3.8	4.8	191.1
1948	4.4	4.6	4.6	4.4	3.8	8.2	4.6	1.8	1.9	3.0	2.2	2.6	46.1
1949	3.6	17.6	11.2	20.2	15.4	8.6	4.0	6.6	5.6	4.0	3.6	4.2	104.6
1950	4.4	5.0	4.2	5.6	9.5	5.2	4.2	1.6	2.1	1.7	1.7	2.4	47.6
1951	2.4	2.4	3.8	3.2	9.4	5.8	0.6	0.1	0.1	0.4	1.0	1.8	31.0
1952	1.7	1.5	2.1	5.6	17.4	7.8	1.8	0.4	107.2	4.0	4.0	9.8	163.3
1953	8.6	5.0	5.7	4.2	2.4	0.5	0.8	0.8	12.6	4.4	3.1	3.2	51.3
1954	3.0	2.2	1.9	1.2	6.0	0.6	0.0	0.0	0.0	1.4	1.0	1.0	18.3
1955	2.0	3.6	1.5	0.8	7.2	1.9	7.2	1.9	0.8	0.7	0.7	1.1	29.4
1956	1.2	1.4	0.8	0.4	1.0	0.0	0.0	0.3	0.4	0.4	0.6	0.3	6.8
1957	0.6	1.6	14.0	76.4	39.5	31.8	3.5	1.4	14.2	74.2	38.4	25.8	321.4
1958	40.4	53.0	57.4	26.8	90.6	35.0	14.2	6.2	34.8	20.0	25.2	16.2	419.8
1959	12.0	10.8	9.4	15.6	11.4	31.4	12.9	6.3	4.2	73.0	10.4	11.2	208.6
1960	14.0	16.8	14.6	12.7	8.0	4.2	7.2	41.2	9.4	68.6	29.2	41.8	267.7
1961	36.0	69.5	37.4	20.9	13.1	23.5	13.7	8.0	6.0	5.4	6.2	5.9	245.6
1962	5.4	4.9	4.9	6.0	4.9	7.6	1.8	0.6	2.4	--	--	--	(38.5)
Total	446.1	523.0	556.2	641.3	907.0	737.0	532.1	194.4	610.3	564.2	335.2	380.4	6,427.2
Average	11.4	13.4	14.3	16.4	23.3	18.9	13.6	5.0	15.6	14.5	8.6	9.8	164.8

TABLE 31

ESTIMATED MONTHLY AND ANNUAL FLOWS IN 1000 ACRE-FEET AT CLOPTIN CROSSING DAM SITE - 2025 CONDITIONS

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
1928	--	--	--	--	--	--	0.6	0.7	0.3	0.4	0.5	0.8	(3.3)
1929	1.2	0.6	0.7	4.9	77.0	15.8	15.4	2.8	1.7	1.0	1.4	1.3	123.8
1930	1.0	0.9	0.9	0.8	14.0	5.3	2.3	0.9	0.7	4.0	1.9	3.5	36.2
1931	8.2	18.9	18.6	17.3	16.1	5.2	10.5	2.6	1.6	1.3	1.2	1.5	103.0
1932	3.3	3.3	8.0	3.3	2.5	1.6	1.6	1.7	1.5	1.0	0.9	0.9	29.6
1933	1.4	1.3	1.7	1.5	1.5	0.9	0.9	1.3	0.9	0.7	0.5	0.6	13.2
1934	2.6	2.8	6.7	13.2	3.4	1.4	1.1	0.8	0.4	0.6	1.7	0.9	35.6
1935	0.8	1.8	0.8	0.7	21.7	36.6	5.4	2.1	6.2	3.1	2.1	2.8	84.1
1936	2.4	1.6	2.0	1.5	10.8	16.0	30.5	4.9	23.0	7.3	5.6	5.2	110.8
1937	7.6	6.6	12.1	6.6	3.0	4.2	2.8	1.2	1.4	4.7	1.1	5.2	56.5
1938	17.8	11.5	7.2	24.4	19.3	6.9	3.7	1.7	1.2	1.1	0.8	1.1	96.7
1939	1.2	0.9	0.8	1.8	0.7	0.5	1.5	0.5	0.4	0.7	0.6	0.6	10.2
1940	0.5	0.7	1.2	2.9	0.8	3.5	2.4	0.9	0.8	0.3	6.3	20.9	41.2
1941	6.7	24.6	29.4	28.7	39.0	30.6	9.3	3.0	2.1	5.3	2.3	1.8	182.8
1942	1.5	1.4	1.5	10.6	3.9	2.2	1.4	3.2	18.9	13.2	8.1	5.5	71.4
1943	4.2	2.9	3.5	4.6	2.9	2.2	3.2	1.2	2.3	1.2	1.0	0.9	30.1
1944	4.5	11.9	18.4	10.0	16.5	11.4	4.4	7.3	9.0	2.4	2.5	13.2	111.5
1945	17.4	18.9	25.6	14.1	6.5	4.8	3.2	1.7	1.7	2.7	1.7	5.1	103.4
1946	5.2	9.2	13.9	7.1	6.3	4.3	2.4	1.7	2.9	4.0	25.5	17.1	99.6
1947	20.4	11.2	7.9	5.7	4.2	2.8	1.7	1.4	1.1	1.1	1.1	1.1	59.7
1948	0.9	0.9	0.8	0.8	3.1	1.1	1.0	0.5	0.5	1.5	0.6	0.6	12.3
1949	0.8	2.1	2.5	14.4	9.1	2.8	1.6	1.1	0.7	0.8	0.7	0.8	37.4
1950	0.7	1.3	0.9	2.1	3.1	2.0	1.2	0.8	0.7	0.6	0.5	0.5	14.4
1951	0.5	0.5	0.7	0.7	0.9	2.5	0.4	0.3	0.6	0.3	0.4	0.4	8.2
1952	0.4	0.4	0.5	2.1	5.3	4.0	1.3	0.6	71.6	3.2	2.4	4.1	95.9
1953	6.4	3.3	3.1	4.4	2.7	1.3	1.0	3.0	10.8	3.2	3.2	3.8	46.2
1954	2.3	1.7	1.4	1.1	0.8	0.5	0.4	0.4	0.3	0.5	0.4	0.5	10.3
1955	0.6	0.7	0.5	0.4	4.6	0.8	0.5	0.5	0.4	0.3	0.3	0.4	10.0
1956	0.3	0.4	0.3	0.2	0.6	0.2	0.1	0.1	0.4	1.7	1.4	1.3	7.0
1957	0.5	1.2	9.9	48.8	17.7	18.9	3.1	1.5	12.2	25.1	20.3	13.3	172.5
1958	12.2	23.4	24.2	12.0	5.6	15.8	5.4	2.8	8.1	8.2	11.9	5.7	135.3
1959	4.2	5.7	5.5	10.8	6.1	5.7	3.2	3.1	2.1	19.3	3.8	5.1	74.6
1960	8.4	10.8	8.1	7.2	5.0	3.3	4.8	5.0	2.7	40.0	16.3	23.5	135.1
1961	20.3	44.8	16.9	7.3	4.5	20.2	8.2	4.6	3.7	3.3	3.0	2.9	139.7
1962	2.5	2.0	2.1	2.2	2.1	8.2	2.4	1.3	2.0	--	--	--	(24.8)
Total	168.9	230.2	238.3	274.2	321.3	243.5	138.9	67.2	194.9	164.1	132.0	152.9	2,326.4
Average	5.0	6.8	7.0	7.1	9.4	7.2	4.0	1.9	5.6	4.8	3.9	4.5	67.2

TABLE 32

SEDIMENT STORAGE - EDWARDS UNDERGROUND RESERVOIR AREA

Reservoir	Contributing drainage area (sq. mi.)	Sediment storage (acre-feet)
Montell	707	12,000 (1)
Concan	391	7,800
Sabinal	210	4,200
Dam No. 7	1,124	17,500
Canyon w/Dam No. 7	301	10,300 (2)
Cloptin Crossing	307	9,200 (3)

(1) 1,200 acre-feet would be deposited in the conservation pool and 10,800 acre-feet in the dual purpose pool.

(2) 8,800 acre-feet would be deposited in the conservation pool and 1,500 acre-feet in the flood control pool.

(3) 8,500 acre-feet would be deposited in the conservation pool and 700 acre-feet in the flood control pool.

therefore, the storage required for recharge can also be used as flood-control storage. In this appendix the joint storage space reserved for recharge and flood-control purposes is referred to as dual-purpose storage.

(2) Those watersheds having little or no natural recharge capacity were investigated for potential surface water supply and flood-control reservoirs. Releases from the flood-control storage were limited to minimum downstream channel capacities as shown in table 16.

(3) The areas that are protected below the recommended reservoirs are predominantly agricultural. It is considered desirable to provide at least 50-year protection for these areas if the storage can be justified economically. The storage requirements for each recommended reservoir are discussed under the appropriate heading in the following paragraphs.

b. Dual-Purpose Storage.

(1) Montell Reservoir.

(a) A continuous daily routing was made for Montell Reservoir for the period 1924 through 1962, with releases being made at the estimated recharge rate of 1,000 second-feet. The results of this routing are shown graphically on plates 14 and 15. It was determined from this routing that the June 1935 flood required 259,200 acre-feet or 6.87 inches of storage, more than any other flood during the period of record, although the September 1955 flood produced the greatest peak discharge since at least 1854 according to historical data. The storages utilized for individual floods during the period of record routing were the basis for a storage-frequency analysis made in accordance with the method set forth in Section VI of "Statistical Methods in Hydrology" by Leo R. Beard, dated January 1962 and recommended for use in ER 1110-2-1450. From this analysis it was determined that the June 1935 flood had a frequency of recurrence of less than once in 50 years. The dual-purpose storage, having an average frequency of recurrence of once in 50 years, is 235,300 acre-feet, or 6.24 inches. An additional 4,000 acre-feet of storage is recommended so that releases may be withheld for up to two days or reduced for a somewhat longer period, depending upon the local runoff downstream from the damsite. This period of withholding or reducing releases will allow a greater percentage of the local runoff to infiltrate into the aquifer. A total storage of 239,300 acre-feet, or 6.35 inches, is, therefore, recommended for inclusion in the Montell Reservoir. It is noted that the flood of June 1935, when routed through the recommended reservoir, produces a maximum spill slightly less than the minimum downstream channel capacity.

(b) The possibility that a major flood could occur prior to the emptying of some antecedent flood volume was also considered. Examination of the period of record routing shows that the major floods generally occur in June and September, with a normal lag of 60-90 days between major floods. A conservative lag of 30 days between the end of the first flood period and the beginning of the second was, however, selected in constructing a flood series composed of the hypothetical 25-year flood followed by the hypothetical 50-year flood. It is noted that this results in a lag of about 40 days between peaks. The routing of this flood series indicated that 248,900 acre-feet or 6.60 inches of storage would be required for its complete control. However, the recommended storage would control the flood series to non-damaging release rates, with the maximum outflow approximately 4,800 second-feet. Results of this routing are shown graphically on plate 16.

(2) Concan Reservoir.

(a) A continuous daily routing was made for Concan Reservoir for the period 1924 through 1962, with releases being made at the estimated recharge rate of 750 second-feet. Results of this routing are shown graphically on plates 17 and 18. It was determined from this routing that the July 1932 flood, largest flood of record, required 137,600 acre-feet or 6.60 inches of storage. The July 1932 flood was not only the largest flood in volume but it produced the highest stage at the Concan gage since at least 1869 according to historical data. The storages utilized for individual floods during the period of record routing were the basis for a storage-frequency analysis made in accordance with the method set forth in Section VI "Statistical Methods In Hydrology" by Leo R. Beard, dated January 1962, and recommended for use in EM 1110-2-1405. From this analysis it was determined that the storage required for the July 1932 flood was in close agreement with the recommended dual-purpose storage. The dual-purpose storage having an average frequency of recurrence of once in 50 years is 138,200 acre-feet or 6.63 inches. An additional 3,000 acre-feet of storage is recommended so that releases may be withheld for up to two days or reduced for a somewhat longer period. This period of withholding or reducing releases will allow a greater percentage of runoff from the uncontrolled area downstream to infiltrate into the aquifer. A total storage of 141,200 acre-feet or 6.77 inches has, therefore, been adopted for inclusion in the recommended Concan Reservoir.

(b) The possibility of a major flood occurring prior to the emptying of an antecedent flood was checked in a manner similar to that discussed in paragraph (b) for Montell Reservoir. The normal lag time between major floods was found to be from 60 to 90 days. A conservative lag of 30 days between the end of the first flood period and the beginning of the second was, however, selected in constructing a flood series composed of the hypothetical 25-year flood

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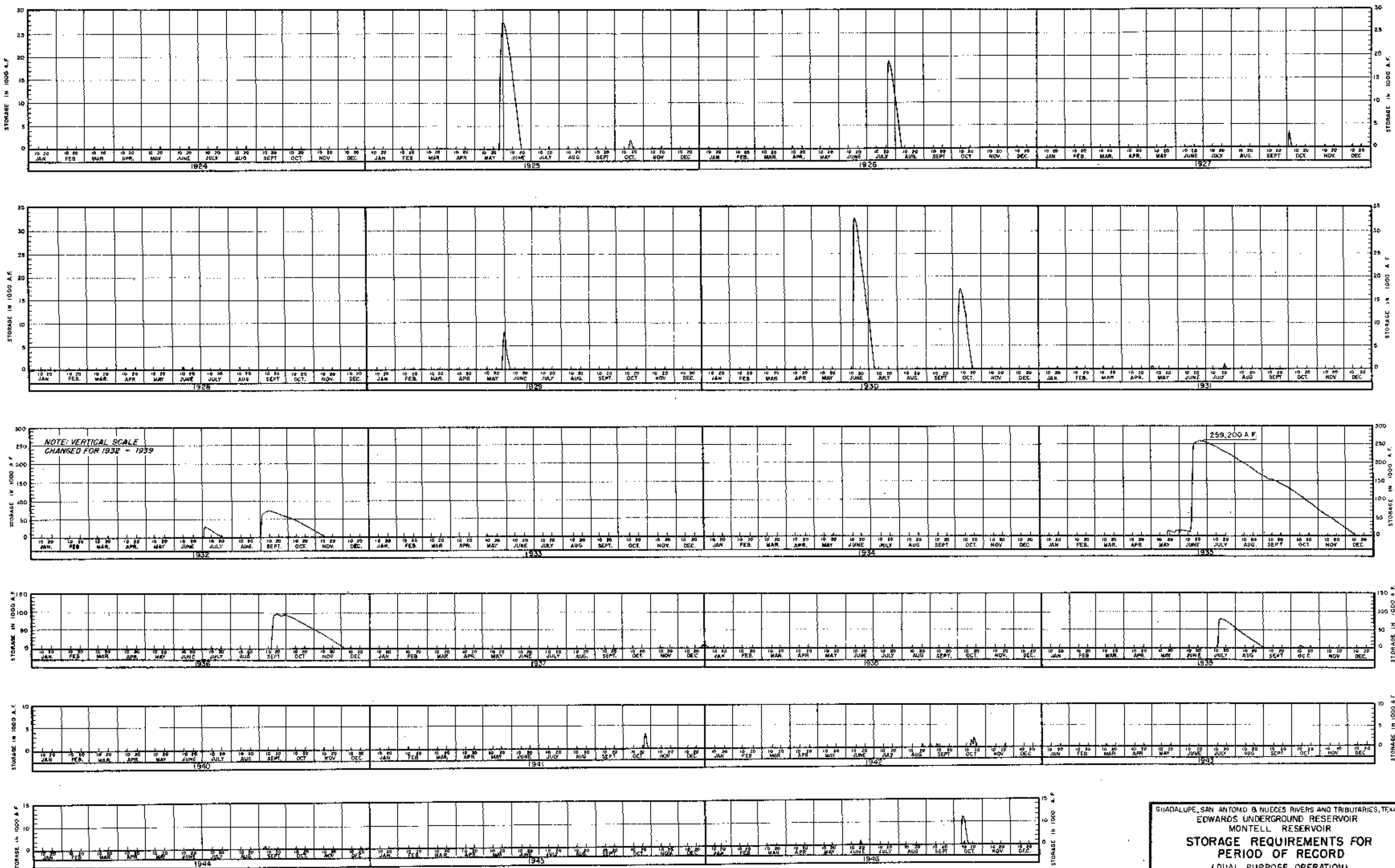


NOTE:
For notes see Sheet 2.

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

STORAGE REQUIREMENTS FOR PERIOD OF RECORD

(DUAL PURPOSE OPERATION)

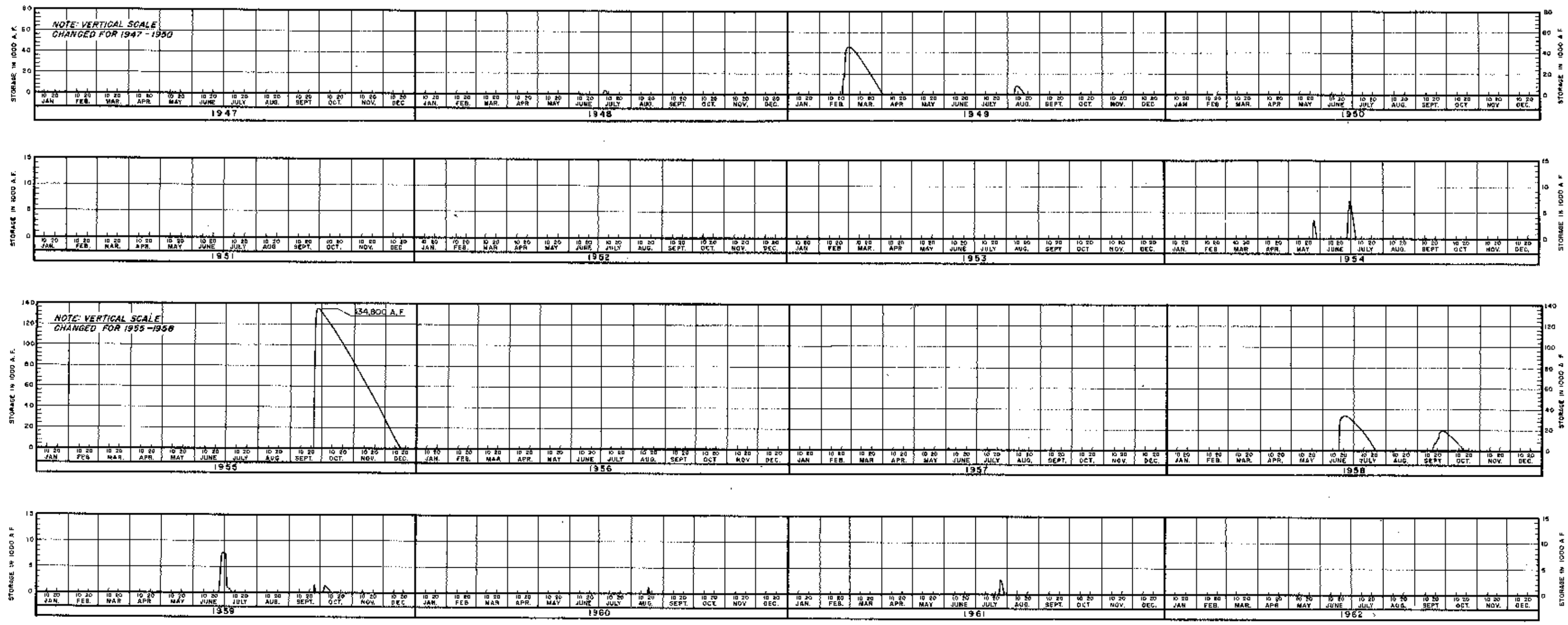
IN 2 SHEETS SHEET NO. 1

SCALES AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Ward, ENGINEER, CHIEF, PLANNING & REPORTS BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED Charles Moore, ENGINEER, CHIEF, HYDROLOGY SECTION	DRAWN BY A.M.T. CHECKED BY	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE GUAD 707-2

PLATE 14



NOTES:

1. Accumulated storage based on constant release rate of 1,000 c.f.s. (2,000 acre feet/day) when available from inflow or storage. Outflow equals inflow for remainder of time
2. Dual purpose operation refers to simultaneous operation for flood control and recharge.
3. Flows for Montell Reservoir based on records at U.S.G.S. gage on Nueces River at Laguna, Texas.

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

STORAGE REQUIREMENTS FOR PERIOD OF RECORD

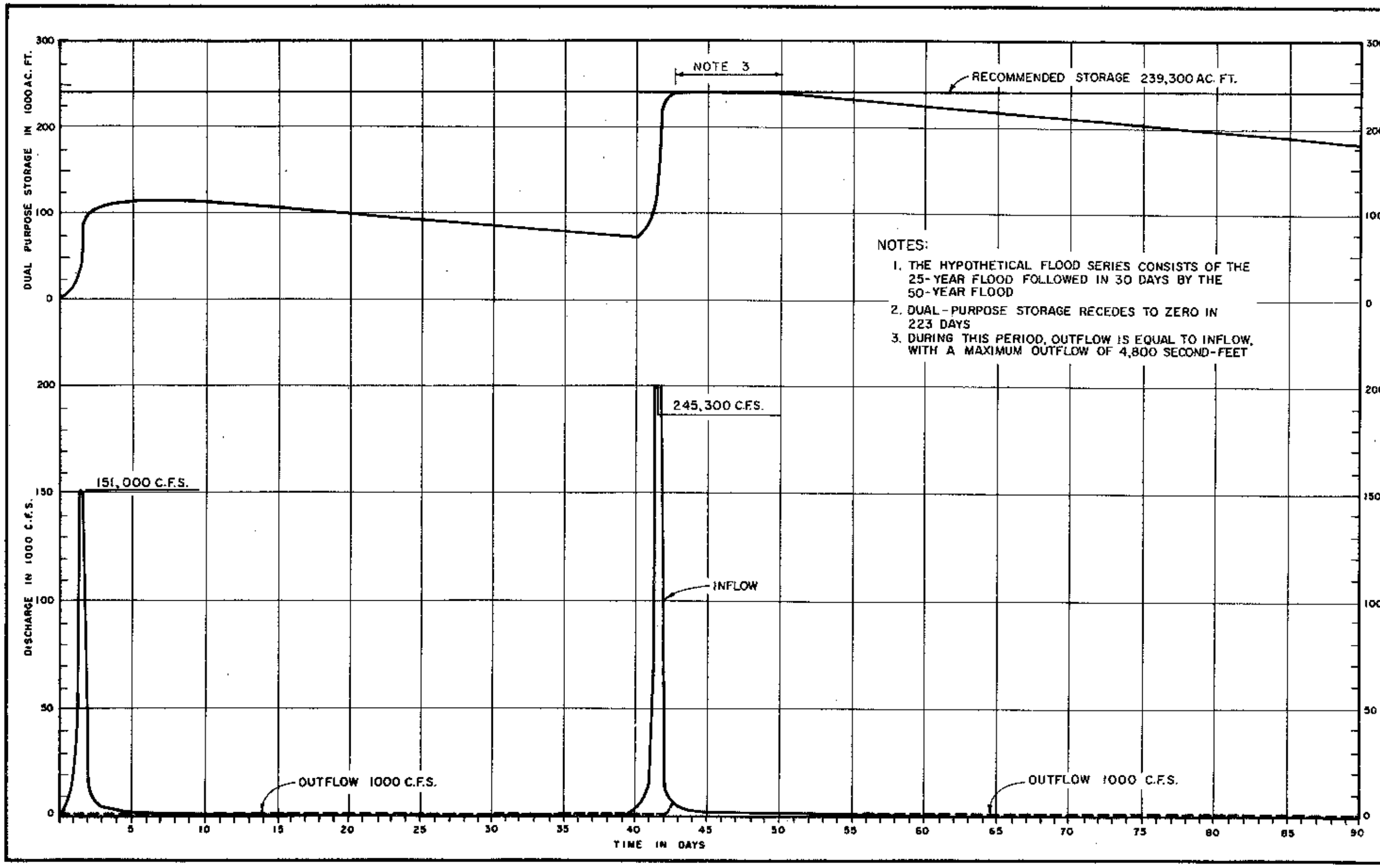
(DUAL PURPOSE OPERATION)

IN 2 SHEETS — SCALES AS SHOWN — SHEET NO. 2

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
Engineer, Chief, Project Planning Branch	Engineer, Chief, Engineering Division	Lt. Corps of Engineers, District Engineer
PREPARED: Engineer, Chief, Hydrology Section	DRAWN BY B.G.S. / CHECKED BY Y.L.R./M.J.S.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2

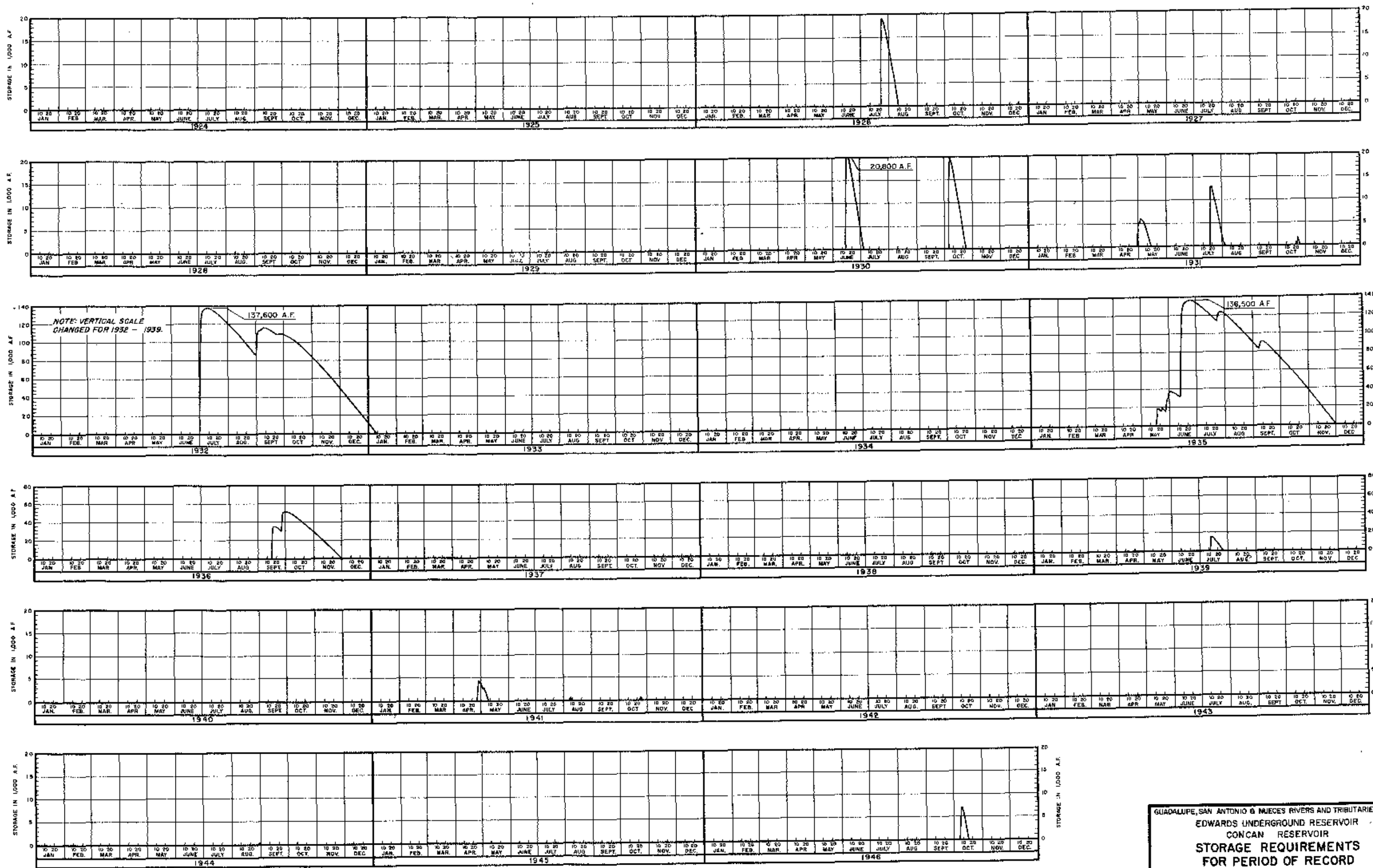
PLATE 15



EDWARDS UNDERGROUND RESERVOIR

MONTELL RESERVOIR
HYPOTHETICAL FLOOD SERIES

DEC. 1964 PLATE 16



NOTE:
For notes see Sheet 2.

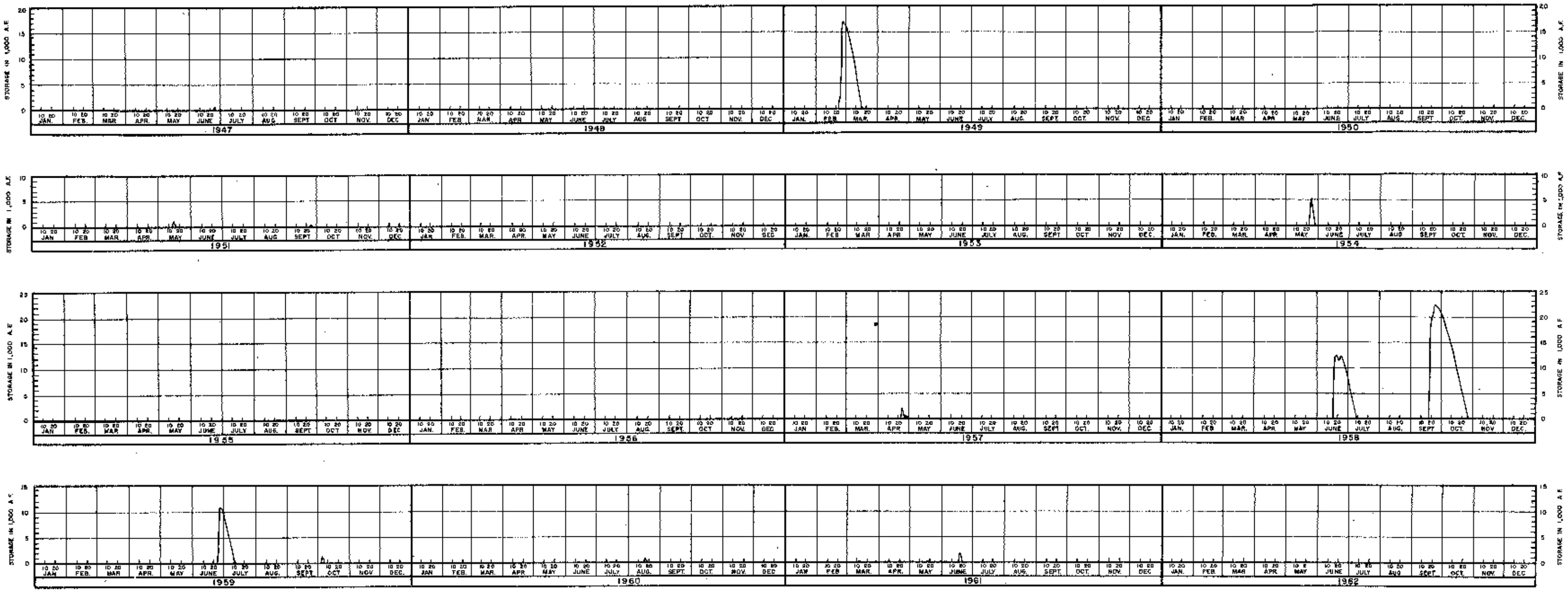
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
CONCAN RESERVOIR
STORAGE REQUIREMENTS FOR PERIOD OF RECORD
(DUAL PURPOSE OPERATION)

IN 2 SHEETS — SCALES AS SHOWN — SHEET NO. 1

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, HYDROLOGY SECTION	DRAWN BY B.O.S. CHECKED BY T.L.K./W.J.E.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE GUAD. 707-2

PLATE 17



NOTES:

1. Accumulated storage based on constant release rate of 750 C.F.S./Day (1500 A.F./Day) when available from inflow or storage. Outflow equals inflow for remainder of time.
2. Dual purpose operation refers to simultaneous operation for flood control and recharge.
3. Flows for Concan Reservoir based on records of U.S.G.S. gage on Frio River at Concan, Texas.

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

CONCAN RESERVOIR

STORAGE REQUIREMENTS FOR PERIOD OF RECORD

(DUAL PURPOSE OPERATION)

IN 2 SHEETS — SCALES AS SHOWN — SHEET NO 2

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, HYDROLOGY SECTION

DRAWN BY TLoMB. CHECKED BY TLR/WJS

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD 707-2

followed by the hypothetical 50-year flood. It is noted that this results in a lag of about 40 days between peaks. The routing of this flood series indicated that 139,600 acre-feet of storage was required which is 1,600 acre-feet less than the recommended size. Results of this routing are shown graphically on plate 19.

(3) Sabinal Reservoir.- The length of stream gage record in the vicinity of the Sabinal Reservoir is less than half that available for analysis for the Montell and Concan Reservoirs and was not considered adequate for the establishment of storage requirements. A regional storage relationship was determined in the following manner: Continuous daily operations were made at the Montell and Concan Dam sites for each of four different release rates. The storages utilized for the individual floods during the entire period of record for each of the four release rates were the basis for storage-frequency analyses as recommended in EM 1110-2-1405. A correlation was developed relating the 50-year storage from these analyses and the coresponding release rates. Examination of these correlation curves for Concan and Montell Reservoirs indicated that for any given release rate, a direct drainage area relationship existed between the required 50-year storages at the two projects. This relationship apparently exists because the areas are adjacent, with similar topography, soils, land use and climatic conditions. Pending the collection of additional runoff data, it has been assumed for this report that a similar relationship exists between the Concan and Sabinal Dam sites since they, too, are located on adjacent watersheds. This is the basis for the selection of the recommended dual-purpose storage for Sabinal Reservoir. This storage, having an average frequency of 50 years, is 87,100 acre-feet, or 7.78 inches. An additional 2,000 acre-feet of storage is recommended so that releases may be withheld for up to two days or reduced for a somewhat longer period. The period of withholding, or of reduced releases, will allow a greater percentage of the local runoff to infiltrate into the aquifer. A total storage of 89,100 acre-feet (7.96 inches) is, therefore, recommended for inclusion in the Sabinal Reservoir.

(4) Because of the short record available, hypothetical 25-, 50-, and 100-year floods were not developed for the Sabinal Reservoir for test routing purposes. However, the location of the dam axis within the recharge zone of the Sabinal River will tend to assure the adequacy of the storage by producing a higher rate of recharge than the 500 second-feet estimated for the streambed below the dam site. It is anticipated that some water will infiltrate into the Edwards Reservoir directly from the bottom and sides of the reservoir. The Medina Reservoir on the Medina River is located on the fault zone and loses a considerable quantity of water to the Edwards Reservoir in this way. It should be noted that though the Medina Reservoir has been constructed since 1913, sedimentation has produced no apparent effect on its recharge capacity.

(5) There exists no means of estimating the magnitude of the recharge which will occur directly from the pool; therefore, all analyses of modified recharge were based on that which it is estimated will take place downstream from the project.

c. Flood Control Storage - Cloptin Crossing Reservoir.

(1) Routings of the major floods of record were made for Cloptin Crossing Reservoir to determine the flood-control storage requirements. These routings assumed a full conservation pool at the project and releases were made to control the non-damaging discharges at selected downstream control points. In addition, hypothetical flood hydrographs for varying frequencies, developed as discussed in paragraph 39, were routed through the reservoir on a full conservation pool. The floods were routed in accordance with the adopted regulating criteria, assuming the coincident occurrence of floods of approximately equivalent frequency on the uncontrolled area downstream from the project. Data obtained from the routings of hypothetical floods were used to establish a relationship between flood-frequency and flood-control storage requirements for Cloptin Crossing Reservoir.

(2) The May 1929 flood when routed through the Cloptin Crossing Reservoir in accordance with the procedure presented in the above paragraph utilized 76,200 acre-feet or 4.65 inches of flood-control storage. Historical data for the Wimberley gage on the Blanco River show the flood of May 1929 to be the maximum since 1869. However, historical data for the San Marcos gage on the San Marcos River indicate that the maximum stage at San Marcos, since at least 1913, occurred in September 1921 and was produced by backwater from the Blanco River. Also, according to historical data, the flood of May 1929 was exceeded by the flood of 1869 or 1870 on the San Marcos River at Luling and by the flood of December 1913 on the San Marcos River at Ottine, with a large flood also occurring at the latter location in 1869 or 1870. From the above data covering a period of about 100 years, it is concluded that at least three historical floods in the San Marcos River watershed have approached or exceeded the flood of May 1929. It is also evident from an examination of the isohyetal patterns of the May 1929 and September 1952 storms on plates 6 and 11, that a transposition of either storm pattern involving a displacement of only 15 miles in the storm center would produce heavier rainfall and resulting runoff on the area above Cloptin Crossing Reservoir.

(3) The storage required to control the hypothetical 50-year flood, whose derivation was discussed in paragraph 39, was 106,400 acre-feet or 6.50 inches. Also, it was concluded that the flood-control storage of 4.65 inches utilized in routing the flood of May 1929 (maximum of record) is equivalent to that required for the control of a hypothetical flood of only 25-year frequency. It is further concluded from the historical data and representative storm

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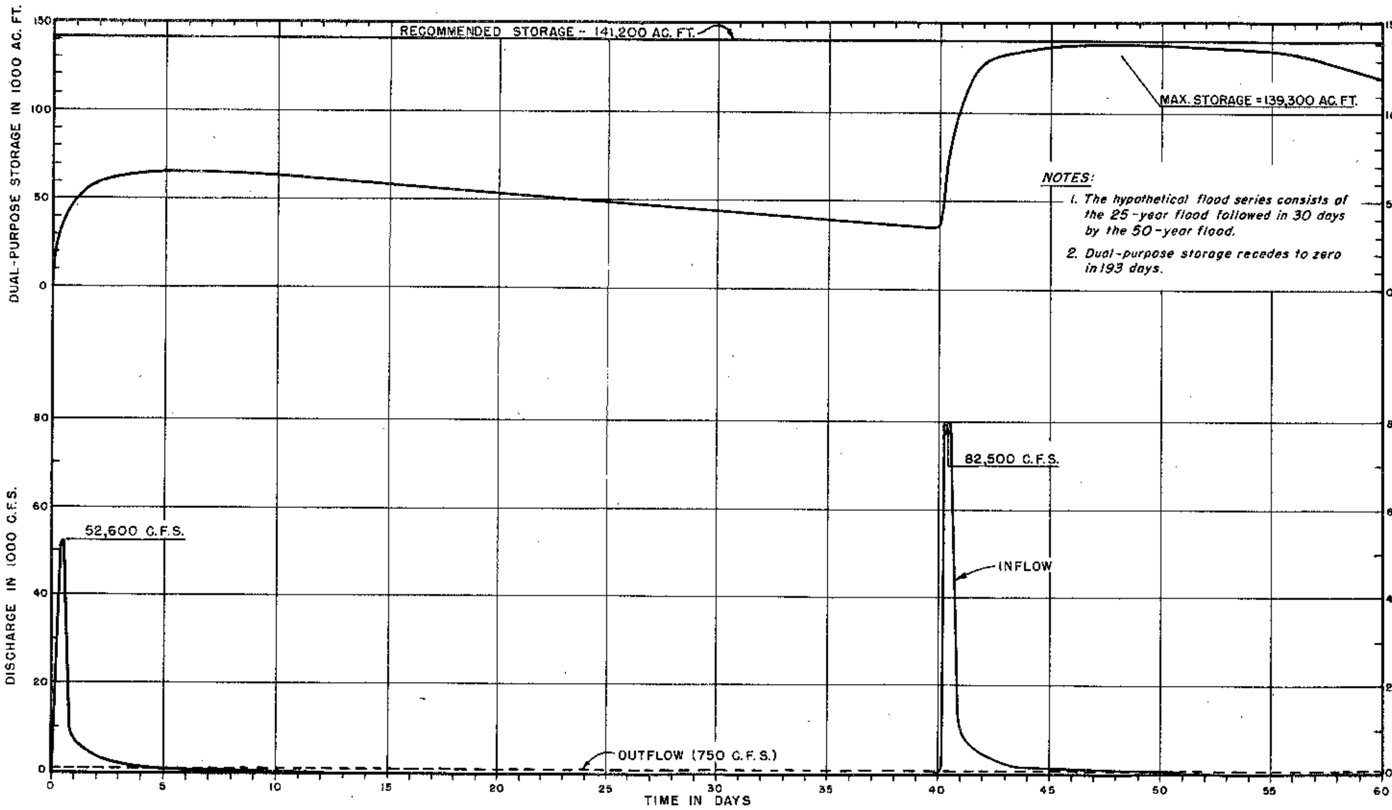

EDWARDS UNDERGROUND RESERVOIR

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patterns previously discussed that the maximum flood of record is not truly representative of the flood potential of the watershed. An analysis of the relationship between cost and benefit for projects containing flood-control storage of varying frequencies led to adoption of a project containing 119,900 acre-feet, or 7.30 inches of flood control storage, having an average frequency of recurrence of once in 75 years.

d. Conservation Storage.

(1) General.- At the present time the municipal and rural water demand of the area is being met by ground water, but projected future demands indicate a need for supplementing the present supply. One of the purposes of this study is to determine the benefits associated with the provision of surface storage on streams within the Edwards Underground area. The reservoirs recommended in connection with this study, the maximum or recommended conservation storage and its associated dependable yield under 2025 conditions of watershed development, are shown in table 17.

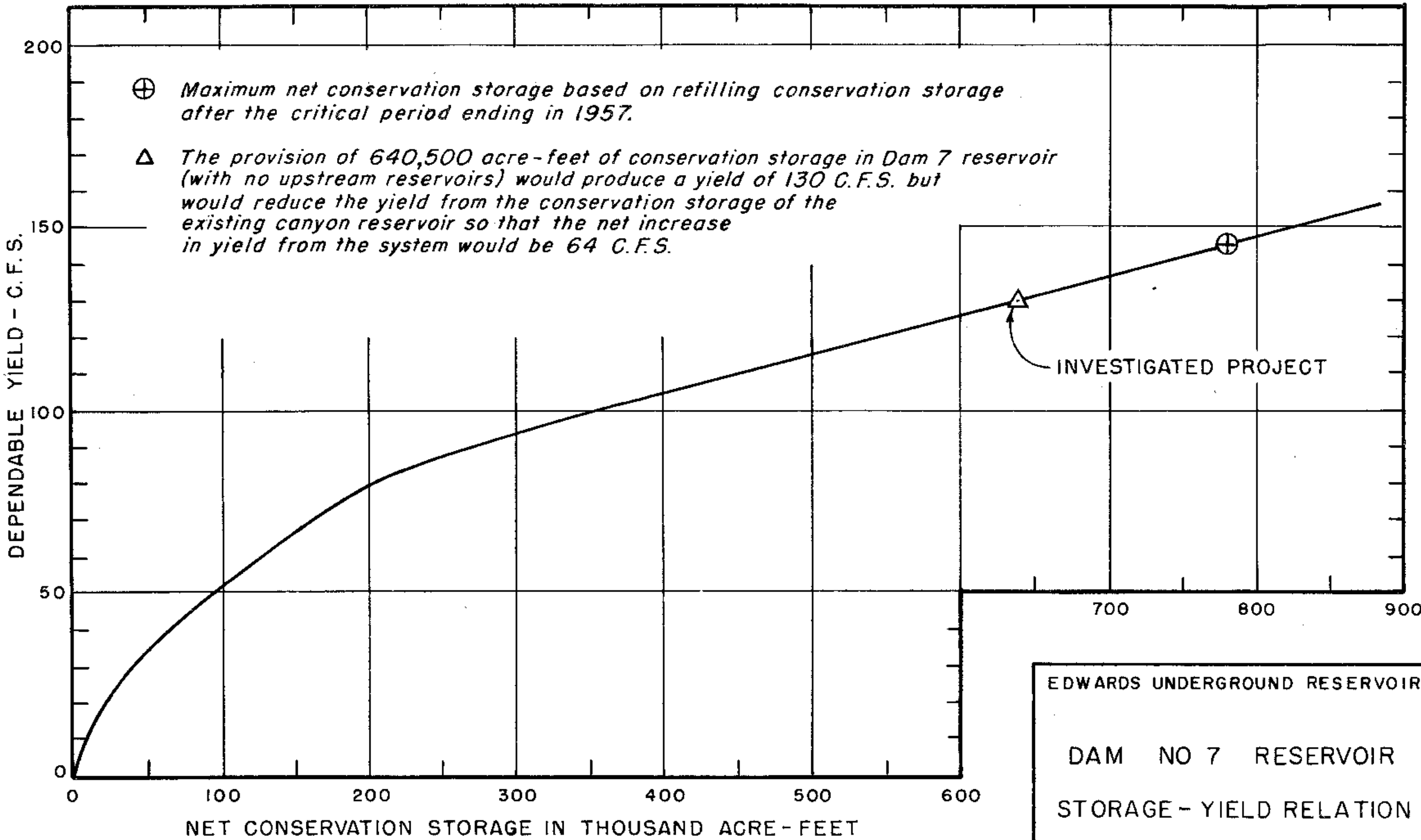
(2) Montell Reservoir.- The Montell Reservoir is the only reservoir in the recommended plan to have both dual-purpose and conservation storage. The reservoir is primarily a recharge project; however, 1,000 acre-feet of conservation storage space has been provided in Montell Reservoir in lieu of construction of Tom Nunn Hill Reservoir. The conservation storage in Montell Reservoir has a dependable yield of 4,300 acre-feet per year (6 second-feet). This was the only point that was developed, consequently, no storage-yield curve is presented for this project. Aspects of the conservation storage in Montell Reservoir are discussed in more detail in paragraph 80.

(3) Dam No. 7 Reservoir.- Economic evaluations indicated that additional flood-control storage for the Guadalupe River Basin could not be economically provided in Dam No. 7 Reservoir; however, because of the need for full development of the area's resources, the reservoir is recommmended for construction by local interests. Dam No. 7 Reservoir is designed to operate in conjunction with Canyon Reservoir to develop to the fullest extent feasible the total resources upstream from Canyon Dam. The provision of 640,500 acre-feet of conservation storage in Dam No. 7 Reservoir would produce a dependable yield for the Canyon-Dam No. 7 system of 142,700 acre-feet per year (197 second-feet). This is an increase of 46,400 acre-feet per year (64 second-feet) over the yield determined for the Canyon Reservoir without upstream development. A curve relating the conservation storage and dependable yield for Dam No. 7 Reservoir is shown on plate 20. This curve was developed from monthly water supply routings based on the runoff in table 30 and evaporation data developed from that presented in table 12.

(4) Cloptin Crossing.- A multiple-purpose reservoir for flood-control, water conservation, recreation, and fish and wildlife is recommended for Federal construction on the Blanco River at the Cloptin Crossing site. The recommended conservation storage of 274,900 acre-feet would fully develop the resources of the Blanco River watershed upstream from the damsite based on refilling the conservation storage after the critical period. The above storage would provide a dependable yield of 42,700 acre-feet per year (59 second-feet) from Cloptin Crossing Reservoir. A curve relating the conservation storage and dependable yield for Cloptin Crossing Reservoir is shown on plate 21. This curve was developed from monthly water-supply routings based on the runoff in table 31 and evaporation data developed from that presented in table 12.

53. FLOOD-CONTROL EFFECTS.- In order to evaluate the flood-control effects of the reservoirs investigated in this study, the peak discharges for the damaging floods of record were determined at the principal gaging stations within the affected areas with and without the reservoirs in operation. The procedures involved the use of observed and estimated reservoir inflows, streamflow records and routing procedures. The floods of record were routed through the reservoirs in accordance with the regulating criteria set forth in paragraph 52, STORAGE REQUIREMENTS. The floods were routed through Montell, Concan, Sabinal and Cloptin Crossing Reservoirs starting with empty flood-control pools. The larger floods of the upper Nueces River Basin which were routed through Montell Reservoir were the June 1935, June 1939, and September 1955 storms; the larger floods of the upper Frio River Basin which were routed through Concan Reservoir were the June-July 1932, June 1935, and September 1936 storms; the June 1958 flood was among the larger floods which were routed through Sabinal Reservoir; and the May-June 1929 and September 1952 storms were among the larger floods in the Blanco-San Marcos River Basin which were routed through Cloptin Crossing Reservoir. The results of these flood routings are summarized in table 33. The reservoir regulation during these flood periods is shown graphically on plates 22 through 28.

54. MINIMUM INFILTRATION INDICES.- Infiltration indices were computed for the Nueces River watershed above the Laguna gage; for the Frio River watershed above the Concan gage; for the Sabinal River watershed above the Sabinal gage; and for the Blanco River watershed above the Wimberley and Kyle gages, using the method described in EM 1110-2-1405, "Flood Hydrograph Analyses and Computations." Initial losses in the watersheds ranged from a minimum of 0.25 inch to a maximum of 3.00 inches. The range in infiltration indices was from 0.09 inch per hour to 0.82 inch per hour, and the runoff varied from 11.2 percent to 80.5 percent of the rainfall. The results of these computations are given in tables 34 and 35. Based upon these studies an initial loss of 1.00 inch and an infiltration rate of 0.15 inch per hour was adopted for the upper Nueces and Frio River watersheds. The



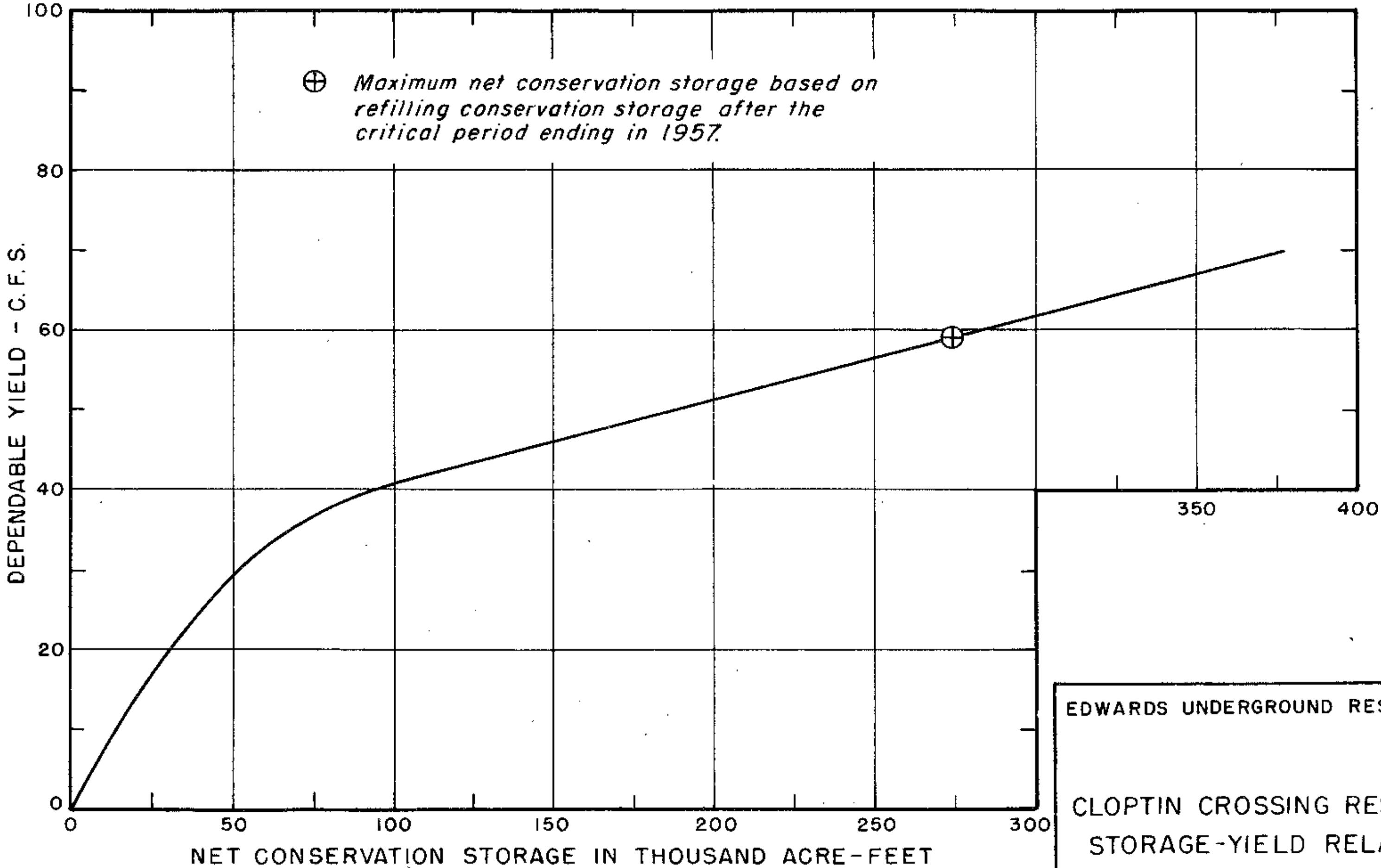
EDWARDS UNDERGROUND RESERVOIR

DAM NO 7 RESERVOIR

STORAGE - YIELD RELATION

DEC. 1964 PLATE 20

CORPS OF ENGINEERS U.S. ARMY



EDWARDS UNDERGROUND RESERVOIR

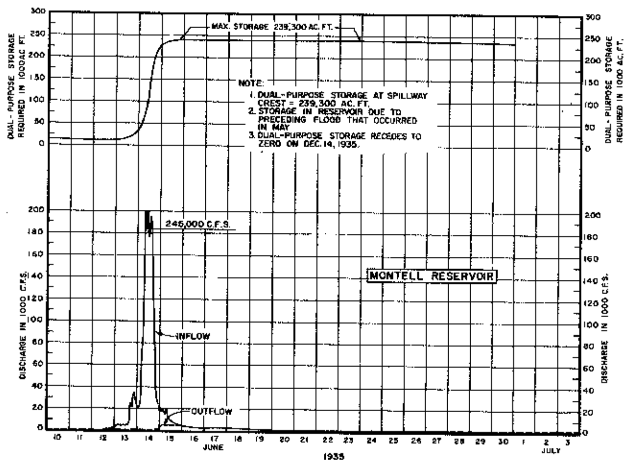
CLOPTIN CROSSING RESERVOIR
STORAGE-YIELD RELATION

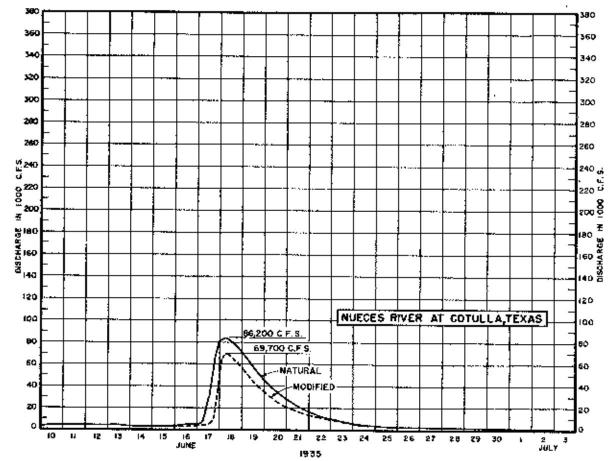
DEC. 1964 PLATE 21

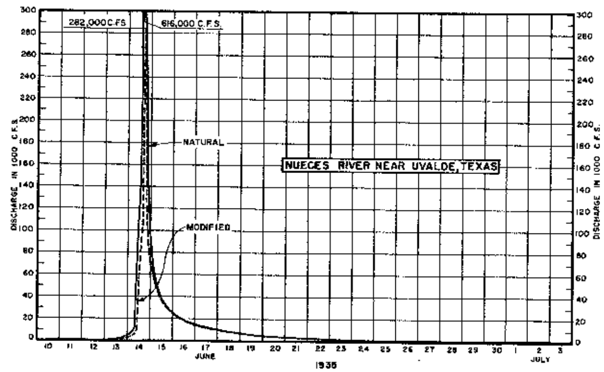
TABLE 33

HYPOTHETICAL RESERVOIR REGULATION

Flood	Peak inflow (c.f.s.)	Peak outflow (c.f.s.)	Storage required (acre feet)
	MONTEILL RESERVOIR D.A. = 707 sq.mi.		
June 1935	245,000	5,000	239,300
July 1939	205,400	1,000	76,400
September 1955	295,300	1,000	134,700
	CONCAN RESERVOIR D.A. = 391 sq.mi.		
July 1932	159,200	750	137,600
June 1935	104,200	750	136,500
September 1936	119,000	750	51,300
	SABINAL RESERVOIR D.A. = 210 sq.mi.		
June 1958	55,200	500	28,500
	CLOPTIN CROSSING RESERVOIR D.A. = 307 sq. mi.		
May-June 1929	105,400	5,000	76,200
September 1952	88,600	5,000	61,100







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

RESERVOIR REGULATION

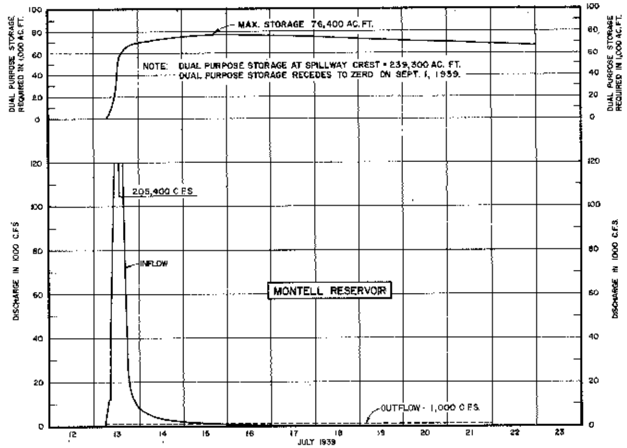
FLOOD OF JUNE 1935

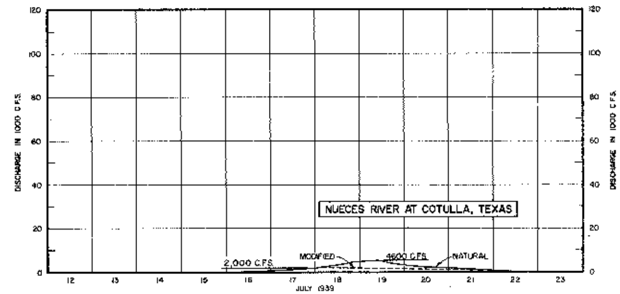
SCALE AS SHOWN

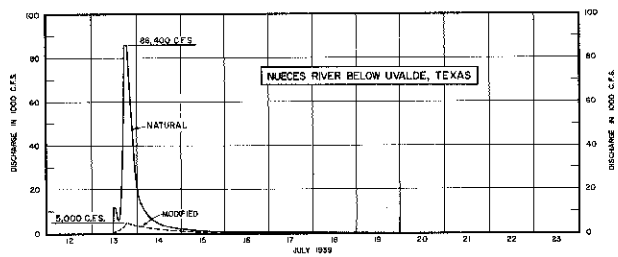
U.S. ARMY ENGINEER DISTRICT, FORT WORTH — DEC. 1964

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Woods, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	LT. COL., CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: Charles ... ENGINEER, CHIEF, HYDROLOGY SECTION	DRAWN BY J. L. / CHECKED BY M. J. S.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE. GUAD 707-2

PLATE 22







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

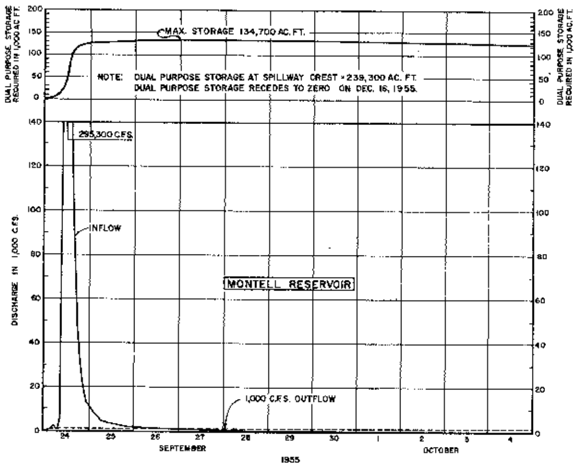
RESERVOIR REGULATION

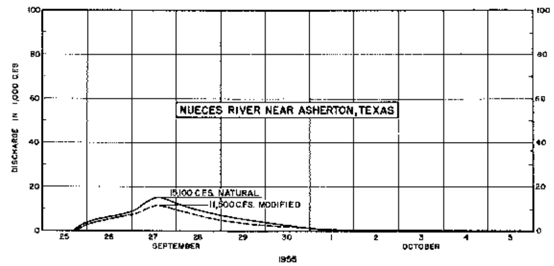
FLOOD OF JULY 1939

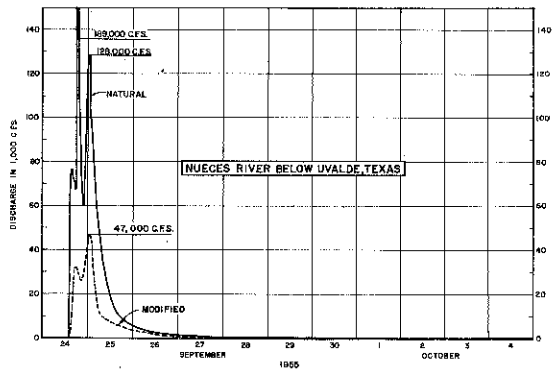
SCALE AS SHOWN

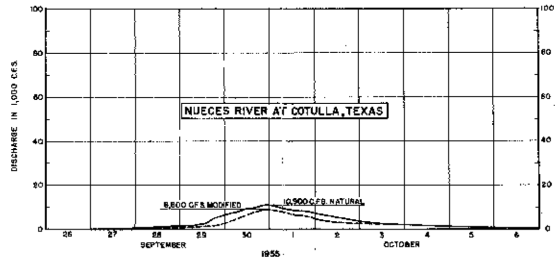
U.S ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
ENGINEER / CHIEF PROJECT PLANNING BRANCH	ENGINEER / CHIEF, ENGINEERING DIVISION	LT. COL. CORPS OF ENGINEERS / DISTRICT ENGINEER
PREPARED ENGINEER / CHIEF, HYDROLOGY SECTION	DRAWN BY T.L.W. / CHECKED BY W.J.S.	TO ACCOMPANY SURVEY REPORT COVERING E. WARDS UNDERGROUND RESERVOIR / FILE GUAD 707-2









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

RESERVOIR REGULATION

FLOOD OF SEPTEMBER-1955

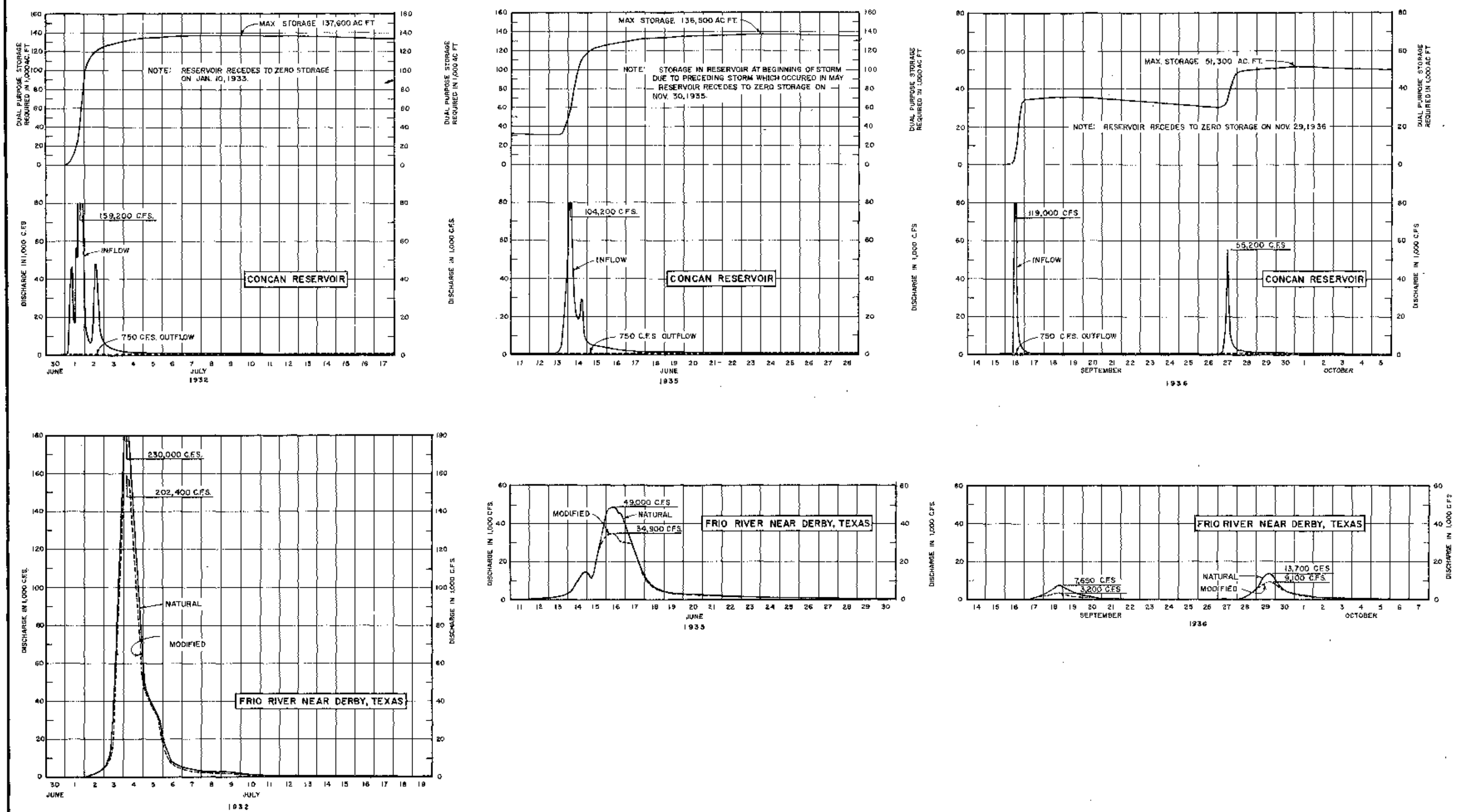
SCALE AS SHOWN

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

SUBMITTED ENGINEER CHIEF, PROJECT PLANNING BRANCH	APPROVAL RECOMMENDED ENGINEER CHIEF, ENGINEERING DIVISION	APPROVED COL. CORPS OF ENGINEERS DISTRICT ENGINEER
PREPARED ENGINEER CHIEF, HYDROLOGY SECTION	DRAWN BY V.J.M. CHECKED BY W.J.B.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR FILE: GUAD. 707-2

PLATE 24

CORPS OF ENGINEERS U.S. ARMY



NOTE:
Dual purpose storage at spillway crest = 141,200 Ac. Ft.

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

RESERVOIR REGULATION

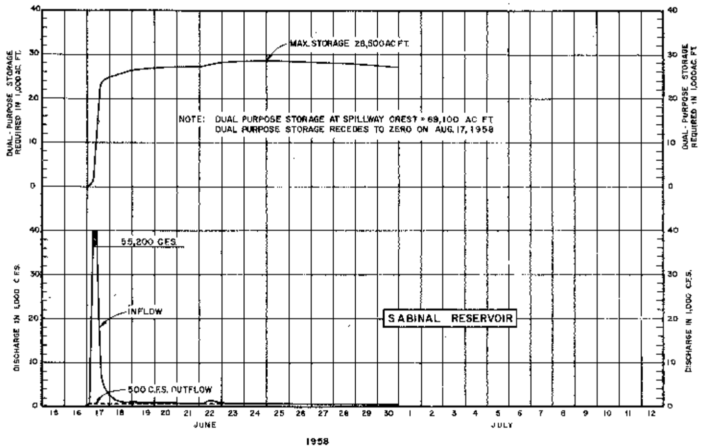
FLOODS OF JULY 1932, JUNE 1935 & SEPTEMBER 1936

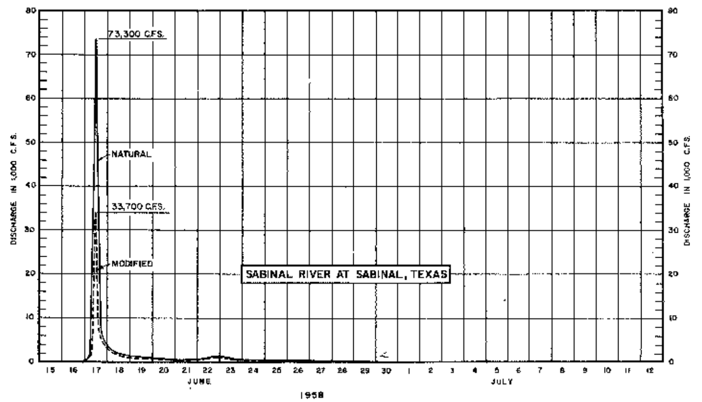
SCALES AS SHOWN

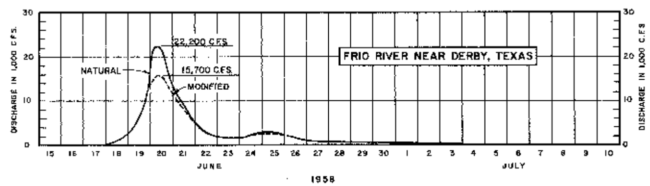
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964

SUBMITTED: W. E. Wood, Chief, Project Planning Branch
APPROVAL RECOMMENDED: Chief, Engineering Division
APPROVED: Col. Corps of Engineers, District Engineer
PREPARED: Chief, Hydrology Section
DRAWN BY T.L.&S. CHECKED BY W.E.S.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD.707-2

PLATE 25







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

RESERVOIR REGULATION

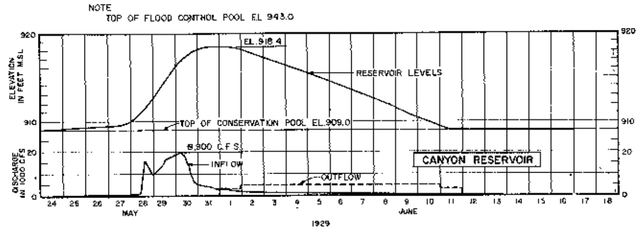
FLOOD OF JUNE 1958

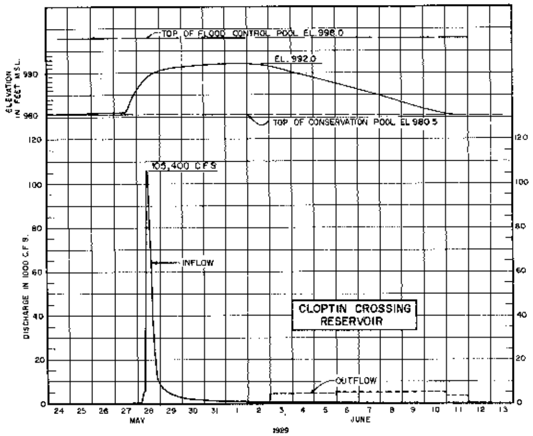
SCALE AS SHOWN

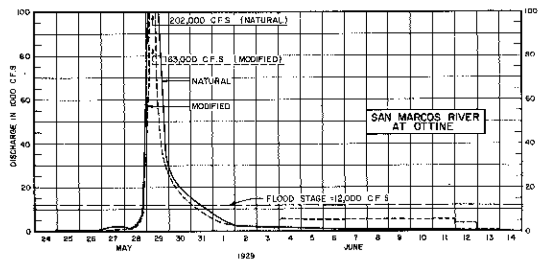
U.S. ARMY ENGINEER DISTRICT, FORT WORTH — DEC. 1964

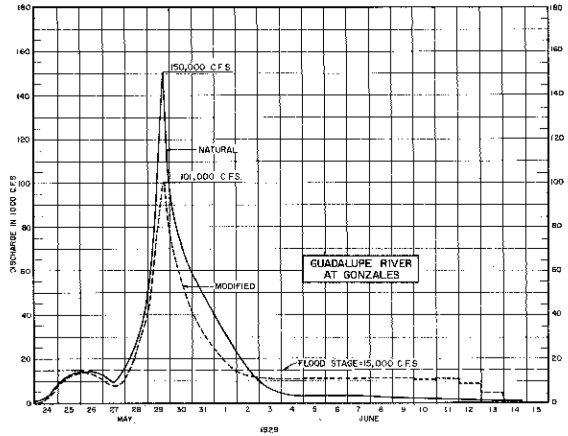
SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED Charles Mixon, ENGINEER, CHIEF, HYDROLOGY SECTION	DRAWN BY T L&M B; CHECKED BY W.J.S.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE GUAD. 707-2

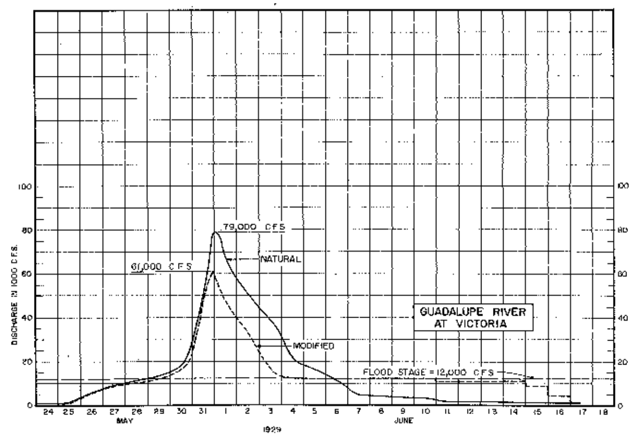
PLATE 26











GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

BLANCO RIVER

RESERVOIR REGULATION

FLOOD OF MAY - JUNE 1929

SCALE AS SHOWN

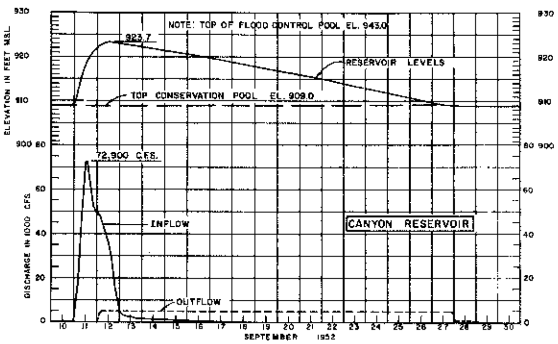
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964

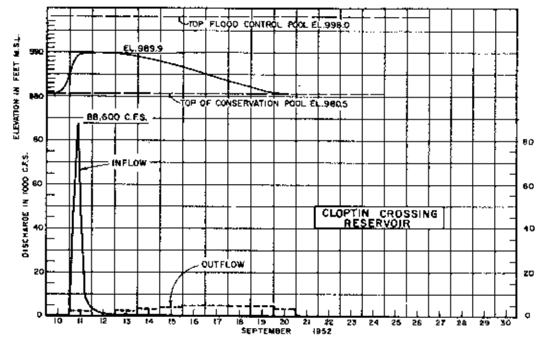
SUBMITTED: CHIEF, PROJECT PLANNING BRANCH — APPROVAL RECOMMENDED: CHIEF, ENGINEERING DIVISION — APPROVED: DISTRICT ENGINEER

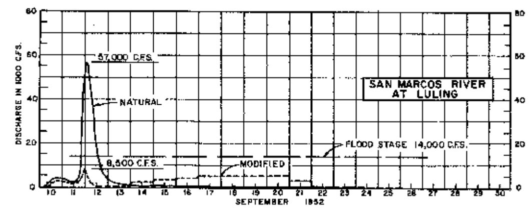
PREPARED: CHIEF, HYDROLOGY SECTION — DRAWN BY — CHECKED BY W.A.S. — TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

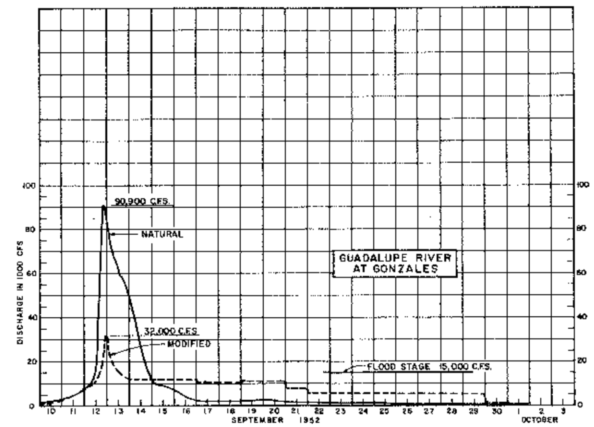
FILE QUAD 707-2

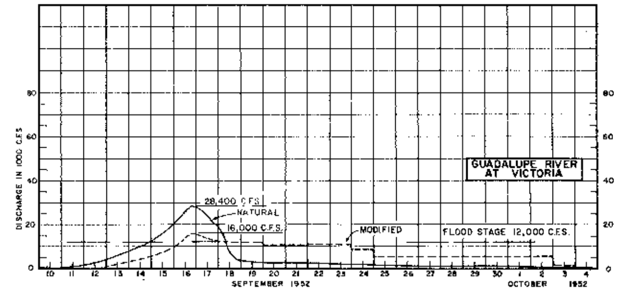
PLATE 27











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

RESERVOIR REGULATION

FLOOD OF SEPTEMBER 1952

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, HYDROLOGY SECTION
DRAWN BY P.R.
CHECKED BY W.A.S.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD 707-2

TABLE 34

INFILTRATION AND RUNOFF DATA
NUECES RIVER BASIN

Date of storm	Rainfall (inches)	Runoff (inches)	Runoff (Percent)	Initial Loss (inches)	Infiltration Index (inches/hr.)	Conditions preceding each storm
NUECES RIVER NEAR LAGUNA, TEXAS (DRAINAGE AREA - 764 square miles)						
September 1-2, 1932	4.60	1.65	35.9	1.50	0.18	Moist - Light rain August 25-30; heavy rain August 31.
September 16, 1936	3.03	1.40	46.2	0.50	0.17	Moist - Light rain on September 12; heavy rain on September 13; light rain on September 14; heavy rain on September 15.
July 12-13, 1939	4.72	2.18	46.2	1.30	0.17	Dry - No rain July 1-8; light rain July 9; no rain July 10; light rain July 11.
September 23-24, 1955	8.47	3.78	44.6	2.00	0.36	Dry - No rain September 1-12; light rain September 13; no rain September 14-22
FRIO RIVER NEAR CONCAN, TEXAS (DRAINAGE AREA - 405 square miles)						
June 30-July 1, 1932	12.59	5.75	46.0	2.80	0.45	Dry - No rain June 5-29.
June 13-14, 1935	5.95	4.79	80.5	0.25	0.09	Wet - Light rain June 1-2; no rain June 3-4; moderate rain June 5: no rain June 6-9; light rain June 10; moderate rain June 11; heavy rain June 12.
September 16, 1936	4.31	1.71	39.7	0.90	0.42	Moist - No rain September 1-12; moderate rain September 13; heavy rain September 14-15.
SABINAL RIVER NEAR SABINAL, TEXAS (DRAINAGE AREA - 206 square miles)						
May 15, 1951	1.46	0.27	18.5	0.50	0.50	Dry - Moderate rain on May 6; no rain May 7-13; light rain May 14.
May 23-24, 1954	2.07	0.44	21.3	1.20	0.30	Dry - No rain May 1-17; light rain May 18; no rain May 19-22.
June 16-17, 1958	10.50	2.46	23.4	3.50	0.48	Dry - No rain June 1-15.

TABLE 35

INFILTRATION AND RUNOFF DATA
BLANCO RIVER WATERSHED

Date of storm	Rainfall (inches)	Runoff (inches)	Runoff (Percent)	Initial Loss (inches)	Infiltration Index (inches/hr.)	Conditions preceding each storm
BLANCO RIVER NEAR WIMBERLEY (DRAINAGE AREA - 353 square miles)						
May 27-28, 1929	8.95	3.69	41.2	1.80	.44	Moist - Light rain May 11-18; no rain May 19-22; heavy rain May 24 & 26; trace on May 25.
May 10-12, 1930	1.67	.28	16.8	1.00	.61	Dry - Light rain May 2-6; moderate rain May 7; no rain on May 8-9.
June 30-July 1, 1936	3.92	1.01	25.8	1.00	.46	Dry - No rain June 1-27; light rain on June 28; moderate rain June 29.
April 27-28, 1938	2.16	.48	22.2	0.90	.49	Dry - No rain April 8-14, moderate rain April 15-19; no rain April 20-24; light rain April 25-26.
April 7-8, 1942	2.34	.30	12.8	1.50	.82	Dry - Light rain April 1; no rain April 2-6.
September 9-10, 1952	13.75	4.02	29.3	1.50	.50	Dry - No rain August 1-September 8.
April 24-25, 1957	4.47	1.22	27.3	2.80	.25	Moist - Light rain April 1-4; no rain April 5-10; trace April 11-14, 18, 21; light rain April 15-17, 23; moderate rain April 19,22.
May 2-3, 1958	3.15	1.68	53.3	0.80	.42	Dry - No rain April 22-25, 29; light rain April 26-27; trace April 28, 30; light rain May 1.
BLANCO RIVER NEAR KYLE (DRAINAGE AREA - 410 square miles)						
October 3-4, 1959	6.08	.68	11.2	3.00	.57	Dry - No rain September 15-21; light rain September 22-25; no rain September 26-28; light rain September 29-30; light rain October 1; no rain October 2.

comparative values adopted for the Sabinal and Blanco River watersheds are 1.00 inch and 0.25 inch per hour. These adopted values were used in the preparation of the spillway design flood hydrographs.

55. UNIT HYDROGRAPH STUDIES AND SYNTHETIC UNIT HYDROGRAPHS.- Unit hydrograph determinations were made for selected storms for which hydrographs were available at the Laguna gage on the Nueces River, at the Concan gage on the Frio River, at the near Sabinal gage on the Sabinal River, and at the Wimberley gage on the Blanco River. These studies were made in accordance with EM 1110-2-1405. The studies on the Blanco River watershed were submitted to the Office, Chief of Engineers, with letter SWFGP-Hy, subject: "Unit Hydrograph Compilation, Blanco River at Wimberley, Guadalupe River Basin, Texas," dated June 19, 1963. Those on the Nueces River watershed were submitted with letter SWFGP-Hy, subject: "Unit Hydrograph Compilations, Nueces River at Laguna, Frio River at Concan, Sabinal River near Sabinal, Nueces River Basin, Texas," dated March 4, 1964. Unit hydrograph pertinent data for the storms studied on the Nueces River at Laguna, Texas; the Frio River at Concan, Texas; Sabinal River near Sabinal, Texas; and the Blanco River at Wimberley, Texas, are shown on plates 29 through 32, respectively. These unit hydrograph determinations were used as a basis for the adoption of the following coefficients to be used in Snyder's equations for the derivation of synthetic 3-hour unit hydrographs: Upper Nueces River watershed $C_t = 0.60$, $C_{p640} = 450$; Blanco River watershed $C_t = 0.65$, $C_{p640} = 450$. The adopted coefficients, representing a 3-hour duration, were adjusted in accordance with EM 1110-2-1405 to a 2-hour duration for use at Sabinal Reservoir. The synthetic unit hydrographs for natural flow at the dam sites were developed for selected periods of rainfall in accordance with EM 1110-2-1405. The unit hydrographs for flow into full reservoirs were derived by subdividing the drainage area above the dam sites into several areas as follows: (a) reservoir area, (b) area adjacent to the reservoir composed of numerous small areas with no well-defined drainage divides, and (c) the portion of several creeks from sides and above the head of reservoirs. Unit hydrographs were developed for the individual areas and the ordinates of these unit hydrographs added graphically to obtain the composite unit hydrograph for flow into full reservoir. The runoff from the reservoir area was not included in the unit hydrograph for flow into full reservoir; but runoff rates were assumed equal to rainfall rates and added directly to the computed design flood. The synthetic unit hydrographs for natural flow and for flow into full reservoir for the four projects are given in tables 36 through 39.

56. SPILLWAY DESIGN STORMS.- The spillway design storms adopted for use in this report were computed following a method described in the U. S. Weather Bureau Hydrometeorological Report No. 33, dated April 1956, subject: "Seasonal Variations of the Probable Maximum Precipitation East of the 105th Meridian for Areas From 10 to 1,000 Square Miles and Durations of 6, 12, 24, and 48 hours." The rainfall quantities as

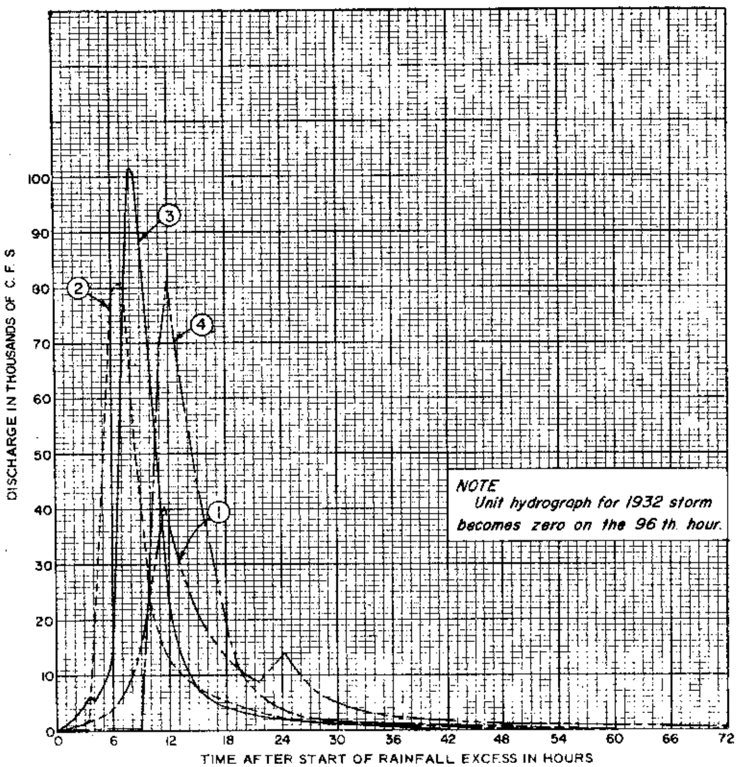
determined from H.R. No. 33 are not adjusted for differences in shape and orientation between the pattern storms and the watersheds above the investigated dam sites. Therefore, based upon analyses of appropriate pattern storms, a ten percent basin shape reduction factor was adopted for each of the projects.

57. The distribution of the maximum 6-hour rainfall was determined in accordance with the method set forth in EM 1110-2-1411 (Civil Works Engineer Bulletin No. 52-8, dated March 26, 1952, subject: "Standard Project Flood Determinations.") A 3-hour increment of rainfall was used for Montell, Concan, and Cloptin Crossing Reservoir. For Sabinal Reservoir the rainfall was broken down in 2-hour increments. The ten percent basin shape reduction factor was applied to the unadjusted rainfall, and smooth curves were drawn through points based upon the adjusted rainfall values. The predetermined increments of rainfall were taken from these curves. The critical arrangements of rainfall adjusted for basin shape and adopted as the spillway design storm rainfall for Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs are shown in tables 40 through 43, respectively. The tables also indicate the loss and rainfall excess for the above projects.

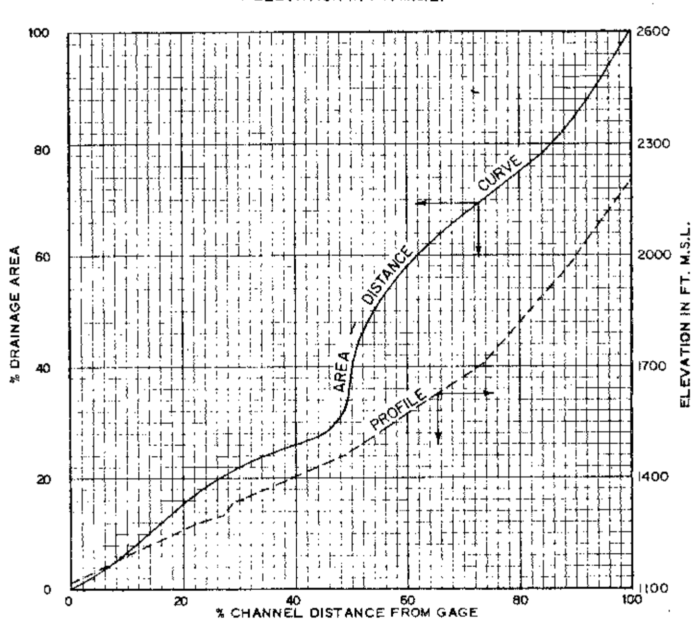
58. SPILLWAY DESIGN FLOOD HYDROGRAPHS.- Spillway design flood hydrographs representing flow into full reservoirs were determined for Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs by applying the rainfall-excess values given in tables 40 through 43 to the appropriate unit hydrographs given in tables 36 through 39, and adding to the resultant flood hydrograph the runoff from the reservoir surface (assumed at a rate equal to the rate of rainfall). As a result of a study of average base flow conditions at the dam sites, no base flow was considered in the computation of the spillway design floods. The resulting spillway design flood hydrographs had, at Montell, a peak discharge of 893,900 second-feet, and a runoff volume of 821,300 acre-feet; at Concan, a peak discharge of 592,500 second-feet, and a runoff volume of 489,400 acre-feet; at Sabinal, a peak discharge of 381,800 second-feet, and a runoff volume of 249,000 acre-feet; and at Cloptin Crossing, a peak discharge of 414,900 second feet, and a runoff volume of 353,000 acre-feet.

59. The spillway design flood hydrographs for natural flow at the dam sites were based on the unit hydrographs for natural flow at dam site given in tables 36 through 39 and the rainfall excess given in tables 40 through 43. The computed natural hydrographs had, at Montell, a peak discharge of 882,000 second-feet, and a runoff volume of 815,600 acre-feet; at Concan, a peak discharge of 591,600 second-feet, and a runoff volume of 485,900 acre-feet; at Sabinal, a peak discharge of 336,700 second-feet, and a runoff volume of 245,300 acre-feet; and at Cloptin Crossing, a peak discharge of 409,800 second-feet, and a runoff volume of 343,800 acre-feet.

OBSERVED UNIT HYDROGRAPHS



DRAINAGE AREA CHARACTERISTICS			
DRAINAGE AREA	764 sq. mi.	L	60.2 mi.
MAXIMUM ELEVATION	2400 ft. m.s.l.	L_{ca}	30.6 mi.
MINIMUM ELEVATION	1220 ft. m.s.l.	$(LL_{ca})^{0.3}$	9.54
MEAN ELEVATION (weighted)	ft. m.s.l.	DRAINAGE DENSITY	0.511 mi. / sq. mi.
LAND SLOPE	ft. / mi.	MAP SCALE	1:250,000
MAIN STREAM SLOPE	17.85 ft. / mi.	METHOD OF FLOW SEPARATION	TYPE "A"
		BASIN SHAPE FACTOR	4.74



DATA FROM OBSERVED UNIT HYDROGRAPHS															
DATE OF RAINFALL	LEGEND	AVE. P (in.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (in.)	L_{cP} (mi.)	STAGE RECORD	Q_{pR} (c.f.s.)	Q_p tr = 2 hrs. (c.f.s.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1-2 SEPT. 1932	1	4.60	6	1.65	Upstr	REC.	40,550	38,600*	8.50	9.0	12.6	.89	451	3.58	11.0
16 SEPT. 1936	2	3.03	3	1.40	Upstr	REC.	80,770	78,290**	5.00	4.5	6.4	.52	530	2.99	7.5
12-13 JULY 1939	3	4.72	6	2.18	Center	REC.	101,610	110,650	3.40	3.0	5.1	.36	452	2.15	5.0
23-24 SEPT. 1955	4	8.47	9	3.78	Upstr	REC.	81,090	82,150	4.59	4.5	6.5	.48	487	3.24	10.5
* tr = 6 hrs. ** tr = 3 hrs.															

ENGINEERING INVESTIGATIONS
UNIT HYDROGRAPHS

PERTINENT DATA

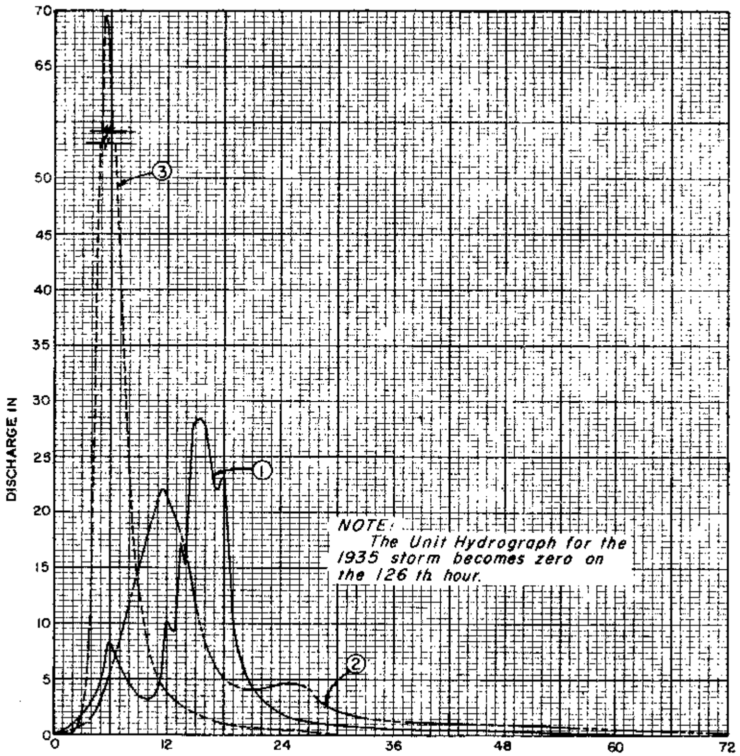
NUECES RIVER BASIN

NUECES RIVER AT LAGUNA, TEXAS

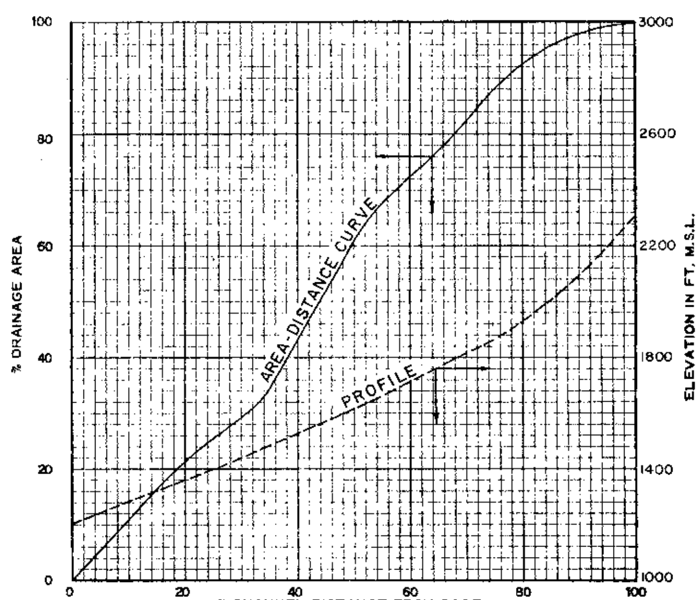
SUBMITTED BY

DISTRICT ENGINEER, FORT WORTH DISTRICT

OBSERVED UNIT HYDROGRAPHS



DRAINAGE AREA CHARACTERISTICS			
DRAINAGE AREA	405 sq. mi.	L	41.8 mi.
MAXIMUM ELEVATION	2371.0 ft. m.s.l.	L_{ca}	23.6 mi.
MINIMUM ELEVATION	1204.0 ft. m.s.l.	$(LL_{ca})^{0.3}$	7.9
MEAN ELEVATION (weighted)	ft. m.s.l.	DRAINAGE DENSITY	0.68 mi. / sq. mi.
LAND SLOPE	ft./mi.	MAP SCALE	1:250,000
MAIN STREAM SLOPE	15.68 ft./mi.	METHOD OF FLOW SEPARATION	TYPE A
		BASIN SHAPE FACTOR	4.31



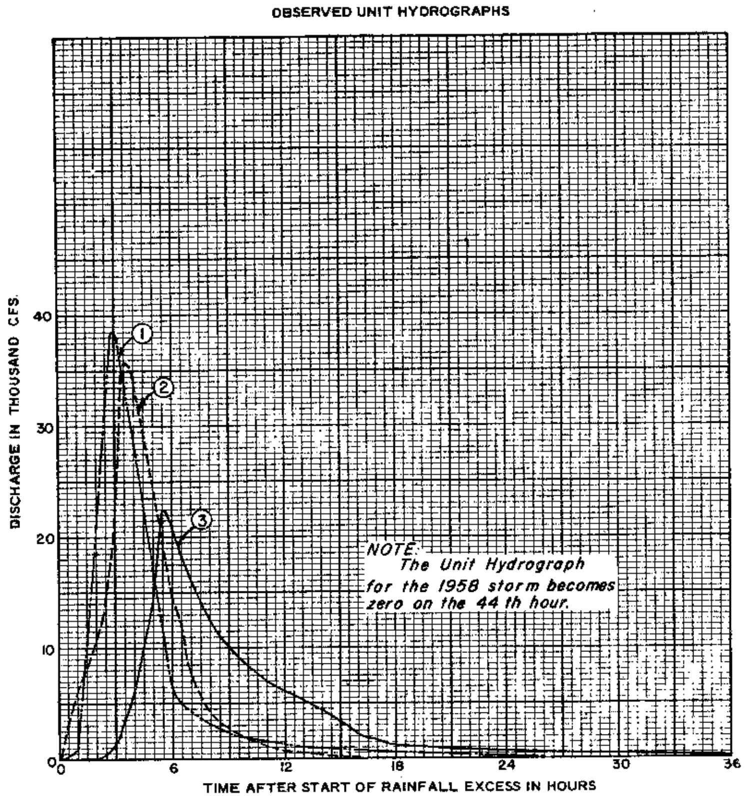
DATA FROM OBSERVED UNIT HYDROGRAPHS															
DATE OF RAINFALL	LEGEND	AVE. P (in.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (in.)	L_{cP} (mi.)	STAGE RECORD	Q_{pR} (c.f.s.)	Q_p tr = 3 hrs. (c.f.s.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
30 JUNE-1 JULY 1932	——(1)	12.59	9	5.75	Upstr	Rec	28080	38400	4.8	4.5	4.0	0.61	332	2.5	4.5
13-14 JUNE 1935	-·-·-(2)	5.95	12	4.79	Upstr	Rec	21920	37690	5.4	4.5	7.2	0.68	293	3.7	4.5
16 SEPT. 1936	----(3)	4.31	4	1.71	Unifor	Rec	69060	69300*	2.7	3.0	2.5	0.34	460	2.0	3.0

*t_r = 2 hours

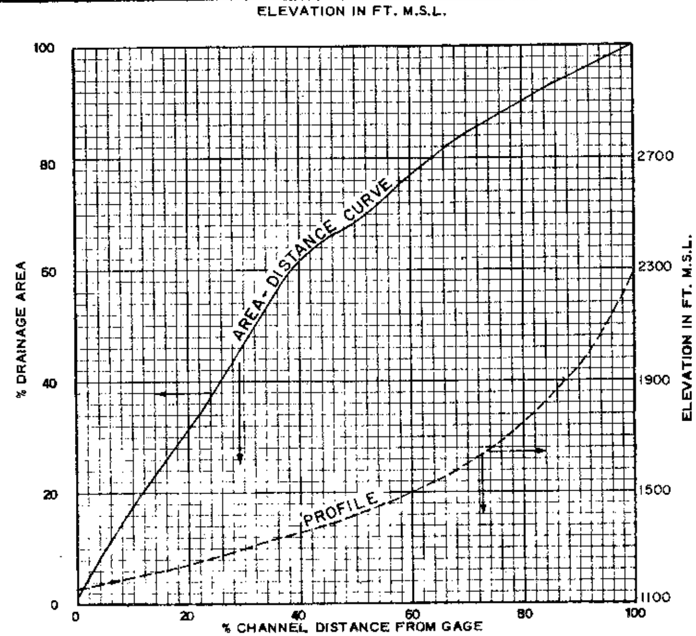
ENGINEERING INVESTIGATIONS
UNIT HYDROGRAPHS

PERTINENT DATA
NUECES RIVER BASIN
FRIO RIVER AT CONCAN, TEXAS

SUBMITTED BY
DISTRICT ENGINEER, FORT WORTH DISTRICT



DRAINAGE AREA CHARACTERISTICS			
DRAINAGE AREA	206 sq. mi.	L	31.96 mi.
MAXIMUM ELEVATION	2300 ft. m.s.l.	L_{ca}	16.69 mi.
MINIMUM ELEVATION	1150 ft. m.s.l.	$(LL_{ca})^{0.3}$	6.58
MEAN ELEVATION (weighted)	ft. m.s.l.	DRAINAGE DENSITY	0.624 mi. / sq. mi.
LAND SLOPE	ft. / mi.	MAP SCALE	1:250,000
MAIN STREAM SLOPE	25.87 ft. / mi.	METHOD OF FLOW SEPARATION	TYPE A
		BASIN SHAPE FACTOR	4.96



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DATA FROM OBSERVED UNIT HYDROGRAPHS															
DATE OF RAINFALL	LEGEND	AVE. P (in.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (in.)	L_{cP} (mi.)	STAGE RECORD	Q_{pR} (c.f.s.)	Q_p tr = 1 hrs. (c.f.s.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
15 MAY 1951	——(1)	1.46	1.0	0.27	Upst	Rec	38560	38560	2.5	2.5	3.3	0.38	468	1.0	4.5
23-24 MAY 1954	--- (2)	2.07	2.0	0.44	unifor	Rec	35710	*38970	2.4	2.2	3.1	0.36	409	2.1	4.1
16-17 JUNE 1958	——(3)	10.50	6.0	2.46	unifor	Rec	22420	**29060	2.4	3.0	4.9	0.37	263	3.1	3.9

* t_r = 0.50 hrs.

** t_r = 2.0 hrs.

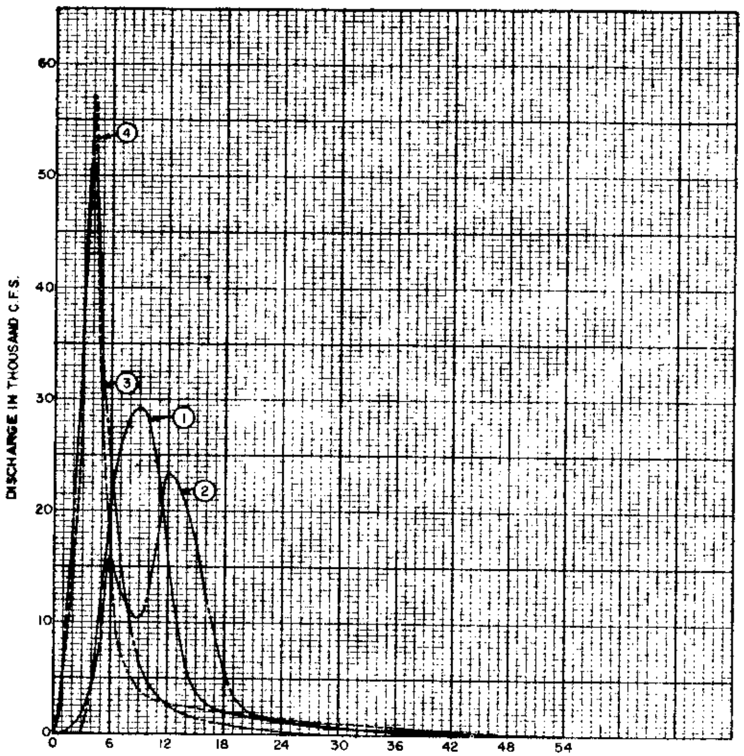
ENGINEERING INVESTIGATIONS
UNIT HYDROGRAPHS

PERTINENT DATA
NUECES RIVER BASIN

SABINAL RIVER
NEAR SABINAL, TEXAS

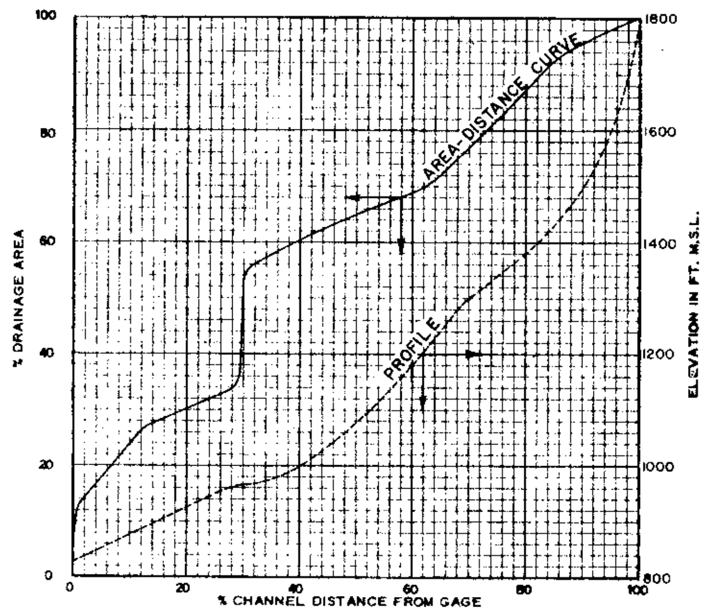
SUBMITTED BY
DISTRICT ENGINEER, FORT WORTH DISTRICT

OBSERVED UNIT HYDROGRAPHS



DRAINAGE AREA CHARACTERISTICS

DRAINAGE AREA	364 sq. mi.	L	56.3 mi.
MAXIMUM ELEVATION	2000 ft. m.s.l.	L_{ca}	29.6 mi.
MINIMUM ELEVATION	820 ft. m.s.l.	$(LL_{ca})^{0.3}$	9.2
MEAN ELEVATION (weighted)	ft. m.s.l.	DRAINAGE DENSITY	.771 mi. / sq. mi.
LAND SLOPE	ft./mi.	MAP SCALE	1:250,000
MAIN STREAM SLOPE	11.2 ft./mi.	METHOD OF FLOW SEPARATION	TYPE A
		BASIN SHAPE FACTOR	8.37



DATA FROM OBSERVED UNIT HYDROGRAPHS

DATE OF RAINFALL	LEGEND	AVE. P (in.)	RAINFALL EXCESS DURATION (hr.)	RAINFALL EXCESS AMOUNT (in.)	$L_{ca}P$ (mi.)	STAGE RECORD	Q_{pR} (c.f.s.)	Q_p tr = 3 hrs. (c.f.s.)	t_{pR} (hr.)	t_p (hr.)	t_v (hr.)	C_{tR}	C_p640	K_m (hr.)	T_c (hr.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
30 JUNE-2 JULY,1936	——(1)	3.97	6	1.01	Dnstr	REC.	29,320	32,000	5.29	4.5	5.66	.57	426	2.4	7.5
9-11 SEPT. 1952	– – –(2)	15.48	3	4.02	Upstr	REC.	23,620	23,600	8.15	7.5	6.39	.89	529	3.0	13.5
24-25 APRIL, 1957	- - - -(3)	4.47	2	1.22	Upstr	REC.	51,050	51,050*	3.0	3.0	2.70	.33	421	2.7	7.0
2-3 MAY, 1958	------(4)	3.15	2	1.68	Upstr	REC.	57,200	57,200*	3.0	3.0	2.64	.33	471	1.8	5.0

NOTE
* tr.= 2.0 HRS.

ENGINEERING INVESTIGATIONS
UNIT HYDROGRAPHS

PERTINENT DATA
GUADALUPE RIVER BASIN
BLANCO RIVER, WIMBERLEY, TEXAS

SUBMITTED BY
DISTRICT ENGINEER, FORT WORTH DISTRICT

TABLE 36
SYNTHETIC UNIT HYDROGRAPH FOR
A UNIFORM 3-HOUR RAINFALL
MONTELL DAM AND RESERVOIR - 707 sq. mi.

Time in 3-hour periods	Unit Hydrographs (cfs)	
	Flow into full reservoir	Natural flow at damsite
0	0	0
1	23,420	5,600
2	59,230	60,940
3	33,780	33,540
4	15,700	18,200
5	8,700	12,200
6	5,000	8,500
7	2,700	5,800
8	1,000	3,900
9	400	2,100
10	0	1,000
11		300
12		0
Total	149,930	152,080

TABLE 37
SYNTHETIC UNIT HYDROGRAPHS FOR
A UNIFORM 3-HOUR RAINFALL
CONCAN DAM AND RESERVOIR - 391 sq. mi.

Time in 3-hour periods	Unit Hydrographs (cfs) Flow into full reservoir	Natural flow at damsite
0	0	0
1	20,610	5,060
2	35,620	37,840
3	14,000	20,210
4	6,000	8,400
5	3,600	5,200
6	1,800	3,400
7	800	2,100
8	390	1,300
9	0	600
10		0
Total	82,820	84,110

TABLE 38
SYNTHETIC UNIT HYDROGRAPHS FOR
A UNIFORM 2-HOUR RAINFALL
SABINAL DAM AND RESERVOIR - 210 sq. mi.

Time in 2-hour periods	Unit Hydrographs (cfs)	
	Flow into full reservoir	Natural flow at damsite
0	0	0
1	14,460	1,220
2	24,430	23,040
3	13,550	16,000
4	7,400	10,000
5	3,700	6,000
6	1,700	4,000
7	700	2,500
8	200	1,500
9	0	700
10		0
Total	66,140	67,760

TABLE 39
SYNTHETIC UNIT HYDROGRAPH FOR
A UNIFORM 3-HOUR RAINFALL
CLOPTIN CROSSING DAM AND RESERVOIR - 307 sq. mi.

Time in 3-hour periods	Unit Hydrographs (cfs)	
	Flow into full reservoir	Natural flow at damsite
0	0	0
1	12,230	4,090
2	23,620	24,15[illegible]
3	13,500	16,400
4	6,300	[illegible],800
5	3,600	5,300
6	2,200	3,500
7	1,350	2,100
8	650	900
9	0	0
Total	63,450	66,040

TABLE 40

RAINFALL AND RAINFALL-EXCESS FOR SPILLWAY DESIGN STORM

MONTELL DAM AND RESERVOIR

3-hour period	Average rainfall (inches)	Loss (inches)	Rainfall-excess (inches)
0	0	0	0
1	.41	.41	0
2	.42	.42	0
3	.43	.43	0
4	.43	.43	0
5	.44	.44	0
6	.45	.45	0
7	.48	.45	.03
8	.49	.45	.04
9	.50	.45	.05
10	.51	.45	.06
11	.52	.45	.07
12	.55	.45	.10
13	.58	.45	.13
14	.60	.45	.15
15	.63	.45	.18
16	.67	.45	.22
17	.76	.45	.31
18	.84	.45	.39
19	1.05	.45	.60
20	1.39	.45	.94
21	2.00	.45	1.55
22	3.11	.45	2.66
23	12.46	.45	12.01
24	2.59	.45	2.14
Total	32.31	10.68	21.63

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TABLE 41
RAINFALL AND RAINFALL-EXCESS FOR SPILLWAY DESIGN STORM
CONCAN DAM AND RESERVOIR

3-hour period	Average rainfall (inches)	Loss (inches)	Rainfall-excess (inches)
0	0	0	0
1	.46	.46	0
2	.46	.46	0
3	.47	.45	.02
4	.47	.45	.02
5	.47	.45	.02
6	.47	.45	.02
7	.47	.45	.02
8	.47	.45	.02
9	.48	.45	.03
10	.50	.45	.05
11	.54	.45	.09
12	.55	.45	.10
13	.56	.45	.11
14	.58	.45	.13
15	.61	.45	.16
16	.63	.45	.18
17	.80	.45	.35
18	.83	.45	.38
19	1.00	.45	.55
20	1.14	.45	.69
21	2.03	.45	1.58
22	2.71	.45	2.26
23	13.94	.45	13.49
24	3.48	.45	3.03
Total	34.12	10.82	23.30

TABLE 42
RAINFALL AND RAINFALL-EXCESS FOR SPILLWAY DESIGN STORM
SABINAL DAM AND RESERVOIR

2-hour period	Average rainfall (inches)	Loss (inches)	Rainfall-excess (inches)
0	0	0	0
1	.31	.31	0
2	.33	.33	0
3	.33	.33	0
4	.33	.33	0
5	.33	.33	0
6	.33	.33	0
7	.33	.33	0
8	.33	.33	0
9	.33	.33	0
10	.33	.33	0
11	.33	.33	0
12	.33	.33	0
13	.33	.33	0
14	.33	.33	0
15	.35	.35	0
16	.35	.35	0
17	.35	.35	0
18	.35	.35	0
19	.35	.35	0
20	.35	.35	0
21	.38	.38	0
22	.40	.40	0
23	.40	.40	0
24	.40	.40	0
25	.42	.42	0
26	.45	.45	0
27	.45	.45	0
28	.50	.50	0
29	.70	.50	.20
30	.90	.50	.40
31	1.30	.50	.80
32	1.60	.50	1.10
33	2.00	.50	1.50
34	3.88	.50	3.38
35	10.67	.50	10.17
36	4.85	.50	4.35
Total	36.00	14.10	21.90

TABLE 43

RAINFALL AND RAINFALL-EXCESS FOR THE SPILLWAY DESIGN STORM
CLOPTIN CROSSING DAM AND RESERVOIR

3-hour period	Average rainfall (inches)	Loss (inches)	Rainfall-excess (inches)
0	0	0	0
1	.46	.46	0
2	.47	.47	0
3	.47	.47	0
4	.47	.47	0
5	.47	.47	0
6	.47	.47	0
7	.48	.48	0
8	.48	.48	0
9	.48	.48	0
10	.48	.48	0
11	.50	.50	0
12	.54	.54	0
13	.58	.58	0
14	.62	.62	0
15	.66	.66	0
16	.70	.70	0
17	.75	.75	0
18	.85	.75	.10
19	.95	.75	.20
20	1.10	.75	.35
21	1.95	.75	1.20
22	3.70	.75	2.95
23	14.80	.75	14.05
24	2.90	.75	2.15
TOTAL	35.33	14.33	21.00

60. SPILLWAY DESIGN FLOOD ROUTINGS.- The spillway design flood hydrographs for flow into full reservoir were routed through Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs assuming an initial reservoir level at the top of the controlled storage. The routing computations indicate the maximum reservoir levels and the peak outflows for the reservoirs would be as follows: 1366.0 feet msl and 581,000 second-feet at Montell, 1394.2 feet msl and 433,000 second-feet at Concan, 1238.8 feet msl and 270,600 second-feet at Sabinal, and 1017.5 feet msl and 196,400 second-feet at Cloptin Crossing Reservoir. The spillway design flood inflow-outflow hydrographs and reservoir elevations for Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs are shown on plates 33 through 36, respectively.

61. FACTORS OF SAFETY AGAINST OVERTOPPING.- To evaluate the factors of safety to the dams provided by the freeboard storages and the spillways, floods greater than the spillway design floods were constructed for routing through the reservoirs. Two tests were imposed on the reservoirs for this purpose. The first test consisted of increasing the peak discharges of the spillway design floods by various amounts but holding the volume equal to that of the spillway design floods. The second test consisted of increasing both the peak discharges and the volumes of the spillway design floods by various percentages.

62. The hypothetical flood hydrographs for the first test, i.e., increasing the peak discharges of the spillway design floods and holding the volumes constant, were computed for flow into full reservoir condition. The unit hydrographs for the flow into full reservoir condition were modified by increasing the unit hydrograph peaks for the areas above head of reservoir by 10, 25, and 50 percent. The hypothetical flood hydrographs were developed by applying the modified unit hydrographs to the rainfall excess from the maximum 6-hour period of rainfall excess for each spillway design storm while using the adopted unit hydrographs for the remaining rainfall excess.

63. The hypothetical flood hydrographs for the second test, i.e., increasing both the peak discharges and flood volumes by various percentages, were developed by increasing each ordinate of the spillway design floods for the flow into full reservoir condition by 10, 25, and 50 percent.

64. In order to obtain a comparison between maximum reservoir elevations produced by the spillway design floods and the hypothetical flood hydrographs, the hypothetical floods were routed through the proposed reservoirs under the same assumptions as were the spillway design floods. The results of these studies for Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs are shown on plates 37 through 40, respectively. The routing studies indicate that the spillway design floods, under conditions of flow into full reservoir, could be increased about

22, 29, 26, and 37 percent in both peak and volume, without overtopping the Montell, Concan, Sabinal, and Cloptin Crossing dams, respectively.

65. GUIDE TAKING LINE.- The guide taking line for the recommended reservoirs has been based upon the policy for real estate acquisition set forth in Change 9 dated March 9, 1962, of EM 405-2-150. The upper guide contour has been established at five feet above the top of controlled storage for Montell, Concan, and Cloptin Crossing Reservoirs and three feet above top of gates for Sabinal Reservoir. The upper guide contours thus established have been adopted throughout the entire reservoir area. More detailed studies will be made during preconstruction planning stages to evaluate the backwater effects in the upper reaches of the reservoirs. The adopted elevations for the upper guide contour are 1336.0 for Montell Reservoir, 1371.5 for Concan Reservoir, 1229.5 for Sabinal Reservoir, and 1003.0 for Cloptin Crossing Reservoir.

66. RELOCATION CRITERIA.- The criteria for the alteration or relocation of railroads, highways, bridges, and utilities is based upon the addition of a reasonable freeboard to the higher of the following levels: (1) the top of the flood-control pool or (2) the maximum elevation of the 50-year reservoir operation resulting from flood occurrences on a full conservation pool after 100 years of sediment deposition. In the upper portions of the main part of a reservoir and on tributary arms, the foregoing criteria or the envelope curve of the backwater profile for the 50-year reservoir operation plus freeboard will be adopted. For the purpose of this report the same elevations adopted for the upper guide taking line in paragraph 65 have been adopted as the basis for relocation estimates. More detailed studies will be made during preconstruction planning stages.

67. FREEBOARD REQUIREMENTS.- Freeboard requirements for the recommended projects were determined in accordance with the method set forth in a paper by Saville, McClendon and Cochran entitled, "Freeboard Allowances for Waves in Inland Reservoirs," Journal of the Waterway and Harbors Division, Proceedings American Society of Civil Engineers, May 1962, distributed by OCE with Civil Works Letter 62-8 dated 6 August 1962. Computations for wave heights and wave runup were based on the computed effective fetch at the maximum water surface for each reservoir. The computed wave height and total freeboard for an overland wind velocity of 40 miles per hour (52 miles per hour over water) was adopted as a basis for design. The results of these computations are summarized in table 44.

68. HYDROLOGIC NETWORK.- It is proposed to supplement the existing rainfall and streamflow stations by expanding the hydroclimatic and hydrologic reporting networks. The records and reports will be used to update hydrologic design criteria for preconstruction planning; in connection with construction activities; and to prescribe

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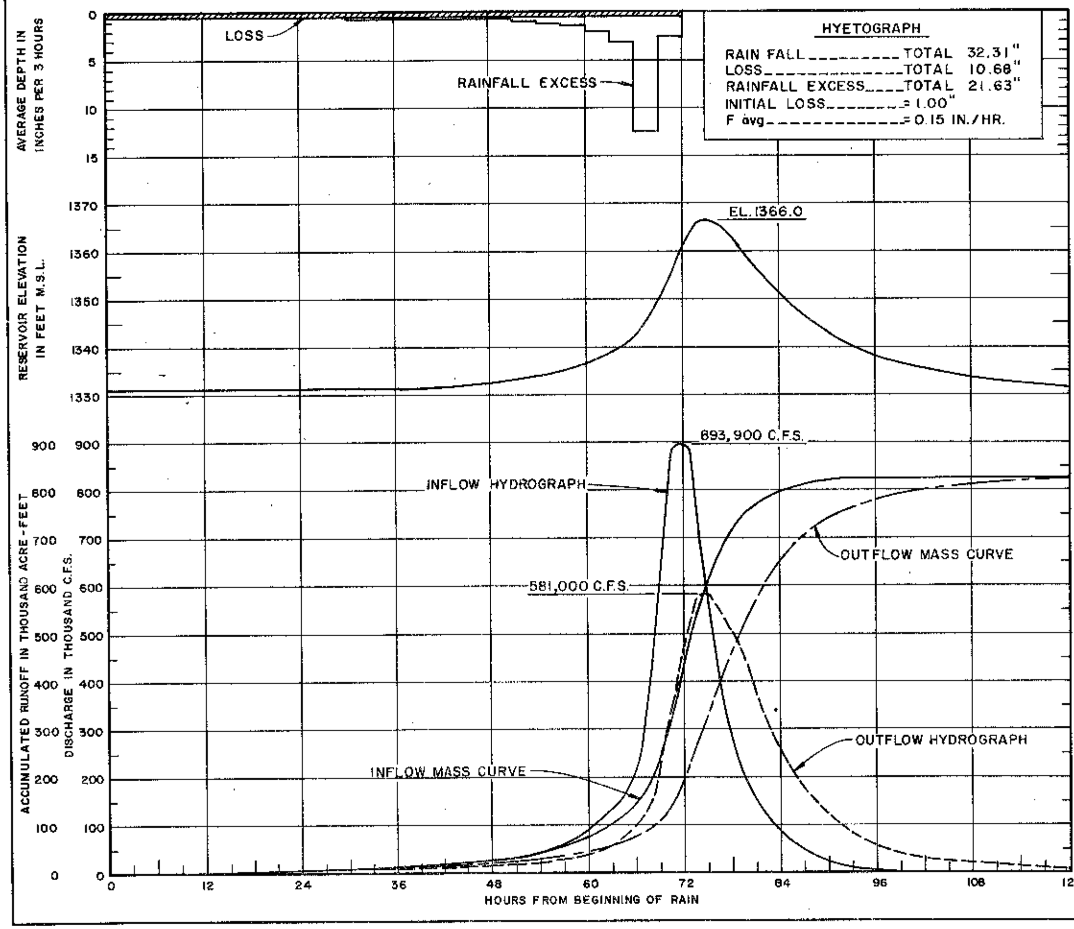

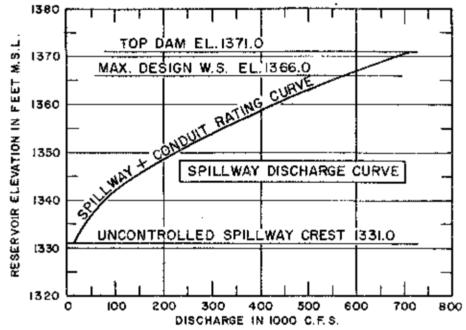

NOTES:

Drainage area 707 square miles. Outflow partially controlled by 1-15' diameter conduit, invert elevation 1216.0 with 3-5'-8" x 12'-0" slide gates. Spillway is uncontrolled 960' broadcrested wier, crest at elevation 1331.0.

Flood-control conduit operative during spillway design flood.

Reservoir level, at spillway crest, elevation 1331.0 at beginning of rain, returns to spillway crest 123 hours after beginning of rain.

EDWARDS UNDERGROUND RESERVOIR

MONTELL RESERVOIR
INFLOW - OUTFLOW HYDROGRAPH
SPILLWAY DESIGN FLOOD

DEC 1964 PLATE 33

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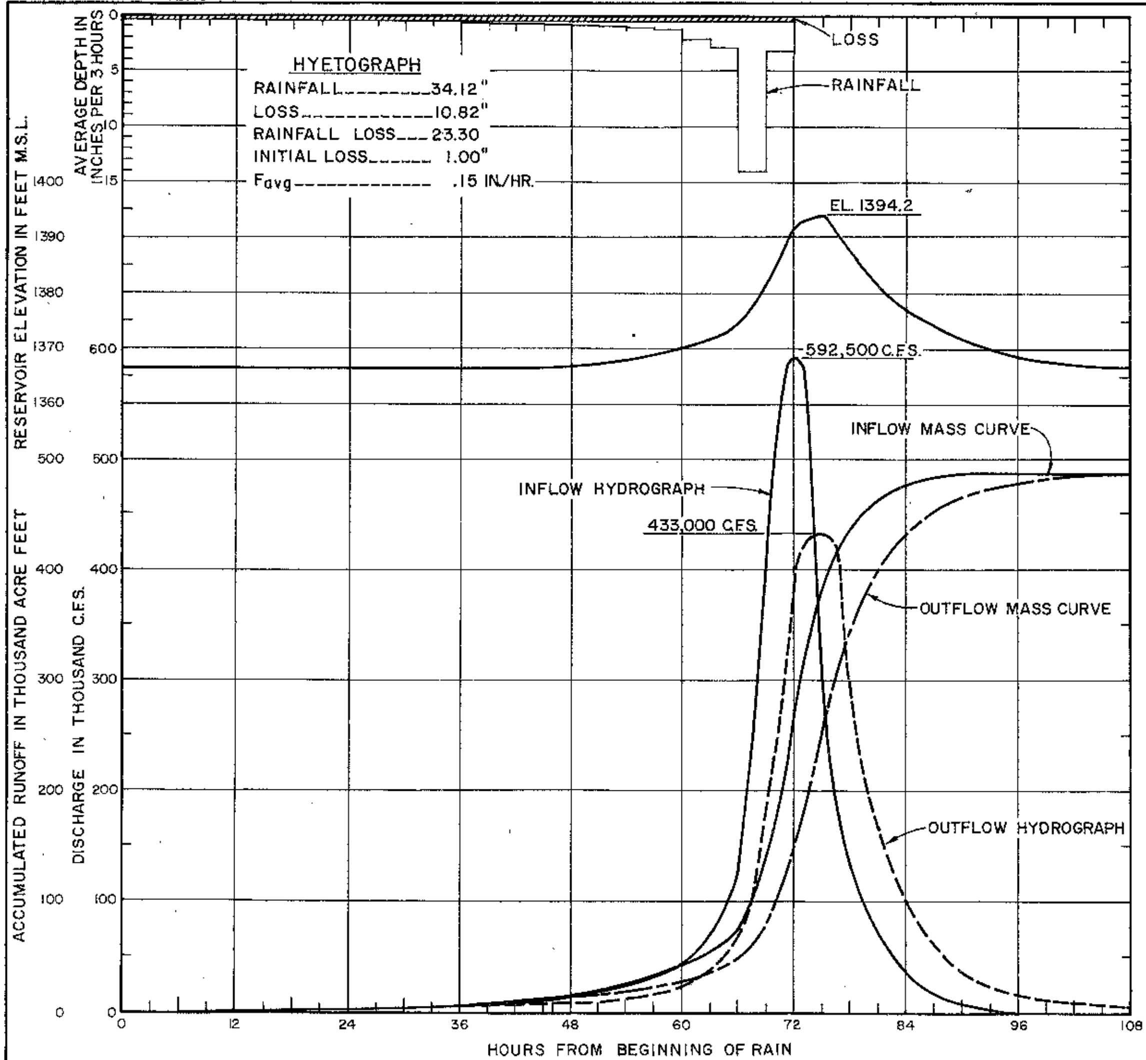

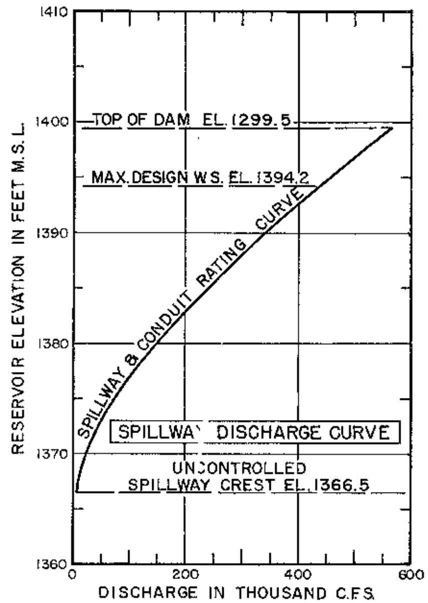

NOTES:

Drainage area 391 square miles. Outflow partially controlled by 1-13' diameter conduit invert elevation 1240.0, with two 6'-13' tractor type gates. Spillway is uncontrolled 1030' Broadcrested Weir, crest elevation 1366.5.

Flood Control conduit operative during spillway design storm.

Reservoir level, at spillway crest elevation 1366.5 at beginning of rain, returns to spillway crest 111 hours after beginning of rain.

EDWARDS UNDERGROUND RESERVOIR

CONCAN RESERVOIR
INFLOW-OUTFLOW
HYDROGRAPHS
SPILLWAY DESIGN FLOOD

DEC. 1964 PLATE 34

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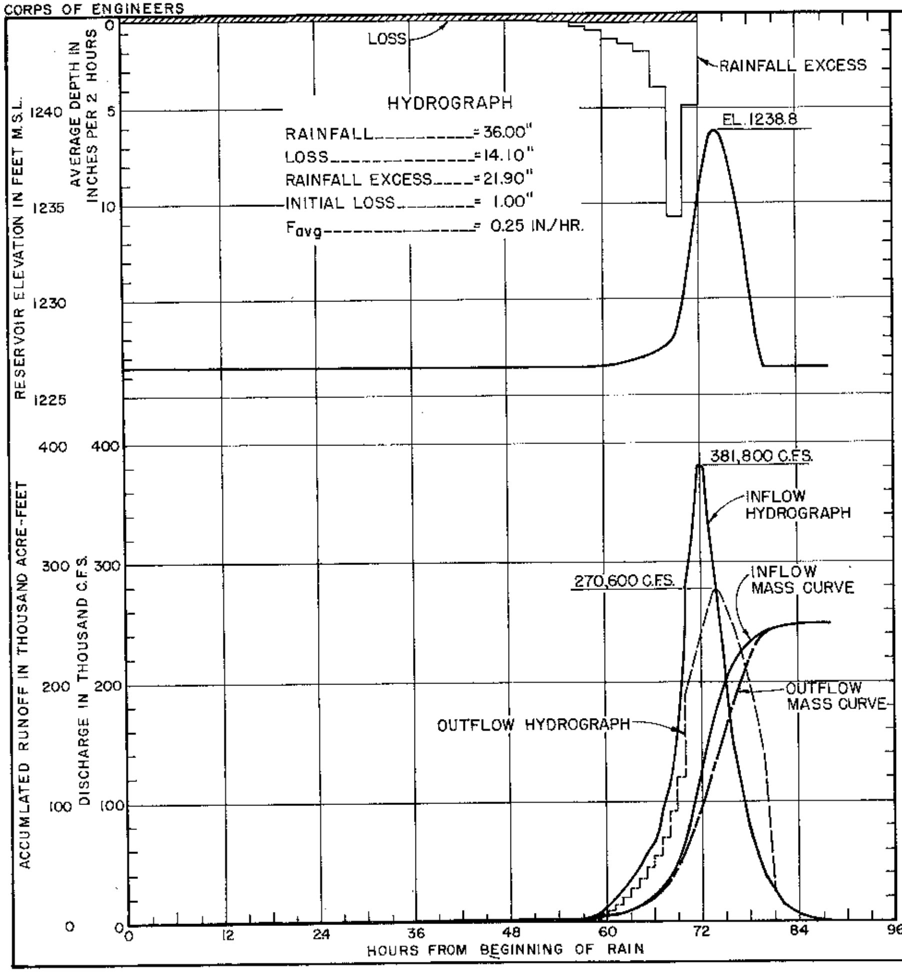

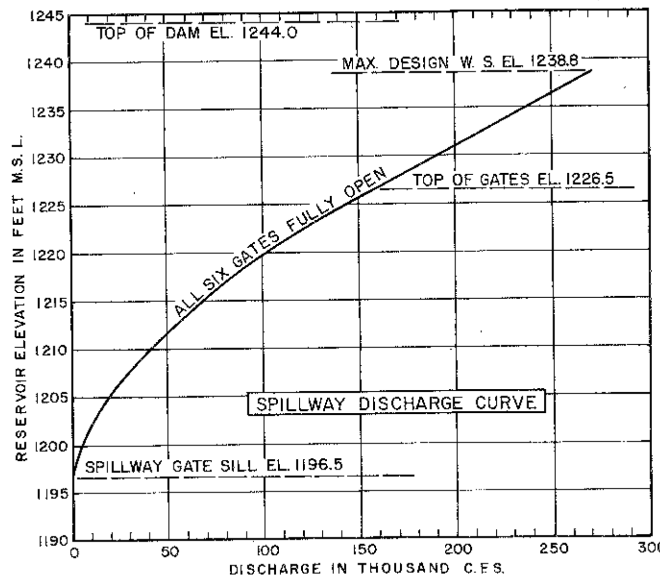

NOTES:

Drainage area 210 square miles. Outflow controlled by six 40' x 30' tainter gates, sill elevation 1196.5

Low flow outflow inoperative during spillway design flood.

Reservoir level at top of gates, elevation 1226.5 at beginning of rain.

EDWARDS UNDERGROUND RESERVOIR

SABINAL RESERVOIR
INFLOW-OUTFLOW HYDROGRAPHS
SPILLWAY DESIGN FLOOD

DEC 1964 PLATE 35

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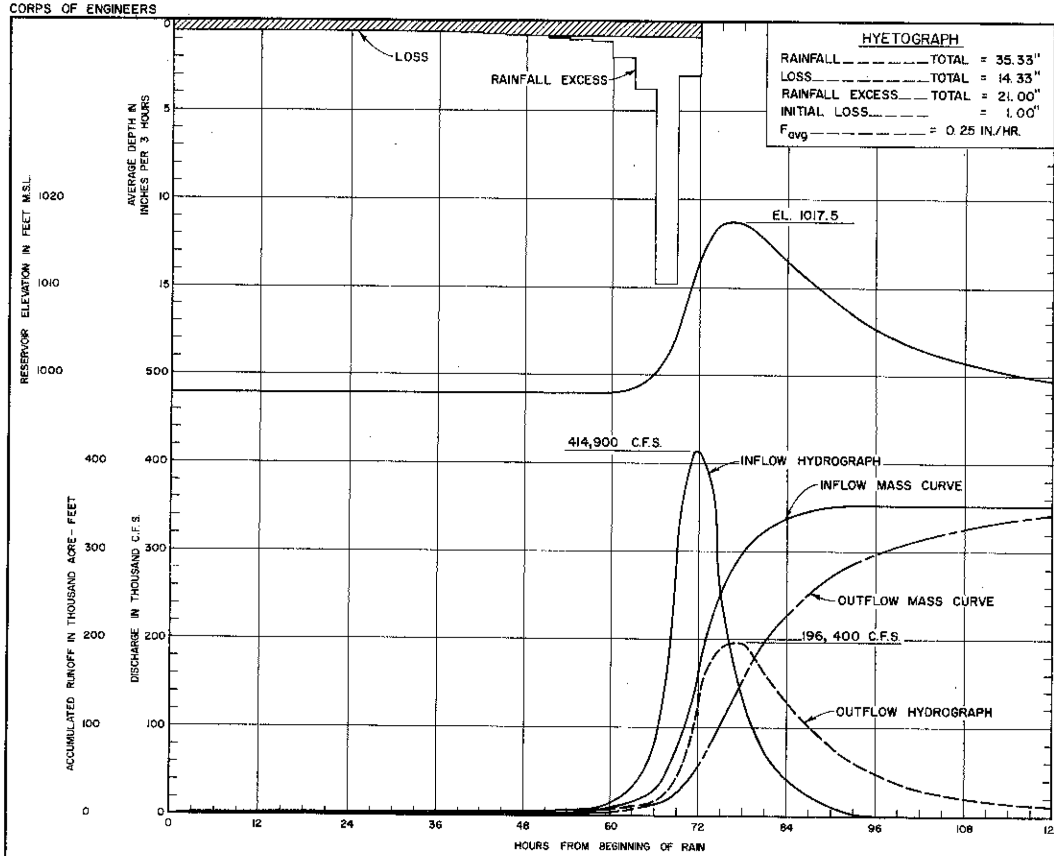
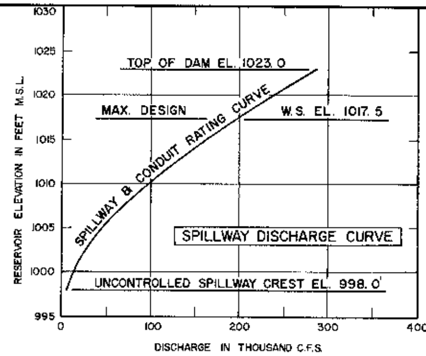




NOTES:

Drainage area 307 square miles. Outflow partially controlled by one 13' diameter conduit, invert elevation 855.0', with two 6'x13' tractor type gates. Spillway is uncontrolled 760' Broadcrested Weir, crest elevation 998.0'

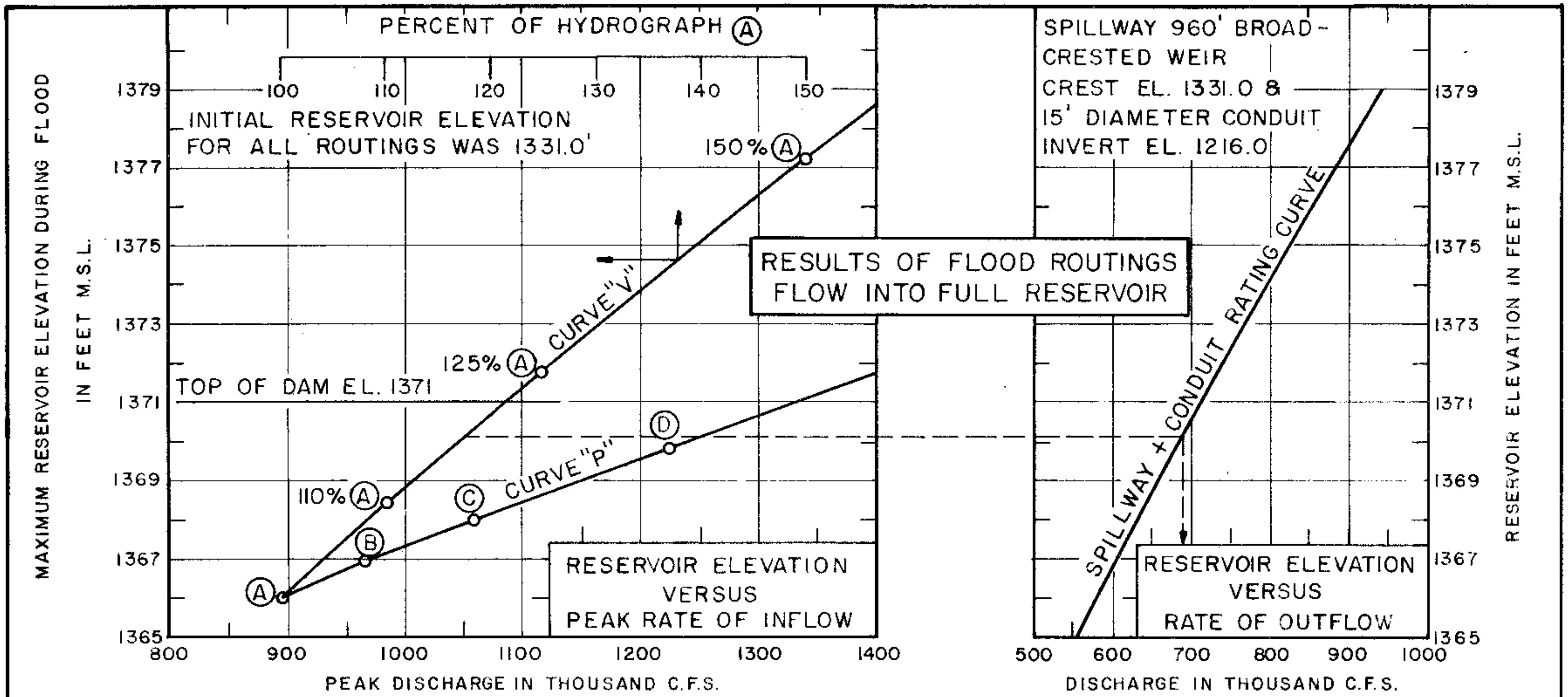
Flood - control conduit operative during spillway design flood.

Reservoir level, at spillway crest elevation 998.0' at beginning of rain, returns to spillway crest 144 hours after beginning of rain.

EDWARDS UNDERGROUND RESERVOIR

CLOPTIN CROSSING RESERVOIR
INFLOW-OUTFLOW HYDROGRAPHS
SPILLWAY DESIGN FLOOD

DEC 1964 PLATE 36



NOTES:

Points (B), (C), (D) on curve "P" were obtained by routing the hydrograph of the computed spillway design flood, for flow into full reservoir, whose peak discharge has been increased by increasing the peak of the unit hydrograph for area above head of reservoir by 10, 25 and 50 percent for the maximum 6 hour rainfall and with no increase in volume.

Points on curve "V" were obtained by routing the hydrograph of the computed spillway design flood, for flow into full reservoir, with all ordinates of flood hydrograph increased by 10, 25 and 50 percent.

EDWARDS UNDERGROUND RESERVOIR

MONTELL RESERVOIR
RESULTS OF FLOOD ROUTINGS

DEC. 1964 PLATE 37

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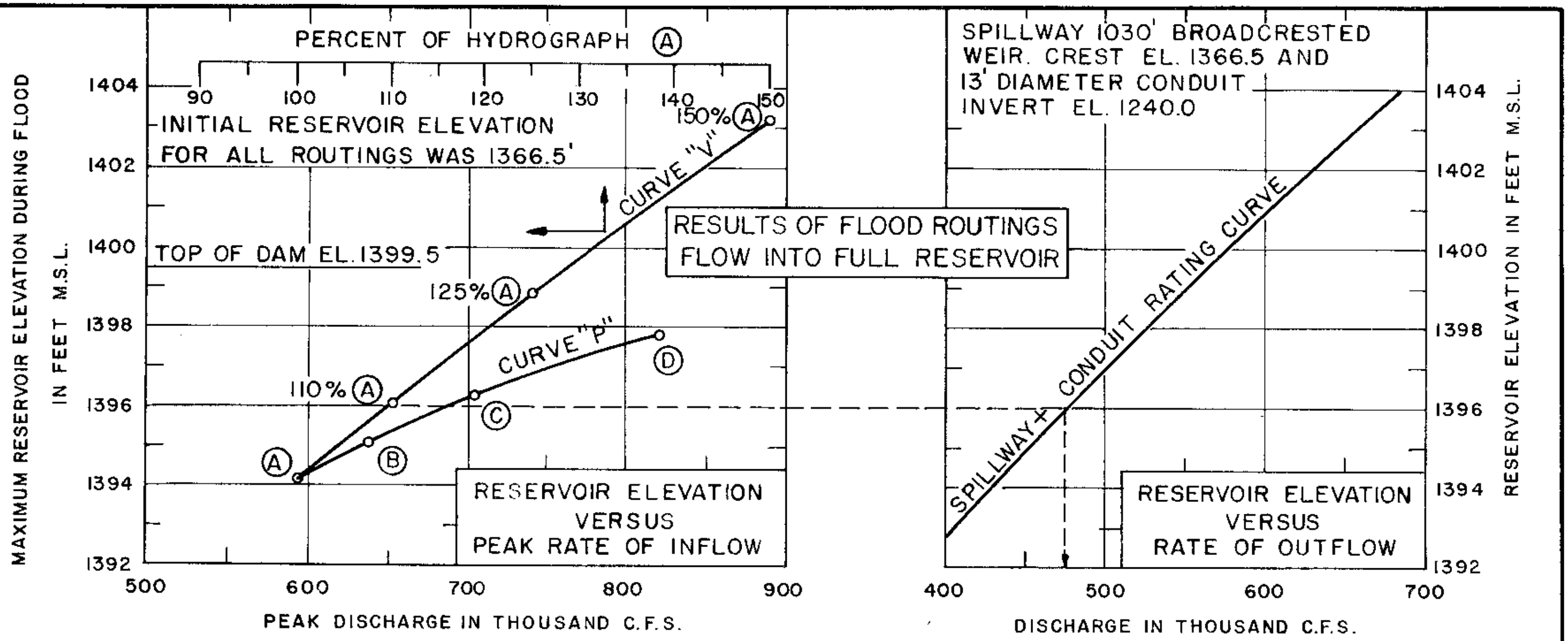

NOTES:

Points (B), (C) & (D) on curve "P" were obtained by routing the hydrographs of the computed spillway design flood, for flow into full reservoir, whose peak discharge has been increased by increasing the peak of the unit hydrograph for area above head of reservoir by 10, 25 and 50 percent for the maximum 6 hour rainfall and with no increase in volume.

Points on curve "V" were obtained by routing the hydrograph of the computed spillway design flood, for flow into full reservoir, with all ordinates of flood hydrograph increased by 10, 25 and 50 percent.

EDWARDS UNDERGROUND RESERVOIR

CONCAN RESERVOIR
RESULTS OF FLOOD ROUTINGS

DEC. 1964 PLATE 38

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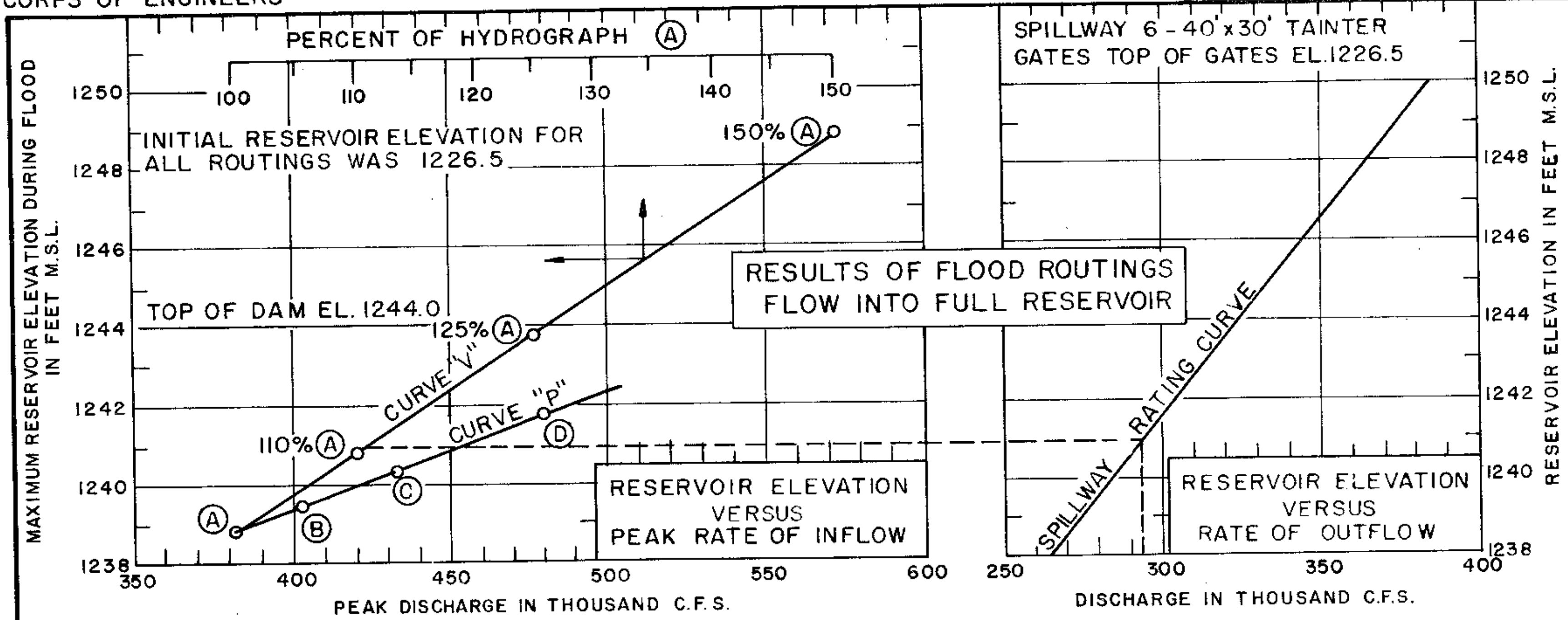


NOTES:

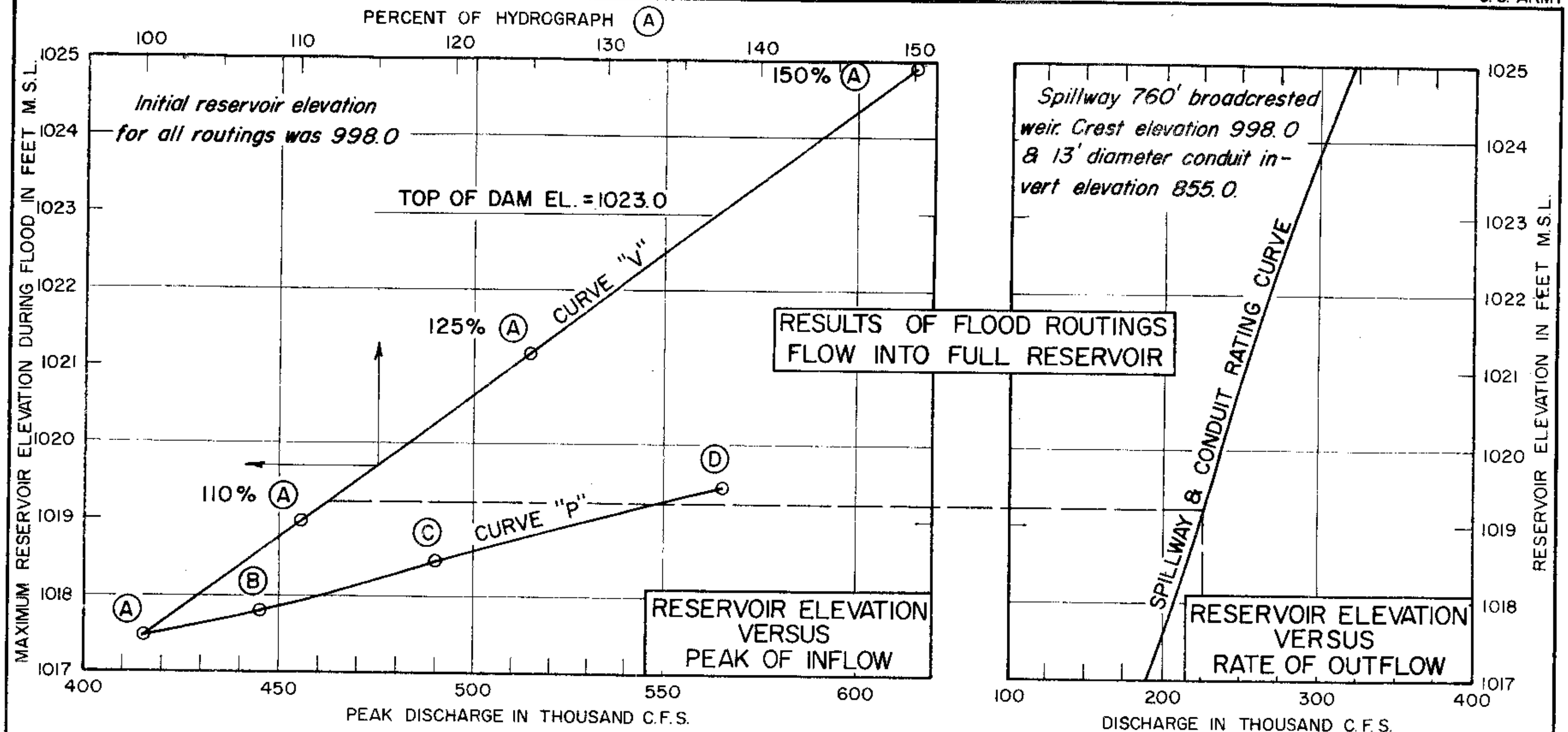
Points (B), (C) & (D) on curve "P" were obtained by routing the hydrograph of the computed spillway design flood, for flow into full reservoir, whose peak discharge has been increased by increasing the peak of the unit hydrograph for area above head of reservoir by 10, 25 and 50 percent for the maximum 6 hour rainfall and with no increase in volume.

Points on curve "V" were obtained by routing the hydrograph of the computed spillway design flood, for flow into full reservoir, with all ordinates of flood hydrograph increased by 10, 25 and 50 percent.

EDWARDS UNDERGROUND RESERVOIR

SABINAL RESERVOIR
RESULTS OF FLOOD ROUTINGS

DEC. 1964 PLATE 39



NOTE:

Points (B), (C), & (D) on curve "P" were obtained by routing the hydrographs of the computed spillway design flood, for flow into full reservoir whose peak discharge has been increased by increasing the peak of the unit hydrograph for area above head of reservoir by 10, 25, and 50 percent for the maximum 6 hour rainfall and with no increase in volume.

Points on curve "V" were obtained by routing the hydrographs of the computed spillway design flood for flow into full reservoir with all ordinates of the flood hydrograph increased by 10, 25, and 50 percent.

EDWARDS UNDERGROUND RESERVOIR

CLOPTIN CROSSING RESERVOIR
RESULTS OF FLOOD ROUTINGS

DEC. 1964 PLATE 40

TABLE 44

FREEBOARD REQUIREMENTS

Reservoir	Max. design water surface elevation (ft. msl)	Effective fetch (miles)	Total required freeboard (feet)(1)	Total freeboard provided (feet)	Elevation at top of dam (ft. msl)
Montell	1366.0	2.96	3.8	5.0	1371.0
Concan	1394.2	1.73	2.9	5.3	1399.5
Sabinal	1238.8	2.01	3.2	5.2	1244.0
Cloptin Crossing	1017.5	2.10	3.3	5.5	1023.0

(1) Based on an overland wind velocity of 40 miles per hour (52 miles per hour over water) and computed wind tide.

flood-control regulations for the recommended reservoirs. The expanded network will include inflow and outflow stations and reservoir level gages at the recommended projects, Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs. Evaporation and recording rainfall stations also will be provided at Montell, Concan, Sabinal, and Cloptin Crossing Reservoirs. Appropriate instrumentation for the study of ground water, the accurate determination of base flows and recharge values and the investigation of water quality will also be considered after the project is authorized, in line with the Bureau of the Budget Circular No. A-67 dated 28 August 1964. Detailed requirements for the complete hydrologic network will be presented in connection with preconstruction planning studies.

THE EDWARDS RESERVOIR

69. GENERAL.- The Edwards Reservoir is a segment of an aquifer that extends some 250 miles from Austin westward to Comstock. That segment of the aquifer known as the Edwards Reservoir, which is the source of water for some one million people in the area including the city of San Antonio, lies between the cities of Kyle in the Blanco River watershed on the east and Brackettville in the West Nueces River watershed on the west. Ground water divides at these two locations separate the Edwards Reservoir hydrologically from adjacent portions of the aquifer. The centerline of the aquifer connects roughly the cities of Kyle, San Marcos, San Antonio, Uvalde, and Brackettville. The aquifer is roughly 175 miles long and varies in width from 5 to 25 miles. The northern or upper boundary of the aquifer coincides approximately with the upper boundary of the Balcones Fault Zone while the lower boundary is less well defined, being simply the beginning of an area of low transmissibility or poor circulation. The normal flow of water to the south in the underground reservoir is blocked by this zone where the circulation is restricted, which causes the water to flow in an easterly direction toward San Antonio, thence in a northeasterly direction toward Kyle. The lower limit of the Edwards Reservoir is commonly called 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. The approximate boundaries of the reservoir are shown on plate 1.

70. As previously stated, one of the purposes of this investigation is the determination of whether improvement of the yield of the Edwards Reservoir is possible. The following excerpt from a published report 1/ is considered pertinent to this investigation:

> "The dependable yield of a reservoir such as the Edwards limestone over a long period cannot be in excess of the average rate of replenishment. . . . Depending on the Edwards Reservoir to meet all future demands . . . would result in overpumping of the reservoir with consequent depletion of storage and large continuing declines of water levels in wells. Eventually the reservoir would be depleted to such an extent that it would be impossible to obtain more water through wells than the amount entering the reservoir as recharge, and large sections of the reservoir would be almost completely dewatered. . . ."

Prior to the drilling of wells into the reservoir, a natural balance existed between recharge to the reservoir and discharge from the springs. Large scale withdrawals from wells upset this balance and result in the lowering of water levels in the reservoir. As the reservoir level continues to be lowered by an excess of pumpage over recharge, the springs stop flowing as the level drops below the spring outlets.

1/ Progress Report on the Edwards Limestone Reservoir by Wm. F. Guyton and Associates, June 1959.

71. RECHARGE.- Inflow to the reservoir is in the form of recharge and cannot actually be measured, but must be estimated by one of several methods. Ideally, the amount of recharge from a particular stream may be determined as the difference between flow measured immediately above and immediately below the recharge zone. If the capacity of the recharge facility may be determined, then the measurement of flow above the recharge zone is sufficient to determine the amount of recharge. Estimates of recharge for each of the several streams crossing the zone of recharge of the Edwards area have been determined by the most applicable procedure and published by the San Antonio City Water Board and by the Texas Water Commission in cooperation with the U. S. Geological Survey and several state agencies. These recharge values were reviewed and those published by the Texas Water Commission were adopted for use in this report. A tabulation of the total annual recharge values for the contributing area is given in table 45.

72. SPRINGFLOW.- The principal springs which serve as natural outlets for the Edwards Reservoir are Leona Springs, San Antonio, and San Pedro Springs, Hueco Springs, Comal Springs, and San Marcos Springs. The flow from each of these springs is dependent to some extent on the level of the underground reservoir. As the level declined in the recent drought period, several of the springs ceased flowing in 1950. Comal Springs ceased flowing from June 13 to about November 3, 1956, and San Marcos Springs experienced one of its lowest flows of record during 1956. Flow from each of the springs has been determined mainly by the Ground Water Branch of the U. S. Geological Survey and published in previous reports. A study of these springflow records and the records of water levels in Beverly Lodges Well (H-26) indicated that a good correlation existed between total annual springflow and the year-end elevation of Beverly Lodges Well. The curve on plate 41, resulting from this correlation, was used in subsequent routing studies for the Edwards Underground Reservoir. A tabulation of the total annual flow of the major springs of the Edwards Reservoir area is given in table 45.

73. WELLS.- The first irrigation well tapping the Edwards Reservoir was drilled about 1884. Accurate early records of withdrawals through wells are not available but it has been estimated that in 1897 well discharge amounted to about 29 million gallons per day in Bexar County. The majority of the wells are in Uvalde, Medina, and Bexar Counties. Table 46 is indicative of the increase in withdrawals through wells which has occurred in these counties The estimated historic annual withdrawal from wells for the period 1934-1962 has been estimated by the Ground Water Branch of the U. S. Geological Survey and is presented in table 45.

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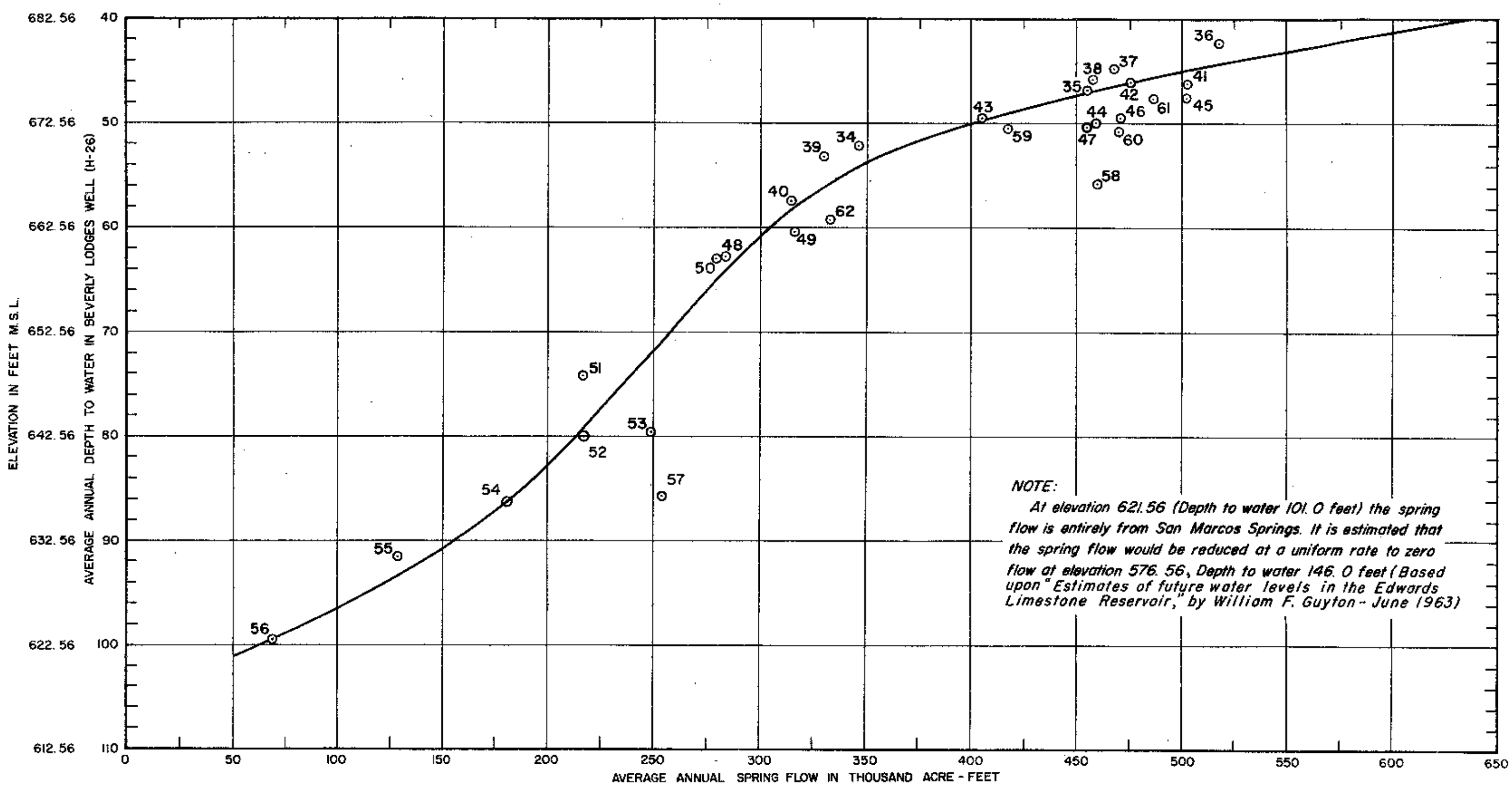


EDWARDS UNDERGROUND RESERVOIR

ESTIMATED
SPRING FLOW VS ELEVATION

DEC. 1964 PLATE 41

TABLE 45

RECHARGE AND DISCHARGE - EDWARDS UNDERGROUND RESERVOIR
(1000 Acre-Feet)

Year	Recharge	Spring flow	Withdrawal through wells
1934	180	346	102
5	1258	454	103
6	910	517	113
7	401	467	120
8	433	457	122
9	399	330	119
1940	309	314	121
1	851	502	138
2	558	475	144
3	273	404	149
4	561	458	149
5	528	502	152
6	556	479	158
7	423	454	167
8	178	283	168
9	508	316	178
1950	200	279	193
1	140	217	206
2	276	217	212
3	168	249	224
4	161	181	242
5	192	128	267
6	44	69	324
7	1143	254	237
8	1711	459	219
9	690	417	235
1960	825	469	228
1	693	486	228
2	252	333	268
Average	511	363	182

TABLE 46

WITHDRAWALS FROM WELLS (ESTIMATED)

Year	Amount Ac.Ft./Yr.	Rate MGD
	BEXAR COUNTY	
1897	32,400	29
1934	96,100	86
1954	207,900	186
1956	233,600	209
	UVALDE AND MEDINA COUNTIES	
1934	3,900	3.5
1954	26,800	24
1956	76,000	68

74. STORAGE CAPACITY.- The total capacity of the underground reservoir is unknown, but by use of the water budget equation "inflow minus outflow equals change-in-storage," the capacity of the recorded range of fluctuation of the water surface is indicated by the elevation of water in wells. Well elevations have been observed and recorded over practically the entire length of the underground reservoir and have been published by the Ground Water Branch of the U. S. Gelogical Survey in several bulletins. The records of well levels indicate that in the aquifer the water surface slopes to the south or southeast in the outcrop area where water table conditions prevail and in a more easterly direction in the artesian zone. Since the water surface slopes due to the nature of the underground reservoir, it was believed that the average of the elevations of a group of wells spaced at intervals along the major axis of the reservoir should be used as a measure of the reservoir water surface. However, a good correlation exists between this average elevation and the elevation of a single well, H-26, known as the Beverly Lodges Well, located about 4 miles northeast of the heart of San Antonio. Accordingly, for simplicity in computations, the accumulated annual differences in recharge and discharge were plotted versus the year-end elevation of Well H-26. This correlation produced a reasonable check on the elevation-storage curve shown in a previous publication.2/ The published curve has been adopted and is shown on plate 42. Bulletin 6201 of the Texas Water Commission 3/ offers a more refined

2/Estimates of Future Water Levels in the Edwards Limestone Reservoir, by William F. Guyton and Associates, June 1963.

3/TWC Bulletin 6201, Recharge, Discharge, and Changes in Ground-Water Storage in the Edwards and Associated Limestones, San Antonio Area, Texas. January 1962.

concept of capacity of the underground reservoir. It divides the reservoir, arbitrarily, into four divisions along its major axis and determines inflow, outflow, and storage changes for each part. The idea of underflow, the underground flow from one segment into the next most down-gradient segment, is introduced, and correlated with differences in elevation of the two segments as indicated by key wells in each segment. The accumulated annual changes in storage within each segment are plotted against the elevations indicated by another key well within that segment. In this manner a separate elevation-capacity relationship is determined for each of the four portions of the reservoir. Because of the many routings which had to be made and the consequent need for a more simplified procedure, the single segment storage curve has been adopted for use in this report.

75. DESIRED MINIMUM RESERVOIR LEVEL.- The computed storage in the Edwards Reservoir is that storage between the recorded extremes of elevation, or some 2-1/2 million acre-feet. However, it is known that storage exists below the recorded low and it has been assumed in this report that the storage capacity below this low is about 30,000 acre-feet per foot which simply represents an extrapolation of the lower part of the curve shown on plate 42. The yield of an underground reservoir cannot, over a long period of time, exceed the average annual recharge. The reservoir might be drawn down to some point such that no springflow would occur and the entire recharge thereafter would be available for pumpage. In this case, if pumpage never exceeded the average recharge during any part of the hydrologic cycle, then the dependable yield during the critical drought period would be the average recharge. This presumes, however, that the level of the reservoir is drawn down far enough that even during periods of exceptionally high recharge, the reservoir would not refill to the spring outlets, and consequently no springflow would occur. For various reasons, however, it is not desirable that the reservoir level be reduced to the extreme level required to develop the maximum pumpage. The following excerpt from a published report 4/ is pertinent to this point:

> " . . . Another factor limiting the safe yield of wells in the reservoir is the presence of water of poor quality in the Edwards formation south and southeast of the Edwards Reservoir. There is apparently no barrier to the movement of this water into the fresh water area if water levels are lowered in the Edwards Reservoir sufficiently and the present hydraulic gradient

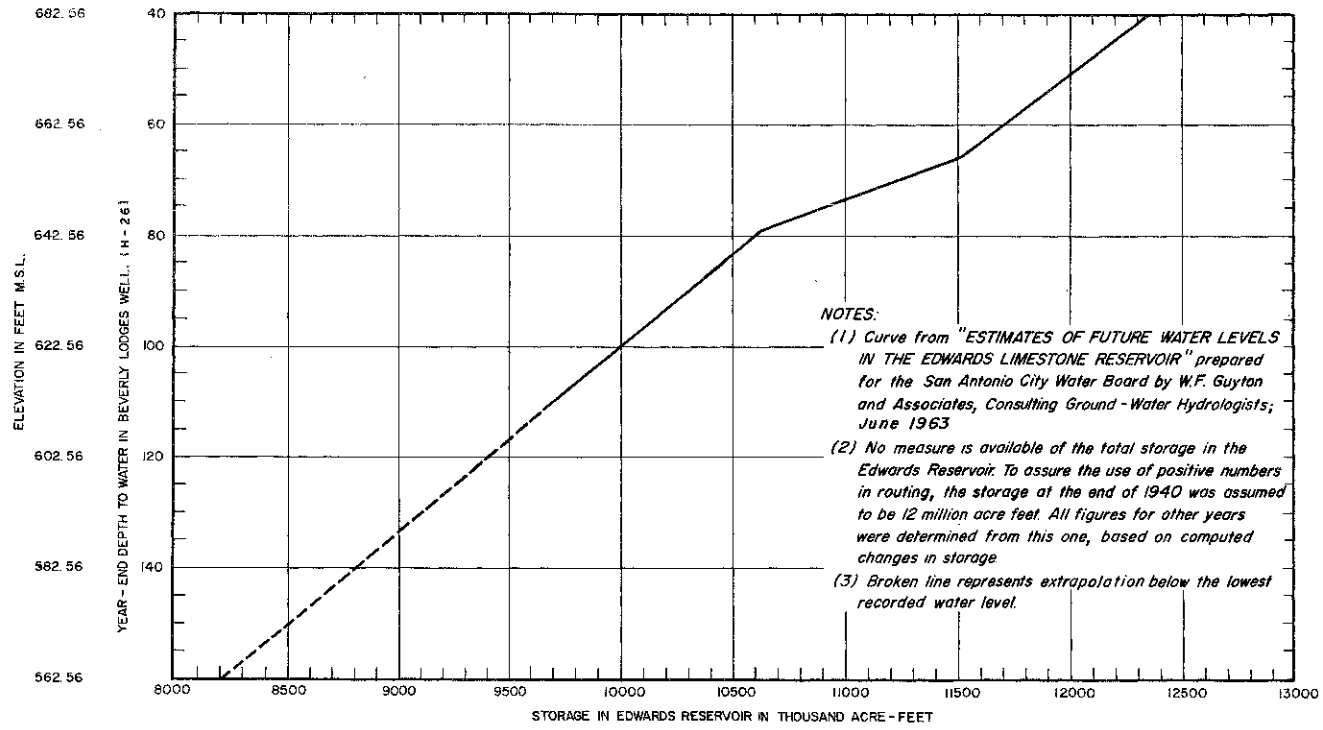
4/ The Edwards Limestone Reservoir by Wm. F. Guyton and Associates, November 1955.

"is reversed. If part of the reservoir becomes contaminated in this manner, it will be made useless as a source of fresh water in the future."

It is not known to what level the reservoir would have to be lowered before the intrusion of the water of poor quality would begin. The volume of water which would move from the bad water area is unknown, and consequently the overall effect of the lowering of the water level cannot be predicted. However, it is considered that in view of the possible consequences of the contamination of the reservoir, the level should not be lowered appreciably beyond its historic low point.

76. METHOD OF UNDERGROUND RESERVOIR ROUTING.- For purposes of analysis, the underground reservoir may be thought of as a large surface reservoir with several controlled and uncontrolled outlets at varying levels. The inflow to the reservoir is largely derived by seepage from streams that cross the outcrop of the aquifer in the Blacones Fault zone. The uncontrolled outflow takes place as springflow and the controlled outflow is in the form of pumpage. The reservoir level fluctuates in reponse to the imbalances in inflow and outflow in a manner somewhat similar to that of a surface reservoir. In order to determine the yield of the Edwards Reservoir which might be associated with varying levels of drawdown, routings were made utilizing the storage curve shown on plate 40, the inflow (recharge) given in table 45, the elevation-springflow relation shown on plate 41, and several constant pumpage rates. In view of the estimated nature of the inflows, the inherent inaccuracies in the relations between storage, springflow, and elevation, annual rather than monthly routings were made. Based upon the relations noted above, a check routing wherein historic pumpage was used indicated reasonably good results.

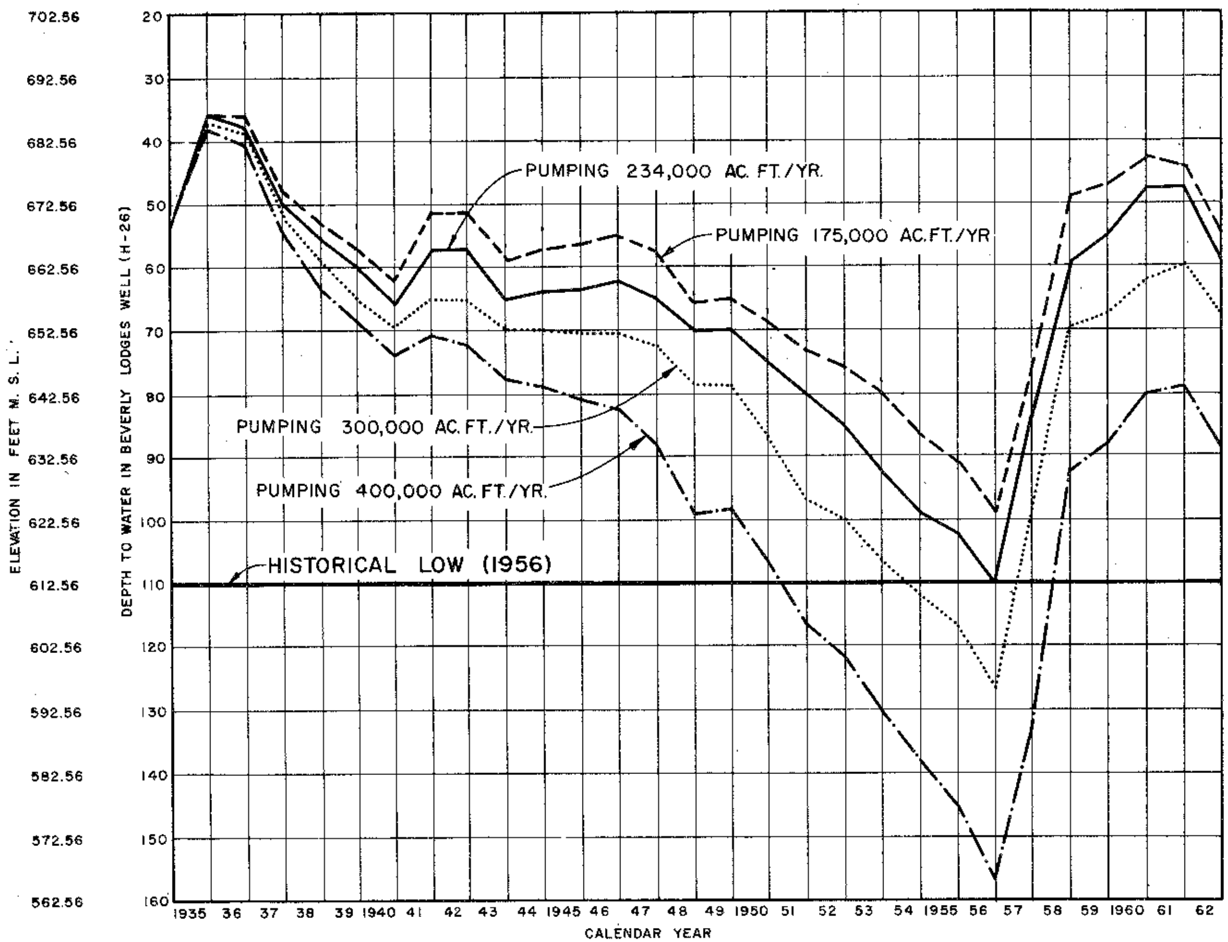
77. RESULTS OF ROUTINGS UNDER EXISTING CONDITIONS.- A number of routings were made under existing conditions to determine the yield of the Edwards Reservoir if the pumpage were constant during the period 1935-1962. Plate 43 presents the computed levels for the Edwards Reservoir based upon constant annual pumpage rates of 175,000 acre-feet, 234,000 acre-feet, 300,000 acre-feet, and 400,000 acre-feet with no new upstream surface reservoirs constructed. Table 47 presents the computed average annual springflow and the low point of elevation for each of the above pumpage rates.



EDWARDS UNDERGROUND RESERVOIR

ESTIMATED STORAGE VS ELEVATION

DEC 1964 PLATE 42



NOTE:
Existing conditions assuming pumpage at constant rate through period 1935-1962.

EDWARDS UNDERGROUND RESERVOIR

COMPARISON OF UNDERGROUND WATER LEVELS EXISTING CONDITIONS

DEC. 1964 PLATE 43

TABLE 47

COMPARISON OF THE EFFECT OF
VARYING PUMPAGE RATES

Pumpage (ac. ft./annum)	Average annual springflow (1) (ac. ft./annum)	Elevation of lowest water level (2) (ft. msl)
	EXISTING CONDITIONS	
175,000	335,700	624
234,000	292,900	612
300,000	251,000	596
400,000	196,000	566

(1) Average annual springflow based on period 1935 through 1956.
(2) Level at Well H-26 (Beverly Lodges Well).

The above routings cover a period of record from 1935 through 1962; however, the period of record that is used to evaluate the differences in average annual recharge, springflow, and pumpage is from 1935 through 1956. This interval includes a period of high rainfall and resulting runoff, and the most critical drought of record.

78. METHODS OF OPERATING SURFACE WATER RESERVOIRS FOR RECHARGE.- The provision of surface storage reservoirs upstream from the fault zone enables the storage of flood flows, which, because of the high rates involved, would flow across the fault zone. The plans of operation that were considered for the surface reservoirs are as follows:

a. Releasing the yield of the reservoirs at a constant rate to the underground reservoir, assuring a supply even during the critical period.

b. Holding the water in storage until the underground reservoir reaches some predetermined level and then releasing sufficient water to maintain the reservoir at that level.

c. Releasing the stored water from the reservoirs at rates equal to or less than the recharge rates, assuring that all of the runoff would be introduced into the underground reservoir as quickly as possible following runoff.

79. COMPARISON OF METHODS OF OPERATION.- Table 48 presents a comparison of the average annual pumpage and springflow from the Edwards Reservoir for the period 1935-1956 based upon the three different plans of operation.

TABLE 48

COMPARISON OF THE EFFECT OF SELECTED OPERATION PLANS

Pumpage (ac. ft./annum)	Method of Operation	Average annual springflow (1) (ac. ft./annum)	Total springflow and pumpage (ac. ft./annum)	Elevation of lowest water level(2) (ft. msl
234,000	Existing conditions	292,900	526,900	612
278,000	Release dependable yield	271,700	549,700	612
307,000	Release during drought period to maintain 612 elevation	233,000	540,000	612
263,000	Immediate recharge	327,800	590,800	612

(1) Average annual springflow based on period 1935 through 1956.
(2) Level at Well H-26 (Beverly Lodges Well).

In each case, Montell, Concan, and Sabinal Reservoirs are considered as the system of reservoirs modifying the natural recharge. As indicated in table 48, the high evaporation rate in this region prevents the efficient and effective recharge of the Edwards Reservoir by storage of floodwaters in permanent conservation pools thereby eliminating the first two plans listed in paragraph 78. The third method of operation would enable the development of maximum water resources at the dam sites with a minimum loss of the resources to evaporation. Studies were made of the effect on the underground water level of various systems of surface reservoirs to be constructed above the fault zone. The locations of the investigated surface reservoirs are shown on plate 4. Analyses of the benefits and costs of the investigated projects resulted in the recommendation of only three reservoirs for the modification of the recharge to the Edwards Reservoir. These projects, which are located on plate 13, are Montell Reservoir on the Nueces River, Concan Reservoir on the Frio River, and Sabinal Reservoir on the Sabinal River. Plate 44 indicates the effect

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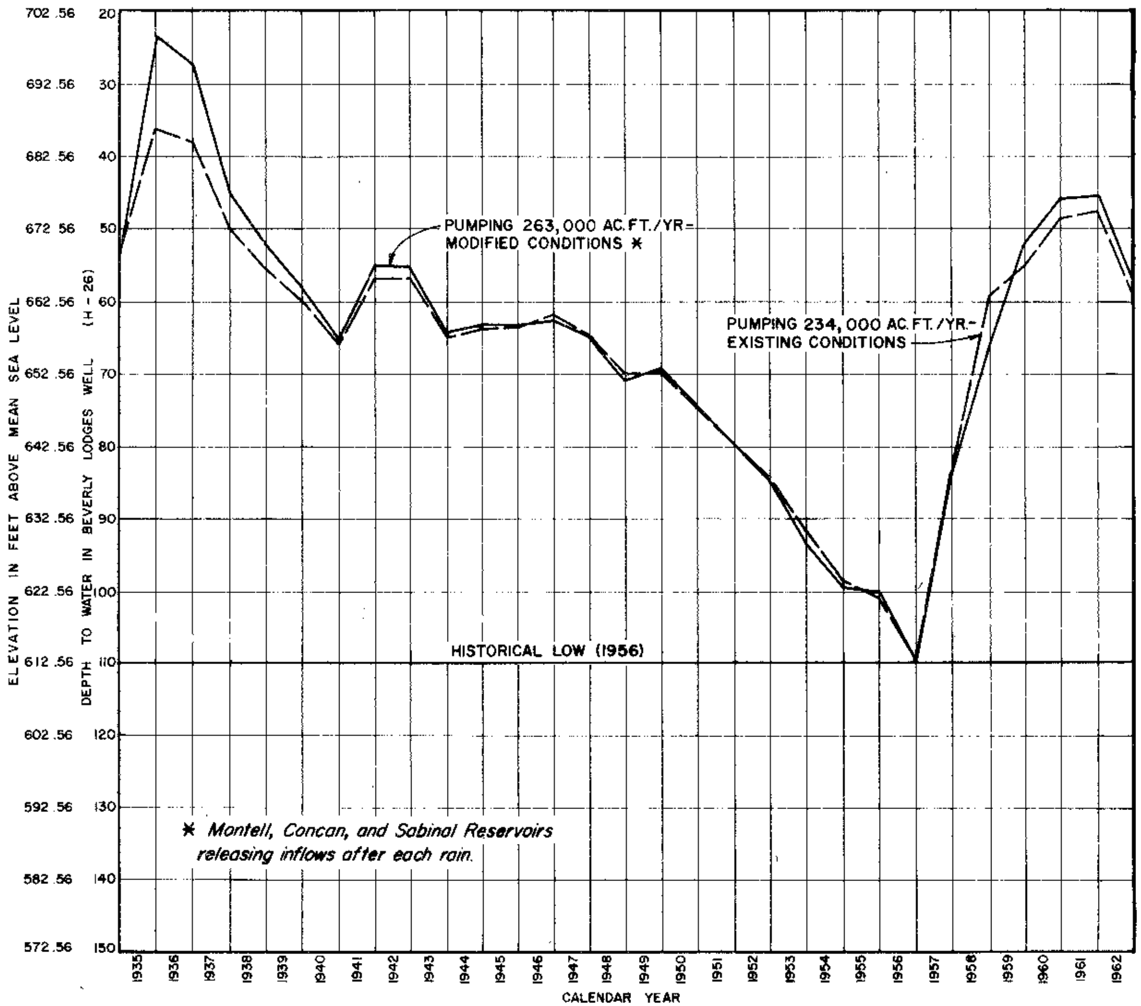

NOTE:
Both routings assume pumpage at constant rate through period 1935 - 1962.

EDWARDS UNDERGROUND RESERVOIR

COMPARISON OF UNDERGROUND WATER LEVELS RESERVOIR IN OPERATION

DEC. 1964 — PLATE 44

TABLE 49

PHYSICAL EFFECTS OF THE PLAN

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

* The annual resources, recharge and runoff (exclusive of springflow) at the lower edge of the Edwards outcrop are averages for the period 1935-56.
** The drainage area at lower edge of the Edwards outcrop, as indicated on plates 2 and 3.
*** Location of dam sites shown on plate 13.
(1) Reduced by estimated net inflow of 49,900 ac-ft/yr to Cloptin Crossing.
(2) Reduced by estimated net inflow of 171,900 ac-ft/yr to Dam No. 7 - Canyon Reservoir system.
(3) Using 16 SCS detention structures on Salado Creek (1962 Work Plan), for increase of 3,000 ac-ft/yr.
(4) Does not include approximately 45,200 ac-ft/yr combined loss to evaporation and use for irrigation.
(5) Does not include 4,300 ac-ft/yr (4 mgd) to be delivered to downstream areas.

on the Edwards Reservoir of this system of reservoirs by comparing underground reservoir levels and pumpage rates for the period 1935-1962. Several rates of constant pumpage were used in preliminary routings both with and without the recharge reservoirs in the system. The comparison presented, however, is only for those rates of pumpage which, for natural and modified conditions, reproduced the historic low level (elevation 612) for the underground reservoir. The plate indicates that under the stated conditions, the increase in average annual pumpage is 29,000 acre-feet. In addition, flow from the major springs was increased by an average of 34,900 acre-feet annually. Water levels in the underground reservoir will be higher with the surface reservoirs in the system for recharge purposes. Under the modified recharge conditions the water levels would range from 1 to 13 feet higher and would average 2 feet higher during the 1935-1956 period. Table 49 shows an estimated geographical distribution of the average annual recharge under natural conditions and the additional average annual recharge creditable to the recommended plan of improvement.

EFFECTS OF PLAN ON DOWNSTREAM RESERVOIRS

80. NUECES RIVER BASIN.

a. The master plan prepared by the Nueces River Conservation and Reclamation District includes the proposed construction of Concan and Sabinal Reservoirs on the Frio and Sabinal Rivers, respectively, for recharge of the Edwards Underground Reservoir. The District has indicated that these recharge projects would have only a negligible effect on downstream water rights. The master plan also recommends construction of the Tom Nunn Hill and the Cotulla Reservoirs and the enlargement of Wesley Seale Reservoir. It was recommended in the master plan that Tom Nunn Hill and Cotulla Reservoirs be constructed with conservation capacities of 50,000 and 300,000 acre-feet, respectively, and that the conservation storage capacity in the existing Wesley Seale Reservoir be enlarged from 300,000 to 500,000 acre-feet. The reservoirs included in the master plan are located on plate 1.

b. The plan of development for the Edwards Reservoir area has been formulated in consonance with the improvements proposed in this master plan. Although Montell Reservoir is proposed in lieu of Tom Nunn Hill Reservoir, storage in the Montell project, with the channel dam and pipeline facilities included, would furnish to the Reclamation District the dependable yield of the Tom Nunn Hill project. The dependable yield for Tom Nunn Hill Reservoir has been estimated to be 4,300 acre-feet per year (6 second-feet). To obtain a yield of 4,300 acre-feet per year from Montell Reservoir a net conservation storage of 1,000 acre-feet has been recommended. In addition, substituting Montell Reservoir in the Tom Nunn Hill-Cotulla-Wesley Seale Reservoir system for Tom Nunn Hill Reservoir would not have an adverse effect on the yield of Wesley Seale Reservoir.

c. Examination of the resources of the Cotulla Reservoir indicates that under natural conditions the Nueces River loses large quantities of water to the Edwards Underground Reservoir as the stream crosses the outcrop of the Edwards limestone in the Balcones Fault zone. In addition, the river loses flow to the alluvial gravels and sand formations downstream from the fault zone. It is estimated that under existing conditions, flow occurring at the Montell Dam site at the rate of 14,000 acre-feet per month would be lost in transit through the fault zone and the gravel and sand formations downstream from the fault zone, and no part of such flow would reach the Cotulla Reservoir. Similarly, it is estimated that under natural conditions a flow of 60,000 acre-feet per month at the Montell Dam site would be reduced to only 10,000 acre-feet at the Cotulla site. It is estimated that if Tom Nunn Hill Reservoir had been in operation during the critical drought period, 1947-1956, the September 1955 storm would have produced the only runoff in the upper basin during this period which would have reached the Cotulla Reservoir. It is estimated that the flow reaching Cotulla Reservoir would have been approximately 16,100 acre-feet. If Montell Reservoir were constructed in lieu of Tom Nunn Hill Reservoir, this flow would not have reached the Cotulla Reservoir. It is considered, however, that the probability of the recurrence of a flood of the magnitude of the September 1955 flood (largest for peak discharge since 1854) during some future critical drought period is so remote that it should be disregarded in establishing reservoir size or yield. This flood was produced from a storm centered over a small area in the upper Nueces River Basin. If this flood were disregarded, construction of Montell Reservoir in lieu of Tom Nunn Hill Reservoir would not have an adverse effect on the yield of either of the two downstream reservoirs as presented in the master plan.

81. GUADALUPE RIVER BASIN.

a. The plan of development for the Guadalupe River Basin is set forth in the "Supplement to the Initial Plan of Development of the Guadalupe-Blanco River Authority," dated May 1961. This master plan provides for the construction of Cloptin Crossing Reservoir, but at a smaller size than that recommended in this report. The master plan also provides for construction of Dam No. 7 Reservoir in case excessive leakage is experienced at Canyon Reservoir; however, it would provide less storage than the project recommended in this report. The locations of the reservoirs included in the master plan are shown on plate 1.

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

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

82. GENERAL.- A study was made of the Edwards Underground Reservoir watershed to determine the hydraulic characteristics under existing conditions, and for various plans of improvement which would alleviate flooding and increase ground water recharge and water conservation.

83. WATER-SURFACE PROFILES - EXISTING CONDITIONS.- Backwater studies of selected water courses in the survey area were made to establish water-surface profiles, limits of flooding, and channel capacities under existing conditions. The backwater computations were based on the Manning formula in accordance with paragraph 10 of EM 1110-2-1409, 7 Dec 1959, using coefficients of roughness, n, of 0.035 to 0.050 for the existing channels and 0.060 to 0.100 for the existing overbanks. The studies were correlated with high-water data and stream-gaging station records. Plates 45 through 52 show the profiles of the major rivers and creeks in the Edwards area and their historical high-water profiles, which are based on high-water marks, stream-gaging records, and available historical information.

84. PLAN OF IMPROVEMENT.- Possible damsites, individually and in conjunction with other sites, and related pipeline distribution systems were investigated. The recommended plan of improvement would consist of two multiple-purpose reservoirs, Montell and Cloptin Crossing; two recharge and flood-control reservoirs, Concan and Sabinal, to be constructed by the Federal Government, and one conservation-only reservoir, Dam No. 7, to be constructed by local interests. Also in conjunction with Montell Dam, there would be a channel dam and pipeline to convey low-flow discharges from Montell Reservoir across a downstream loss zone.

85. MONTELL DAM-SPILLWAY.- The Montell Dam would be located on the Nueces River at river mile 401.6, with the spillway in the left bank. The spillway would consist of a 960-foot uncontrolled broadcrested weir with crest at elevation 1331.0. Details of the dam and spillway are shown on plate 53. Under conditions of the spillway design discharge (570,600 second-feet), the reservoir would be at elevation 1366.0. The spillway rating curve, adjusted for approach losses, is shown on figure 2, plate 54.

86. MONTELL DAM-OUTLET WORKS.- The flood-control outlet works would consist of a 15-foot diameter conduit controlled by three 5-foot, 8-inch by 12-foot tractor-type gates. The conduit would be located in the main embankment, with inlet invert at elevation 1216.0 and outlet invert at elevation 1214.0, as shown on plate 53. The outlet works would be used for diversion during construction, for the passage of flood releases, and for the passage of low-flow discharges. The capacity of the conduit with the reservoir water surface level at

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top of conservation pool, elevation 1237.0, and at maximum design water surface, elevation 1366.0, would be about 3,400 second-feet and 10,400 second-feet, respectively. Figure 1, plate 54 shows the rating curve for the outlet works.

87. MONTELL DAM - TAILWATER RATING CURVE.- The tailwater rating curve at the Montell Dam site is shown on figure 3, plate 54. This rating curve was developed by slope-area computations at the dam site.

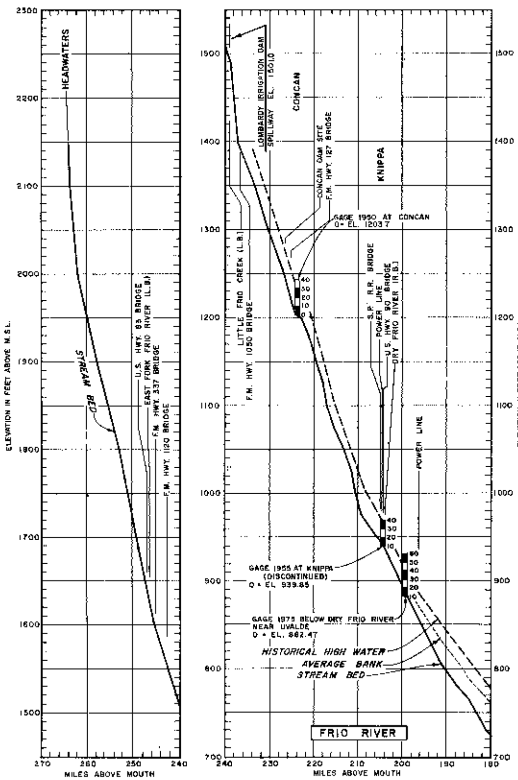
88. CONCAN DAM - SPILLWAY.- The Concan Dam would be located on the Frio River at river mile 226.2, with the spillway in a saddle on the right bank. The spillway would consist of a 1,030-foot uncontrolled broadcrested weir with crest at elevation 1366.5. Details of the dam and spillway are shown on plate 55. Under conditions of the spillway design discharge (425,300 second-feet), the reservoir would be at elevation 1394.2. The spillway rating curve, adjusted for approach losses, is shown on figure 2, plate 56.

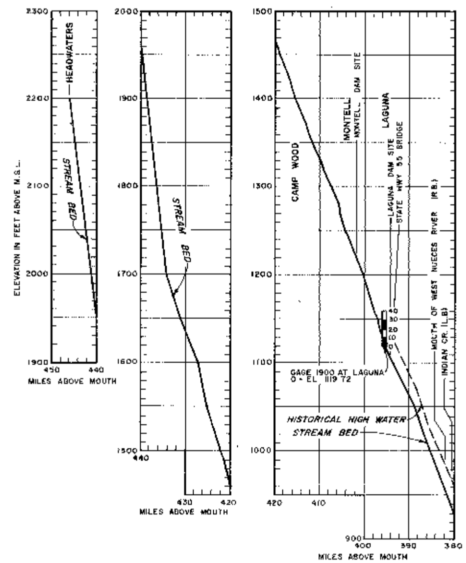
89. CONCAN DAM - OUTLET WORKS.- The outlet works would consist of a 13-foot diameter conduit controlled by two 6-foot by 13-foot tractor-type gates. The conduit would be located in the main embankment, with inlet invert at elevation 1240.0 and outlet invert at elevation 1238.0, as shown on plate 55. The outlet works would be used for diversion during construction and for passage of flood-control releases. The capacity of the conduit with reservoir water surface level at spillway crest, elevation 1366.5, and at maximum design water surface, elevation 1394.2, would be about 8,000 second-feet and 7,700 second-feet, respectively. The outlet works rating curve is shown on figure 1, plate 56.

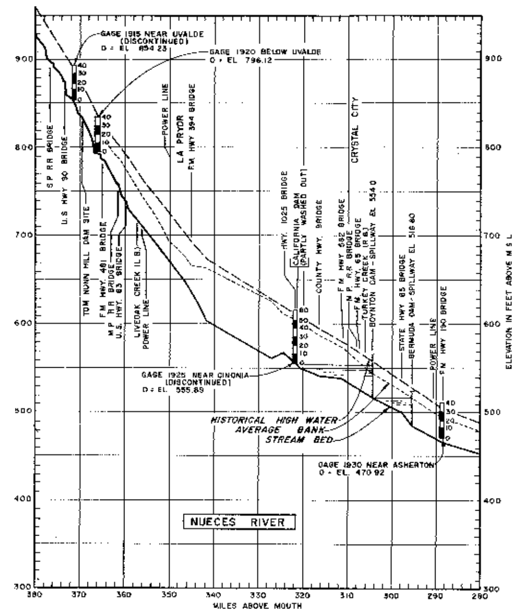
90. CONCAN DAM - TAILWATER RATING CURVE.- The tailwater rating curve at the damsite is shown on figure 3, plate 56. The tailwater rating curve was developed by backwater methods from the U. S. Geological Survey stream-gaging station Number 081950 on the Frio River at Concan, Texas, 2.1 miles downstream from the dam site, and extended by slope-area computations to encompass the spillway design discharge.

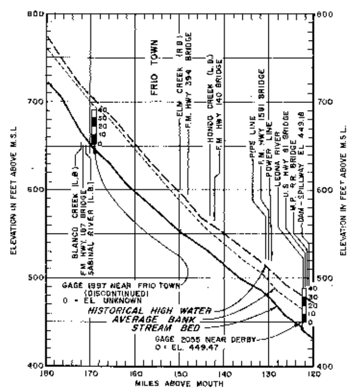
91. SABINAL DAM - SPILLWAY.- The Sabinal Dam would be located on the Sabinal River at river mile 42.3, with a gated spillway adjacent to the river channel. The spillway would consist of a 240-foot ogee weir with crest at elevation 1196.5, controlled by six 40- by 30-foot tainter gates separated by five 8-foot piers. Details of the dam and spillway are shown on plate 57. Under conditions of the spillway design discharge (270,600 second-feet), the reservoir water surface level would be at elevation 1238.8. Figure 2, plate 58 shows the rating curve for the spillway.

92. SABINAL DAM - OUTLET WORKS.- The outlet works would consist of two 3-foot by 6-foot conduits located in two gate piers.









NOTES:

Abbrevations L.B. and R.B. refer to left and right bank, respectively.
High-water profiles depict maximum known water surface levels.
Gage numbers refer to U.S.G.S. permanent numbering system.
Add prefix 08. to gage number to obtain complete number.
Profile data from Corps of Engineers survey.

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

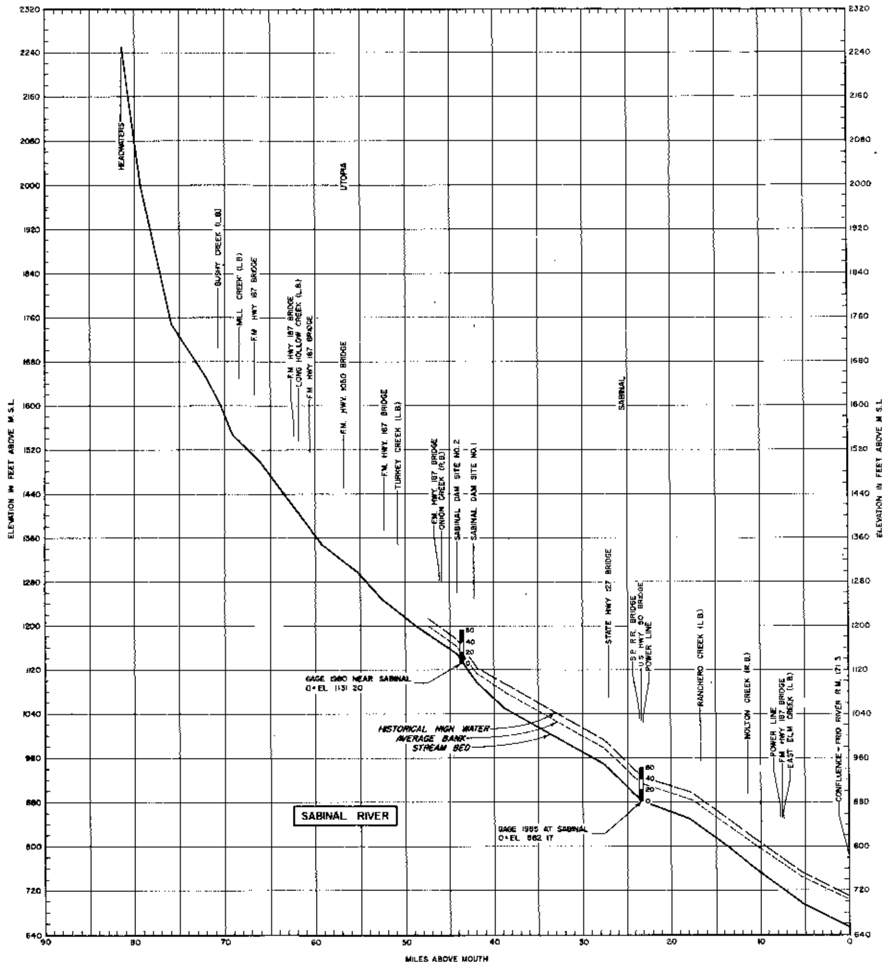
NUECES RIVER AND TRIBUTARIES

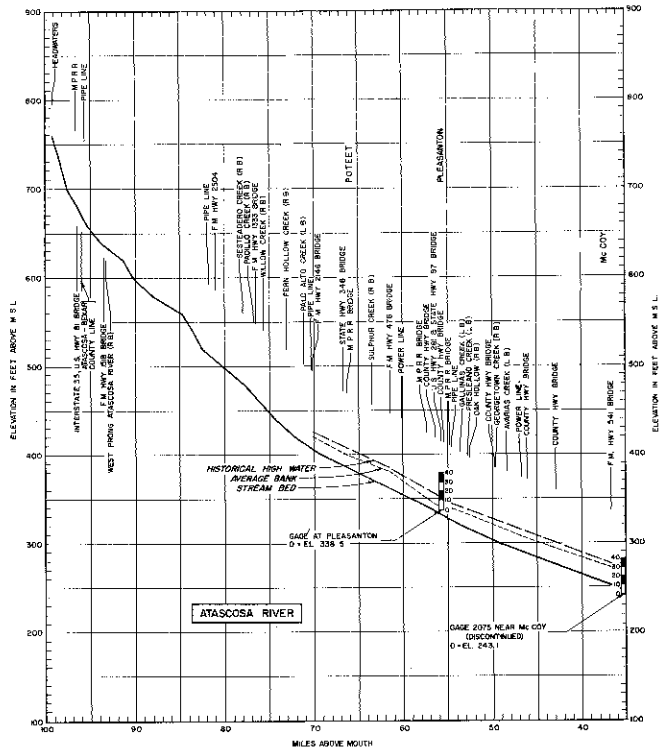
PROFILES

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: ENGINEER, CHIEF, GEN. INVESTIGATIONS SECTION
DRAWN BY B.G.S.
CHECKED BY D.T.K.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD.707-2





NOTES:

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High-water profiles depict maximum known water surface levels.
Gage numbers refer to U.S.G.S. permanent numbering system.
Add prefix 08 to number to obtain complete gage number.
Sabinal River profile data obtained from A.M.S. maps, and stream gaging stations. Atascosa River data obtained from C of E. Survey.

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

NUECES RIVER TRIBUTARIES

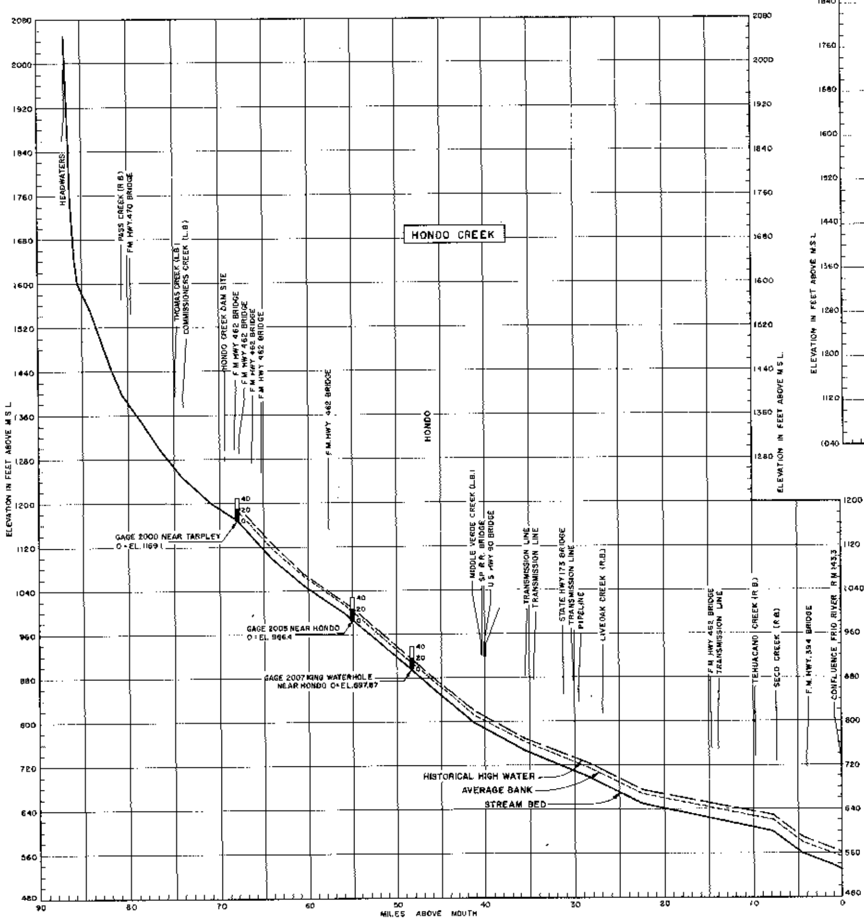
PROFILES

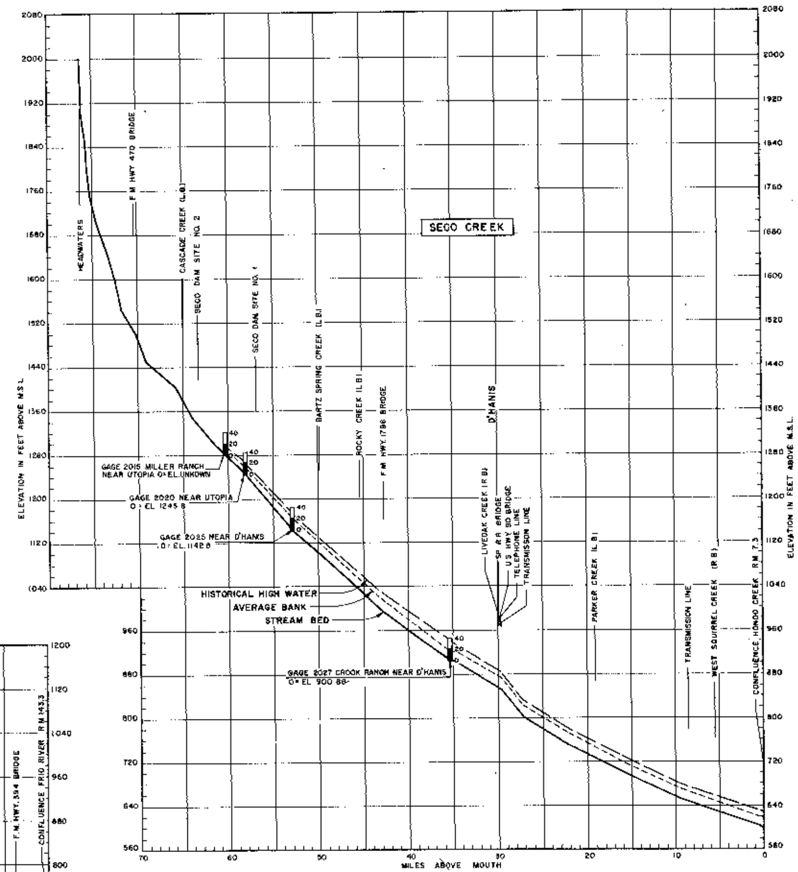
SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
Chief, Project Planning Branch	Chief, Engineering Division	District Engineer
PREPARED — Chief, Gen. Investigations Section	DRAWN BY T.L.W. / CHECKED BY D.T.K.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD 707-2

CORPS OF ENGINEERS U.S. ARMY





NOTES.

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High-water profiles depict maximum known water surface levels. Gage numbers refer to U.S.G.S. permanent numbering system.

Add prefix 08. to number to obtain complete Gage number. Profile data obtained from A.M.S. maps and stream gaging stations.

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

NUECES RIVER TRIBUTARIES

PROFILES

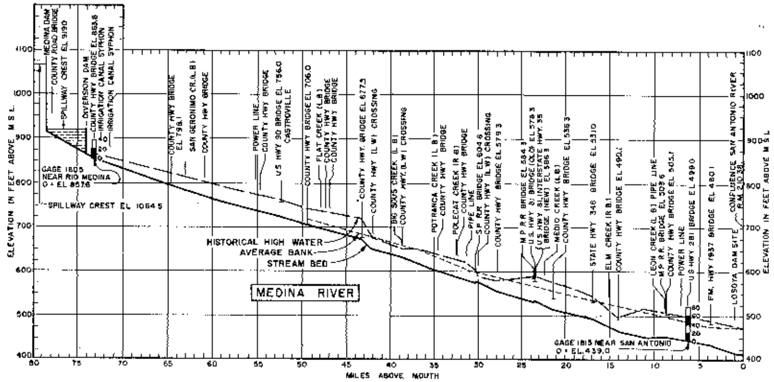
SCALE AS SHOWN

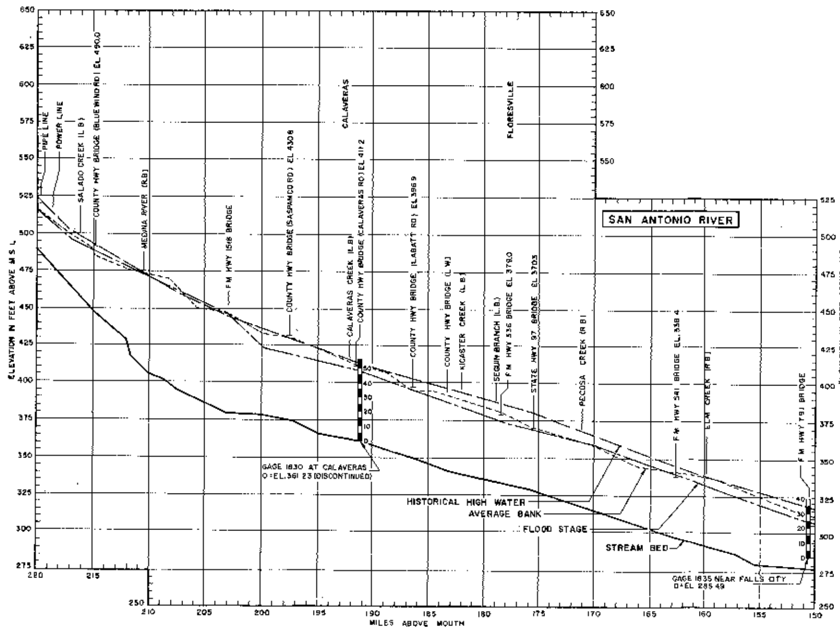
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964

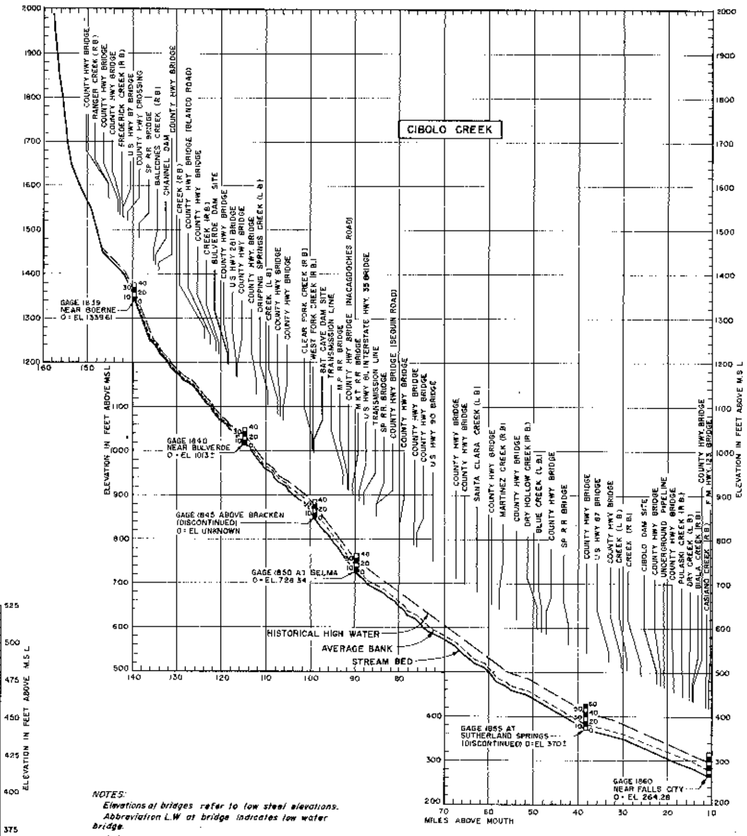
SUBMITTED	APPROVAL RECOMMENDED	APPROVED
ENGINEER, CHIEF, PROJECT PLANNING BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	COL. CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF, GEN. INVESTIGATIONS SECTION	DRAWN BY J.L. CHECKED BY D.T.K.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR. FILE: GUAD. 707-2

PLATE 47

CORPS OF ENGINEERS U.S. ARMY







NOTES:

Elevations of bridges refer to low steel elevations.

Abbreviation L.W. at bridge indicates low water bridge.

Abbreviations L.B. and R.B. refer to left bank and right bank, respectively.

High-water profiles depict maximum known water surface levels.

Gage numbers refer to U.S.G.S. permanent numbering system. Add prefix 08 to number to obtain complete number.

San Antonio and Medina River profiles are from C of E. surveys.

Cibolo Creek profile data are from U.S.G.S. and A.M.S. maps, and stream gaging stations.

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

SAN ANTONIO RIVER AND TRIBUTARIES

PROFILES

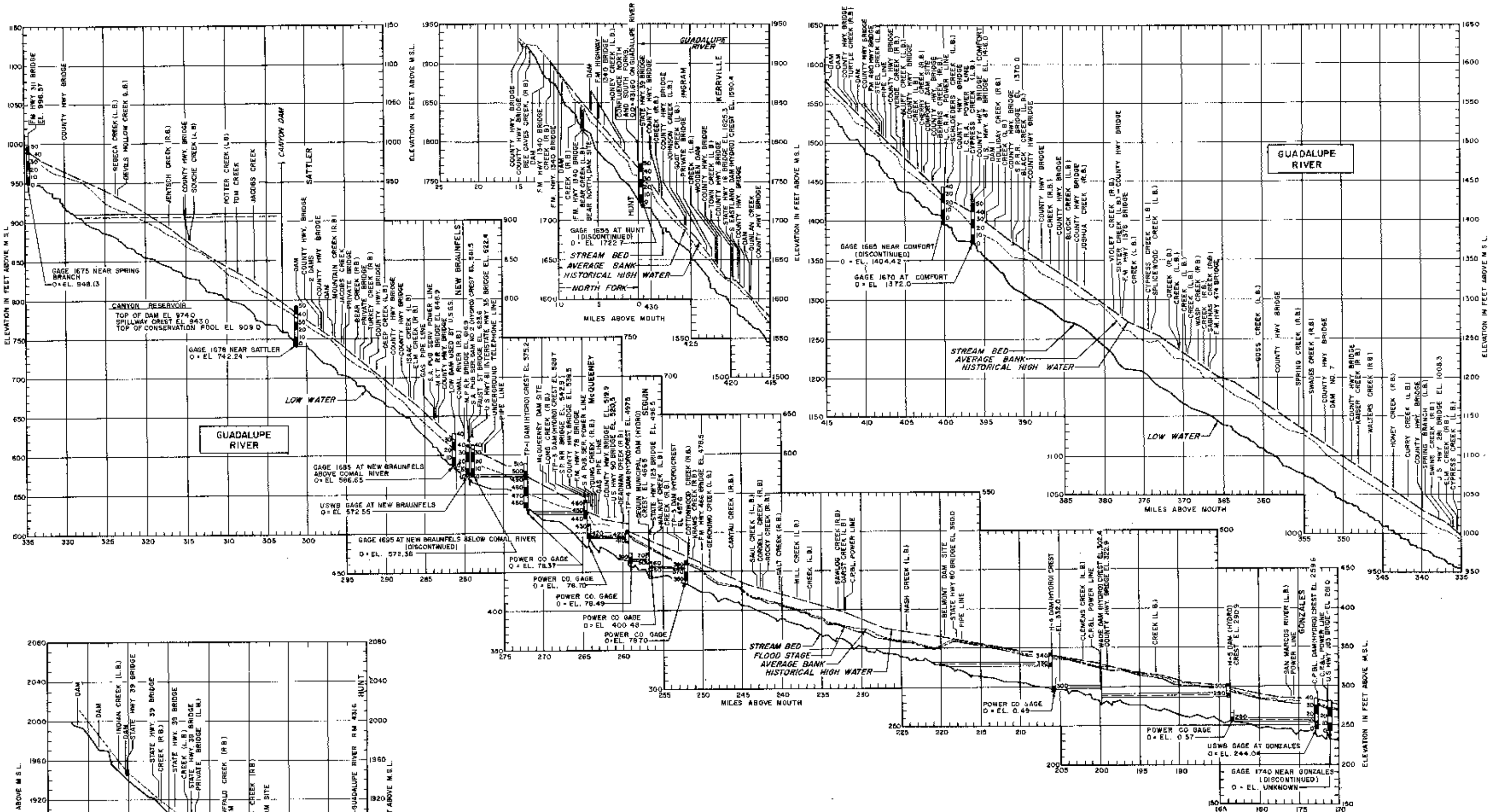
SCALE AS SHOWN

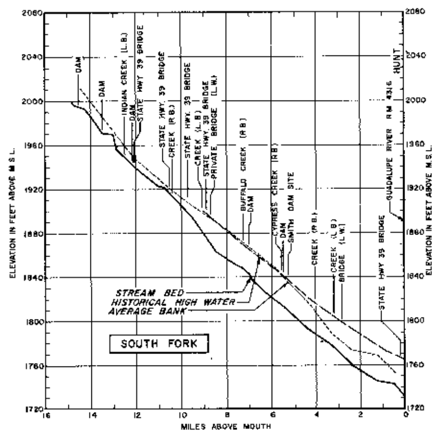
U.S. ARMY ENGINEER DISTRICT, FORT WORTH — DEC. 1964

SUBMITTED — APPROVAL RECOMMENDED — APPROVED

PREPARED — DRAWN BY J.C. — CHECKED BY D.T.K.

FILE GUAD 707-2





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NOTES:

Elevations at bridges refer to low steel elevations.
L.W. at bridge indicates low water bridge L.B and RB are abbreviations for left bank and right bank, respectively.
High-water profiles depict maximum known water surface levels.
Gage numbers refer to U.S.G.S. permanent numbering system.
Add prefix O8, to number shown to obtain complete gage number.
Mile 170.00 to mile 281.05 & mile 367.46 to mile 14.92 (North Fork), show stream bed profile.
Mile 281.06 to mile 367.46, show low water profile.
Corps of Engineers - 1935 and 1939 survey data, Central Power & Light Company Data.
Texas Power & Light Co. - 1928 survey data was used to supplement the water surface data obtained by the Corps of Engineers field party from miles 367.0 to miles 419.0.

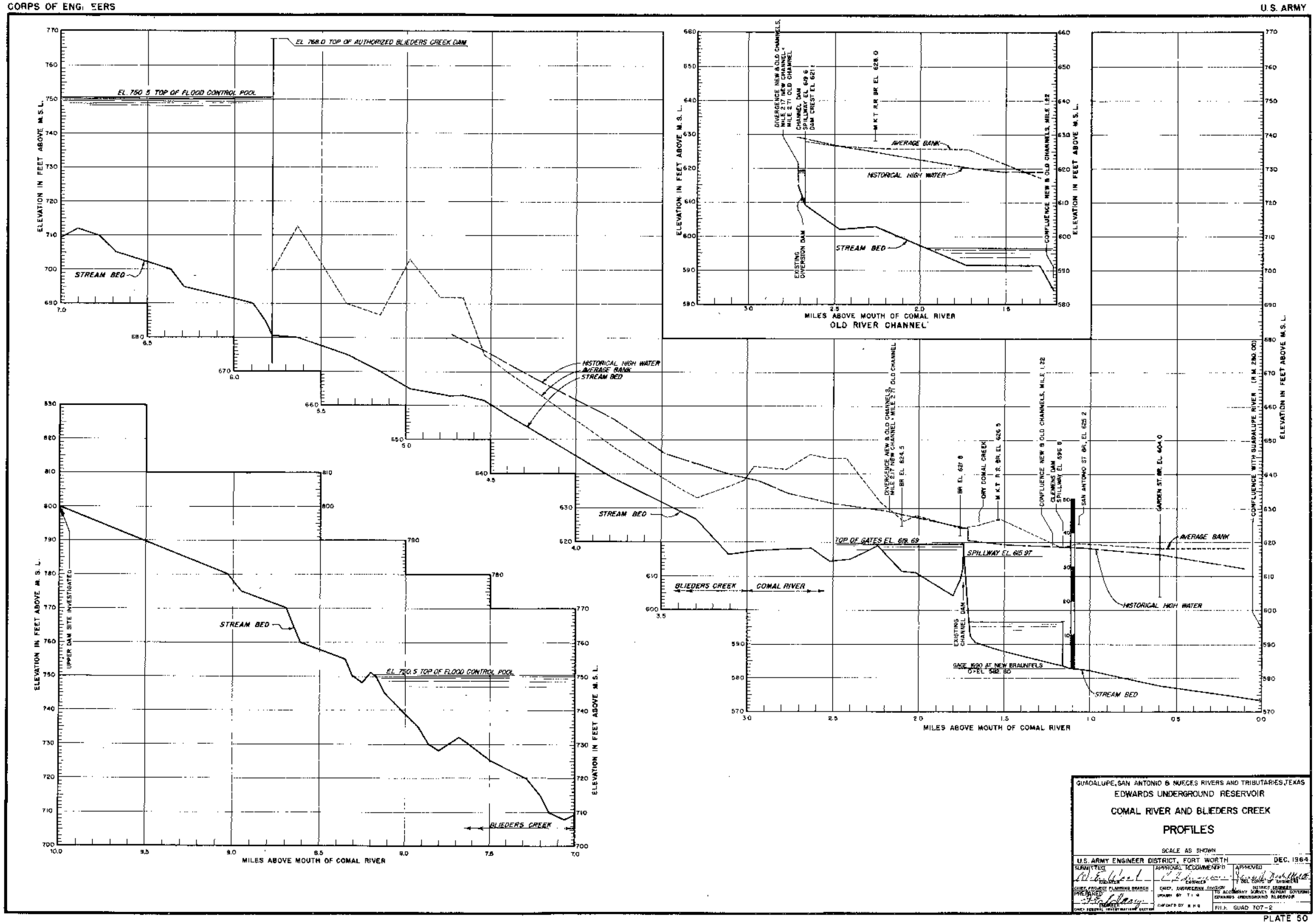
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE RIVER

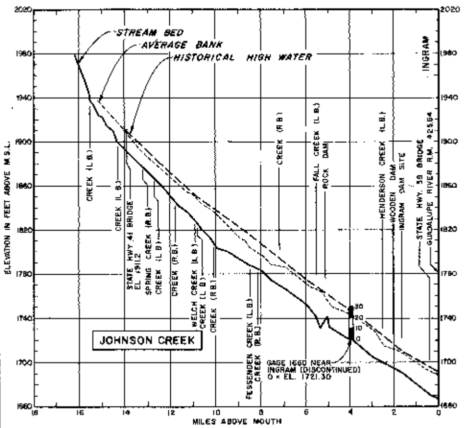
PROFILES

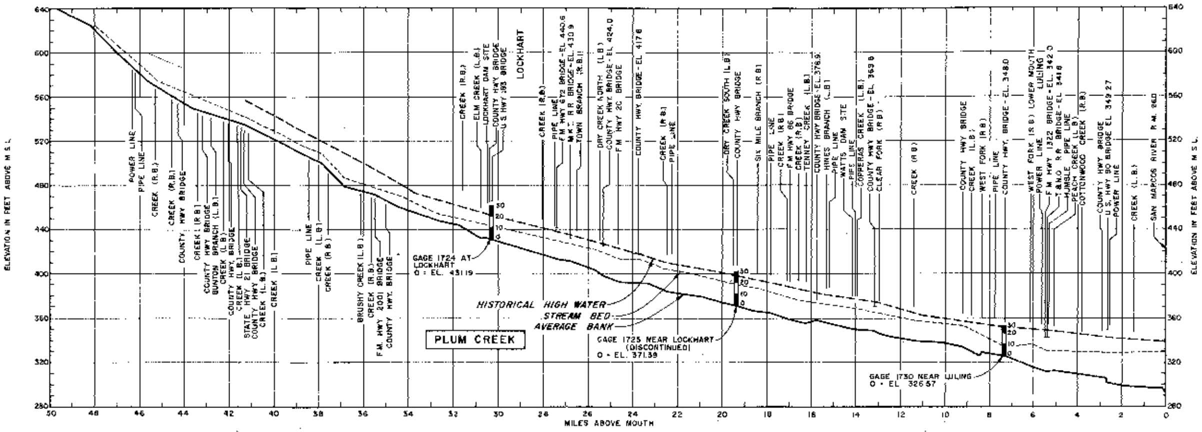
SCALE AS SHOWN

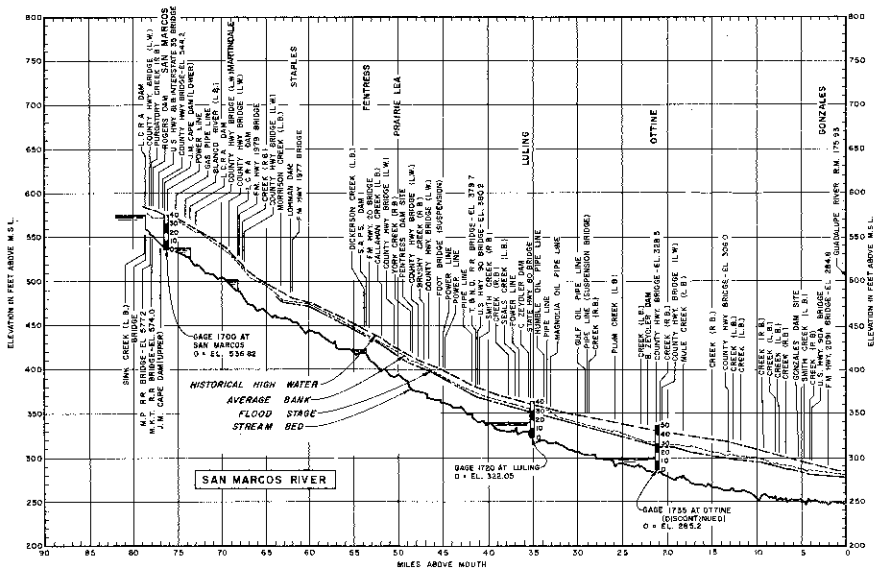
U.S ARMY ENGINEER DISTRICT, FORT WORTH — DEC. 1964

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
[signature] ENGINEER, CHIEF, PROJECT PLANNING BRANCH	[signature] ENGINEER, CHIEF, ENGINEERING DIVISION	[signature] COL CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED [signature] ENGINEER, CHIEF, GEN. INVESTIGATIONS SECTION	DRAWN BY B.O.S. / CHECKED BY D.T.K.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2


EL. 768.0 TOP OF AUTHORIZED BLIEDERS CREEK DAM
EL. 750.5 TOP OF FLOOD CONTROL POOL
STREAM BED
ELEVATION IN FEET ABOVE M.S.L.
HISTORICAL HIGH WATER
AVERAGE BANK
STREAM BED
DIVERGENCE NEW & OLD CHANNELS, MILE 2.17 NEW CHANNEL - MILE 2.71 OLD CHANNEL
CHANNEL DAM SPILLWAY EL. 619.6 DAM CREST EL. 621
M.K.T. R.R. BR. EL. 628.0
EXISTING DIVERSION DAM
CONFLUENCE NEW & OLD CHANNELS, MILE 1.22
MILES ABOVE MOUTH OF COMAL RIVER
OLD RIVER CHANNEL
BR. EL. 624.5
BR. EL. 627.8
DRY COMAL CREEK
M.K.T. R.R. BR. EL. 626.5
CLEMENS DAM SPILLWAY EL. 596.8
SAN ANTONIO ST. BR. EL. 625.2
GARDEN ST. BR. EL. 604.0
CONFLUENCE WITH GUADALUPE RIVER (R.M. 280.00)
TOP OF GATES EL. 618.69
SPILLWAY EL. 615.97
BLIEDERS CREEK
COMAL RIVER
EXISTING CHANNEL DAM
GAGE 1690 AT NEW BRAUNFELS 0=EL. 582.80
UPPER DAM SITE INVESTIGATED
EL. 750.5 TOP OF FLOOD CONTROL POOL
BLIEDERS CREEK
MILES ABOVE MOUTH OF COMAL RIVER
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
COMAL RIVER AND BLIEDERS CREEK
PROFILES
SCALE AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC. 1964
FILE: GUAD 707-2







NOTES:

Elevations of bridges refer to low steel elevations.
Abbreviation L.W. of bridge indicates low water bridge.
Abbreviations L.B. and R.B. refer to left bank and right bank respectively.
High-water profiles depict maximum known water surface levels.
Gage numbers refer to U.S.G.S. permanent numbering system. Add prefix 08. to number to obtain complete number.
Profile data from Corps of Engineers survey.

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

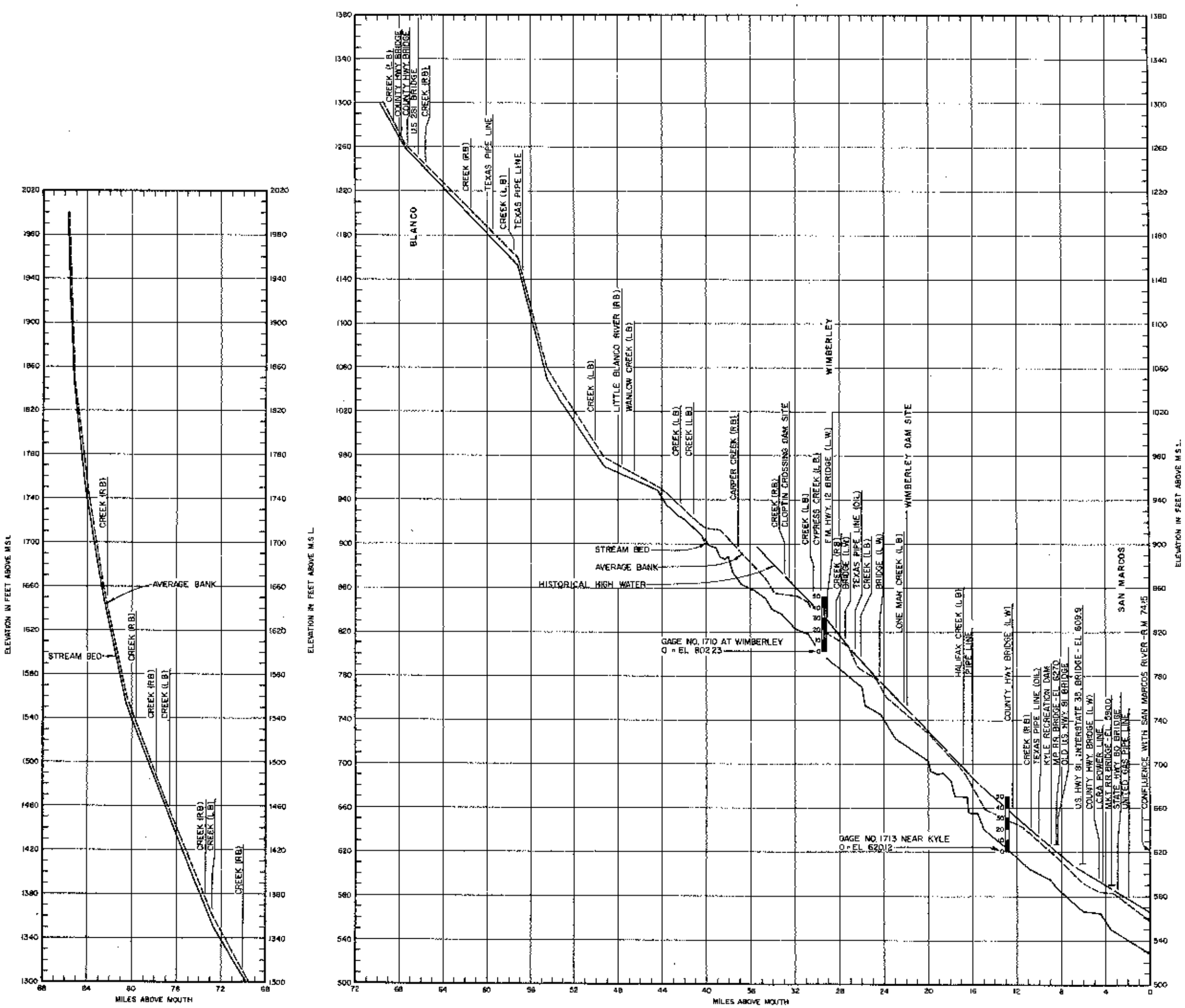
GUADALUPE RIVER TRIBUTARIES

PROFILES

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], LT COL CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: [signature], ENGINEER, CHIEF, GEN. INVESTIGATIONS SECTION	DRAWN BY B.S.S. / CHECKED BY D.T.K.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2



NOTES
1. *Abbreviation (L.W) at bridge indicates low water bridge.*
2. *Elevations at bridges refer to low steel elevations*
3. *High-water profile depicts maximum known water surface levels.*
4. *Abbreviations (L.B) and (R.B) refer to left bank, and right bank, respectively*
5. *Profiles above mile 44 from U.S.G.S quadrangle sheets*
6. *Profiles below mile 44 from Corps of Engineer survey.*

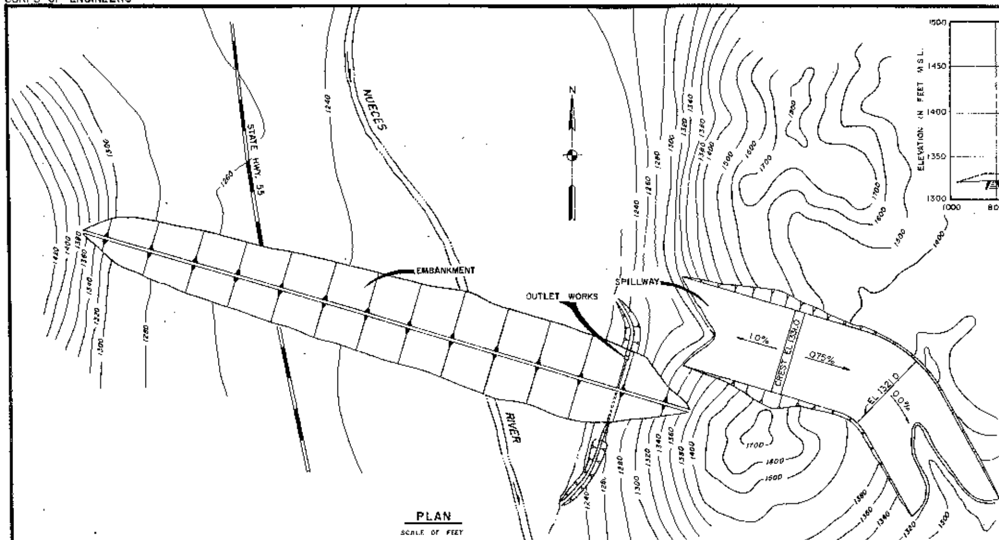
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER
PROFILES

SCALES AS SHOWN

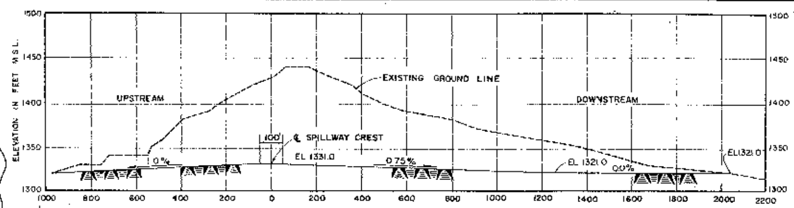
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC. 1964

SUBMITTED / APPROVAL RECOMMENDED / APPROVED

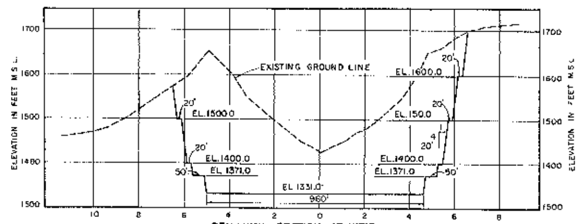
FILE GUAD 707-2



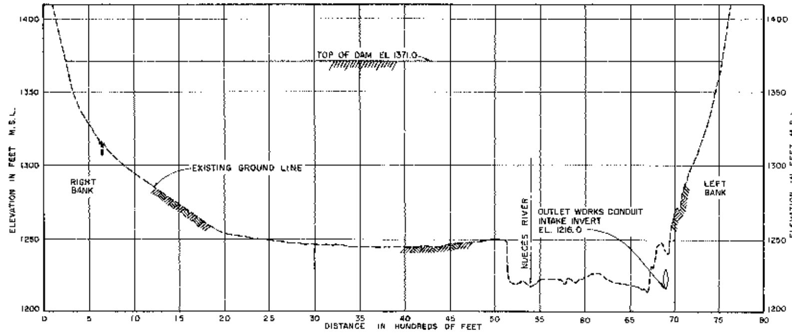
PLAN



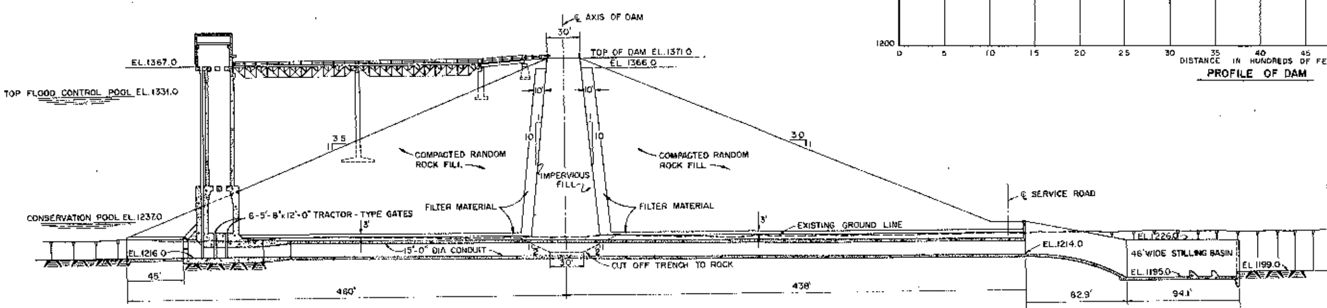
SPILLWAY PROFILE



SPILLWAY SECTION AT WEIR



PROFILE OF DAM



EMBANKMENT SECTION - OUTLET WORKS PROFILE

NOT TO SCALE

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

PLAN, PROFILES AND SECTIONS

MONTELL DAM SITE

SCALES AS SHOWN

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

SUBMITTED: W. E. Wood — CHIEF, PLANNING & REPORTS BRANCH
APPROVAL RECOMMENDED: C. F. Sussman — CHIEF, ENGINEERING DIVISION
APPROVED: DISTRICT ENGINEER
CHIEF, CIVIL ENGINEERING SECTION
DRAWN BY: S.M.F. CHECKED BY: W.R.B.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD.707-2

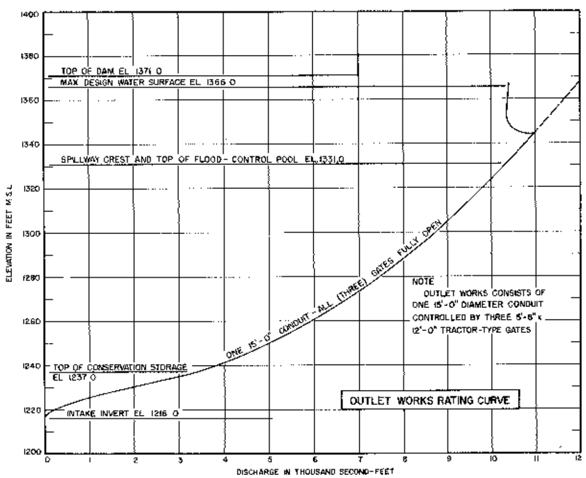


FIG. 1

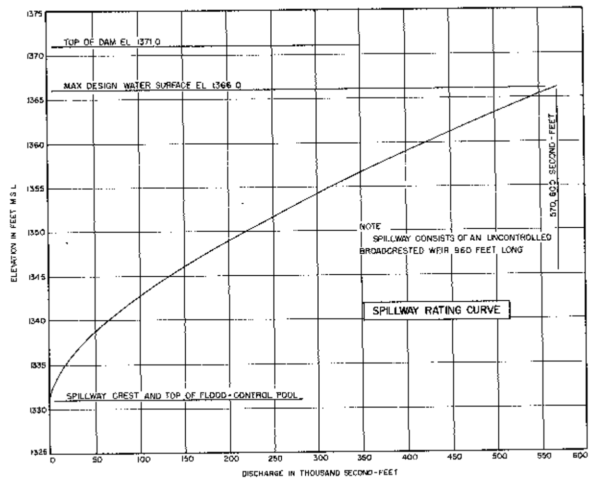


FIG. 2

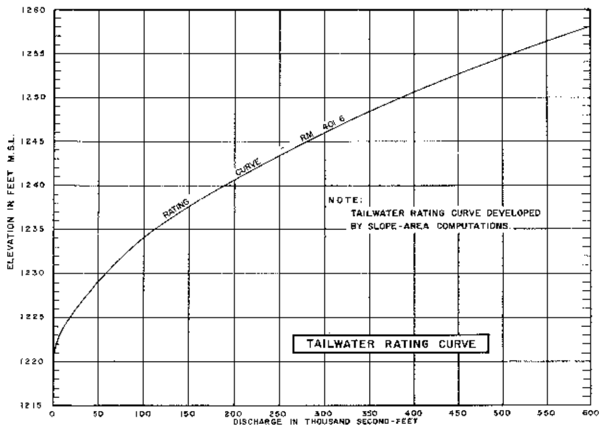
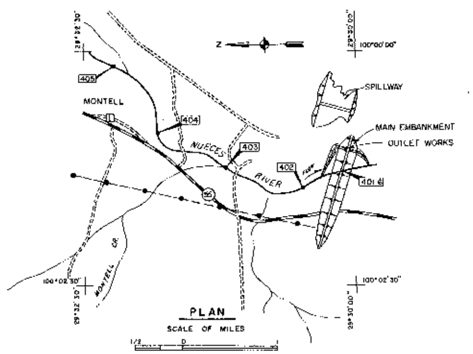


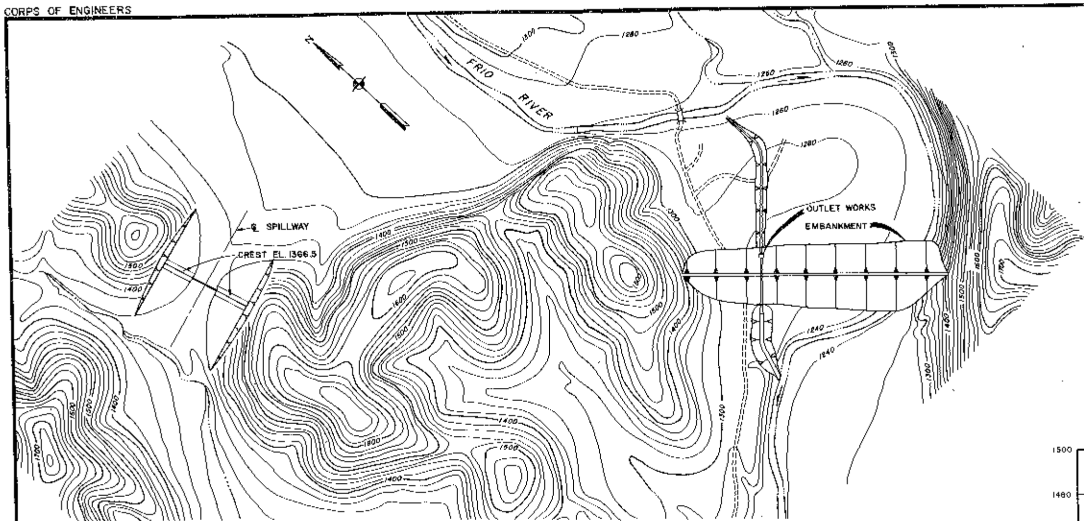
FIG. 3



GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
NUECES RIVER
GENERAL HYDRAULIC DATA
MONTELL DAM AND RESERVOIR
SCALES AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC 1964

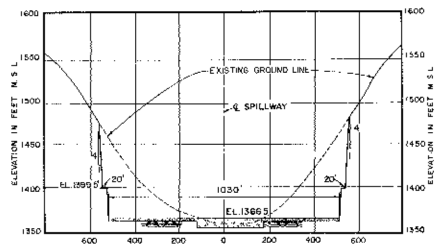
U.S. ARMY CORPS OF ENGINEERS

143

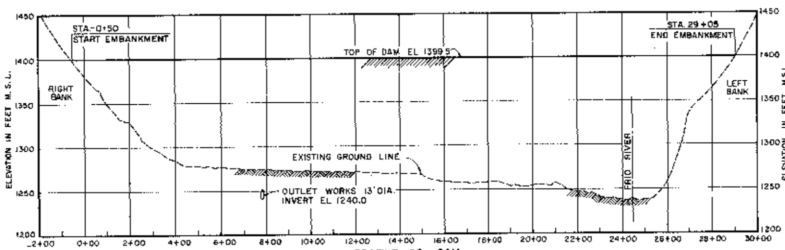


PLAN

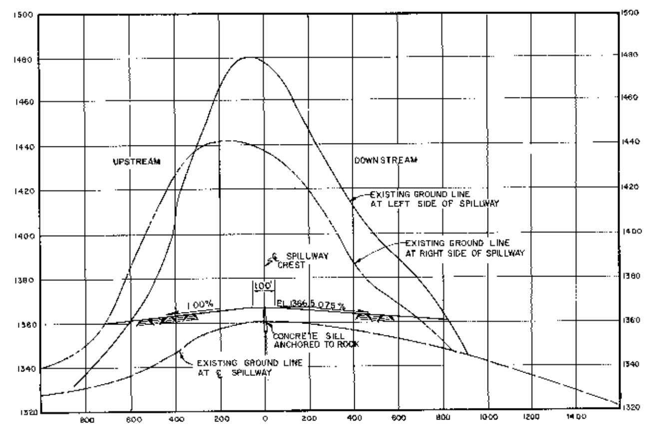
SCALE OF FEET 500 0 500 1000



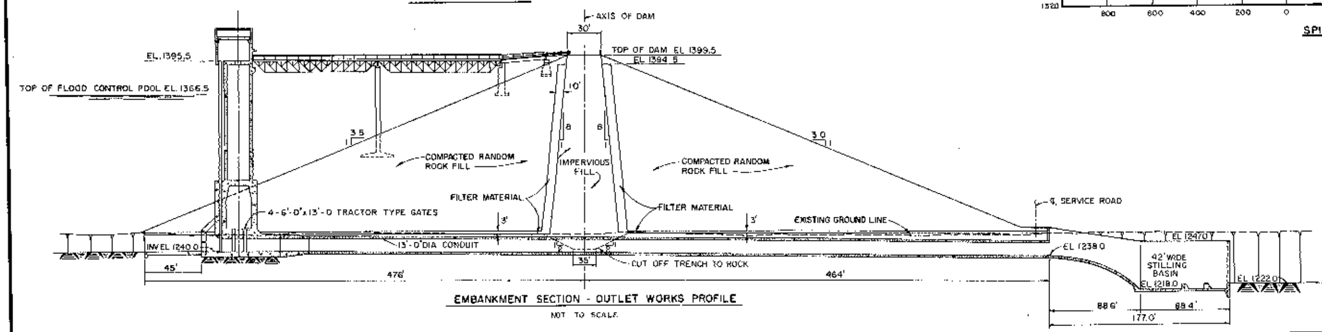
SPILLWAY SECTION AT WEIR



PROFILE OF DAM



SPILLWAY PROFILE



EMBANKMENT SECTION - OUTLET WORKS PROFILE

NOT TO SCALE

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

PLAN, PROFILES AND SECTIONS
CONCAN DAM SITE

SCALES AS SHOWN

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

SUBMITTED ... APPROVAL RECOMMENDED ... APPROVED

FILE GUAD. 707-2

PLATE 55

CORPS OF ENGINEERS

U.S. ARMY

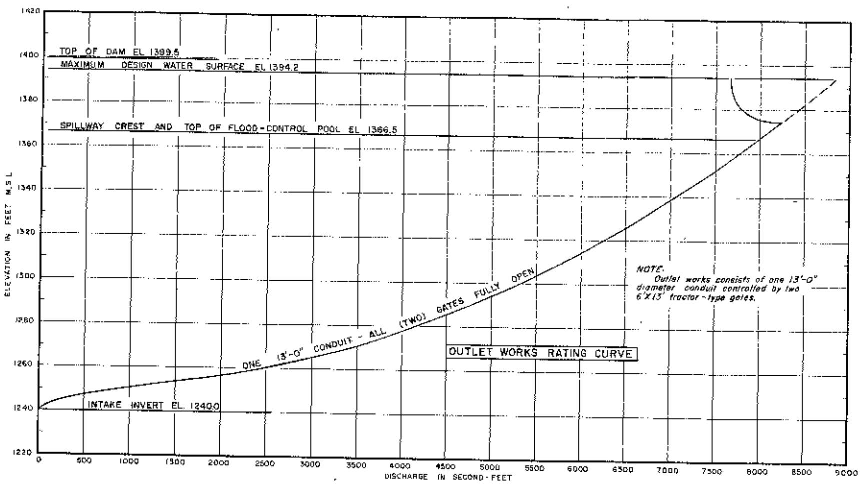
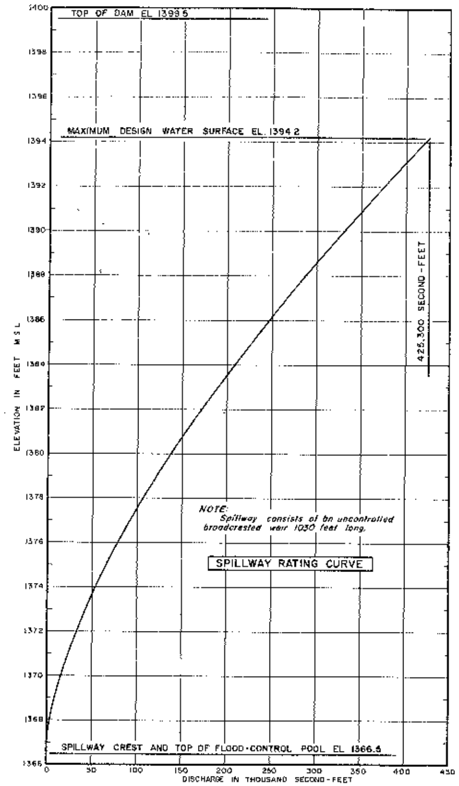


FIG. 1



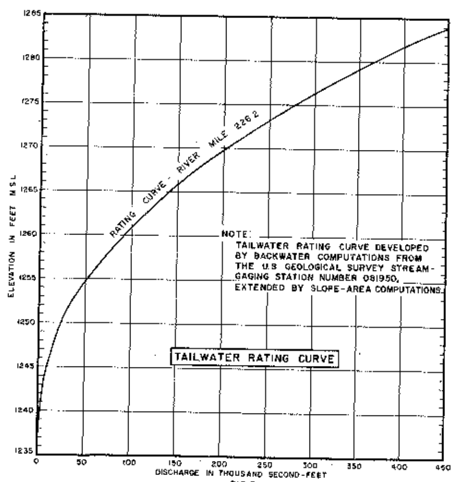
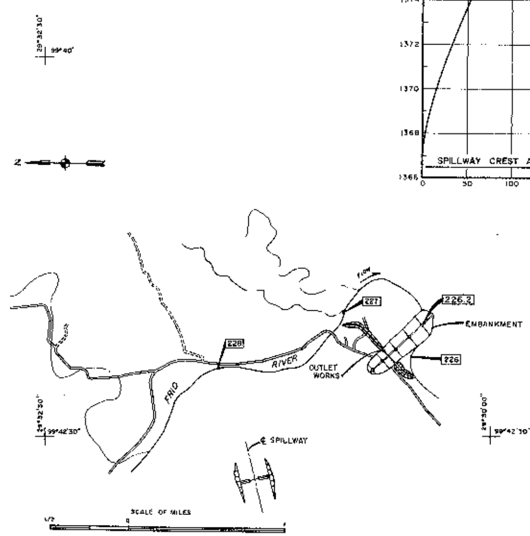


FIG. 3



PLAN

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

GENERAL HYDRAULIC DATA

CONCAN DAM AND RESERVOIR

SCALES AS SHOWN

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

SUBMITTED | APPROVAL RECOMMENDED | APPROVED

CHIEF, PROJECT PLANNING BR. | CHIEF, ENGINEERING DIVISION | DISTRICT ENGINEER

PREPARED | DRAWN BY J.C.-&W.F. | CHECKED BY D.T.K.

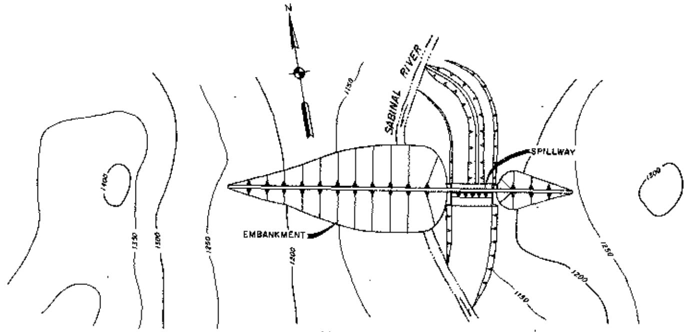
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD 707-2

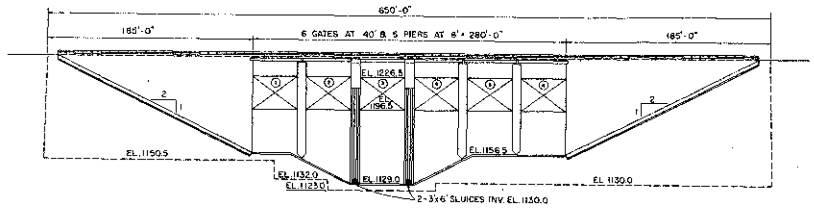
PLATE 56

CORPS OF ENGINEERS

U.S. ARMY

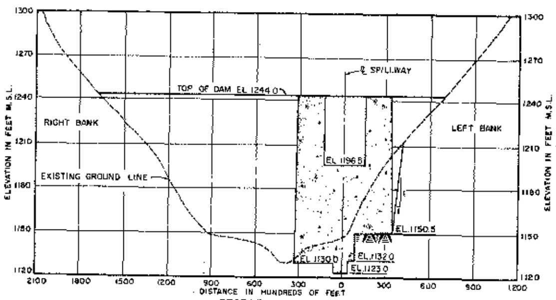


PLAN

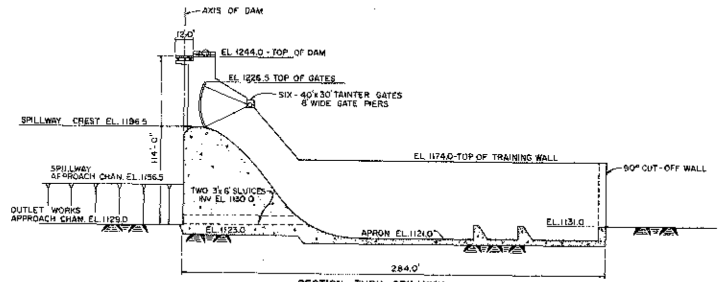


UPSTREAM ELEVATION OF SPILLWAY

SCALE: 1 INCH = 40 FEET

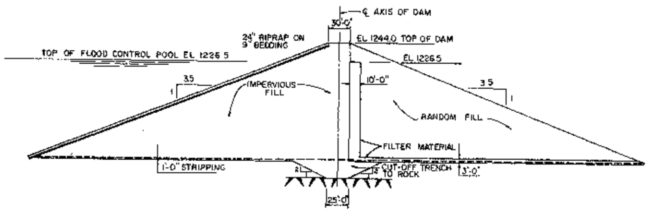


PROFILE OF DAM



SECTION THRU SPILLWAY

SCALE: 1 INCH = 30 FEET



SECTION THRU EMBANKMENT

NOT TO SCALE

GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

SABINAL RIVER

PLAN, PROFILES AND SECTIONS

SABINAL DAM SITE

SCALES AS SHOWN

U.S. ARMY ENGINEER DISTRICT, FORT WORTH		DEC. 1964
SUBMITTED W. E. Wood ENGINEER CHIEF, PLANNING & REPORTS BRANCH	APPROVAL RECOMMENDED [signature] ENGINEER CHIEF, ENGINEERING DIVISION	APPROVED [signature] COL. CORPS OF ENGINEERS DISTRICT ENGINEER
PREPARED [signature] ENGINEER CHIEF, CIVIL ENGINEERING SECTION	DRAWN BY A.M.F. CHECKED BY W.R.B.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR FILE GUAD. 707-2

PLATE 57

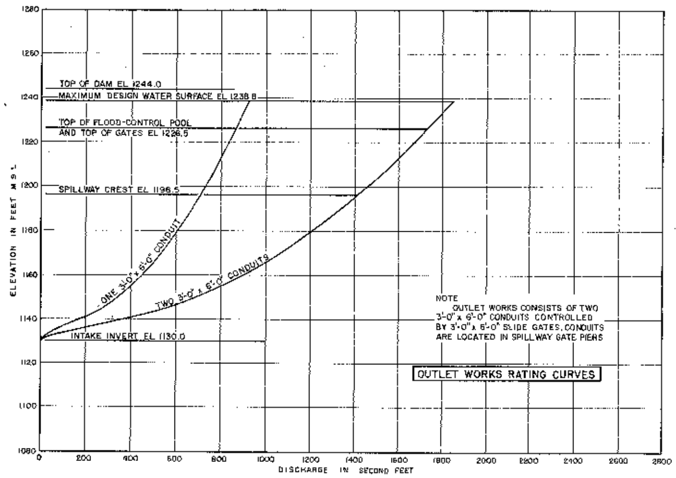


FIG. 1

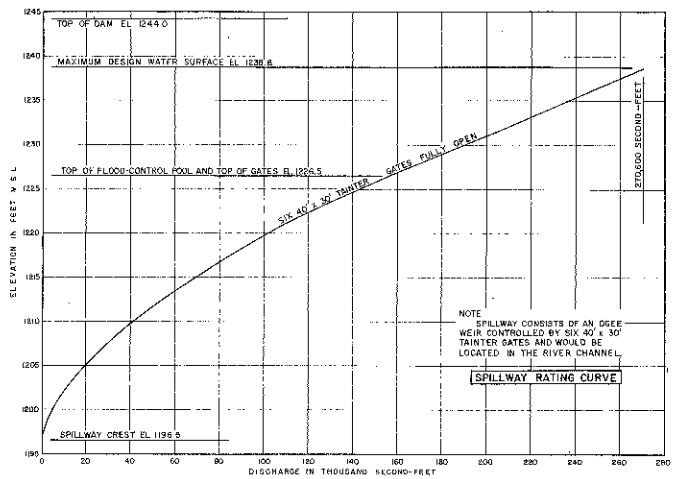


FIG. 2

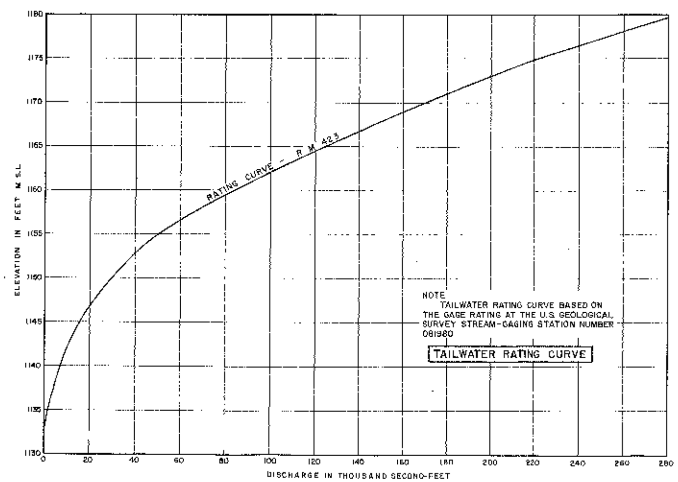
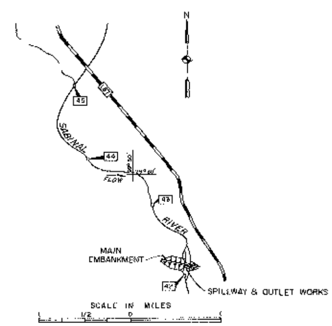


FIG. 3



PLAN

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

GENERAL HYDRAULIC DATA
SABINAL RESERVOIR

SCALES AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC 1964

FILE GUAD 707-2

PLATE 56

Each conduit would have intake invert at elevation 1130.0 and would be controlled by a 3-foot by 6-foot slide gate, as shown on plate 57. The outlet works would be used for diversion during construction and for passage of flood-control releases. The total capacity of the outlet works with reservoir water surface level at spillway crest, elevation 1196.5, and at maximum design water surface, elevation 1238.8, would be about 1,420 second-feet and 1,850 second-feet, respectively. The outlet works rating curves are shown on figure 1, plate 58.

93. SABINAL DAM - TAILWATER RATING CURVE.- The tailwater rating curve at the dam site is shown on figure 3, plate 58. This rating curve is based on the rating curve developed for the U. S. Geological Survey stream-gaging station Number 081980 on the Sabinal River near Sabinal, Texas, in the vicinity of the dam site.

94. CLOPTIN CROSSING DAM - SPILLWAY.- The Cloptin Crossing Dam would be located on the Blanco River at river mile 32.5, with the spillway in a saddle on the left bank. The spillway would consist of a 760-foot uncontrolled broadcrested weir with crest at elevation 998.0. Details of the dam and spillway are shown on plate 59. Under conditions of the spillway design discharge (187,200 second-feet), the reservoir would be at elevation 1017.5. The spillway rating curve, adjusted for approach losses, is shown on figure 2, plate 60.

95. CLOPTIN CROSSING DAM - OUTLET WORKS.- The flood-control outlet works would consist of a 13-foot diameter conduit controlled by two 6-foot by 13-foot tractor type gates. The conduit would be located in the main embankment, with inlet invert at elevation 855.0 and outlet invert at elevation 852.0, as shown on plate 59. The outlet works would be used for diversion during construction, for the passage of flood releases, and for the passage of low-flow discharges. The capacity of the conduit with reservoir water surface at top of conservation pool, elevation 980.5, and at maximum design water surface, elevation 1017.5, would be about 8,100 second-feet and 9,200 second-feet respectively. Figure 1, plate 60 shows the rating curve for the outlet works.

96. CLOPTIN CROSSING DAM - TAILWATER RATING CURVE.- The tailwater rating curve at the dam site is shown on figure 3, plate 60. This rating curve was developed by backwater methods from the U. S. Geological Survey stream-gaging station Number 081710 on the Blanco River at Wimberley, Texas, 2.5 miles downstream from the dam site. Results of the backwater study were correlated with observed flood flow data.

97. CHANNEL DAM AND PIPELINE.- A pipeline for conveying conservation water across an infiltration loss zone existing in the

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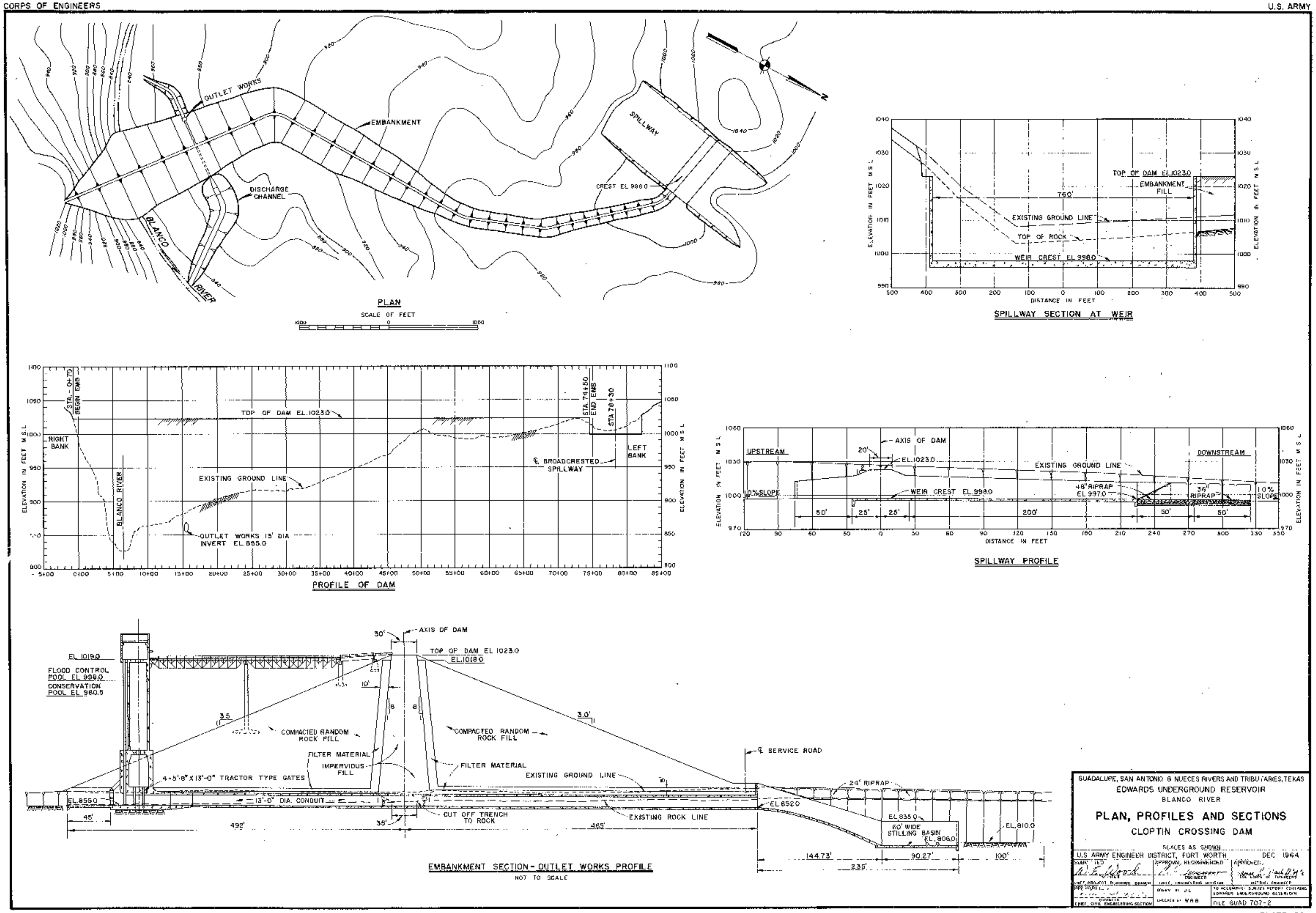
Nueces River channel from about river mile 386.5 to 377.3 would be constructed adjacent to the river channel downstream from Montell Reservoir. The pipeline would have gravity flow and would consist of 24-inch diameter concrete pipe with an average grade of about 0.3 percent. A low channel dam would be constructed at Nueces River mile 387.0 to establish the necessary entrance conditions for the conduit. The pipeline would be about 8.5 miles long and would discharge back into the Nueces River channel at about river mile 376.5. The capacity of the pipeline would be from 6 to 12 second-feet and the average velocity in the conduit would be about 4 feet per second. The details for this pipeline are shown on plate 61.



PLAN
SCALE OF FEET
OUTLET WORKS
EMBANKMENT
SPILLWAY
DISCHARGE CHANNEL
CREST EL 998.0
BLANCO RIVER
SPILLWAY SECTION AT WEIR
TOP OF DAM EL.1023.0
EMBANKMENT FILL
760'
EXISTING GROUND LINE
TOP OF ROCK
WEIR CREST EL.998.0
ELEVATION IN FEET M.S.L.
DISTANCE IN FEET
PROFILE OF DAM
STA -0+70 BEGIN EMB
STA 74+50 END EMB
STA 78+30
TOP OF DAM EL.1023.0
RIGHT BANK
LEFT BANK
BLANCO RIVER
EXISTING GROUND LINE
℄ BROADCRESTED SPILLWAY
OUTLET WORKS 13' DIA INVERT EL.855.0
SPILLWAY PROFILE
UPSTREAM
DOWNSTREAM
AXIS OF DAM
EL.1023.0
WEIR CREST EL.998.0
48" RIPRAP EL 997.0
36" RIPRAP
1.0% SLOPE
EMBANKMENT SECTION - OUTLET WORKS PROFILE
NOT TO SCALE
AXIS OF DAM
TOP OF DAM EL 1023.0
EL.1018.0
EL 1019.0
FLOOD CONTROL POOL EL 998.0
CONSERVATION POOL EL 980.5
COMPACTED RANDOM ROCK FILL
FILTER MATERIAL
IMPERVIOUS FILL
4-5'8" X 13'-0" TRACTOR TYPE GATES
13'-0" DIA. CONDUIT
EL.855.0
CUT OFF TRENCH TO ROCK
EXISTING GROUND LINE
EXISTING ROCK LINE
℄ SERVICE ROAD
24" RIPRAP
EL 852.0
EL 835.0
60' WIDE STILLING BASIN EL. 806.0
EL. 810.0
492'
465'
144.73'
90.27'
235'
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
BLANCO RIVER
PLAN, PROFILES AND SECTIONS
CLOPTIN CROSSING DAM
SCALES AS SHOWN
U.S. ARMY ENGINEER DISTRICT, FORT WORTH DEC 1964
FILE GUAD 707-2

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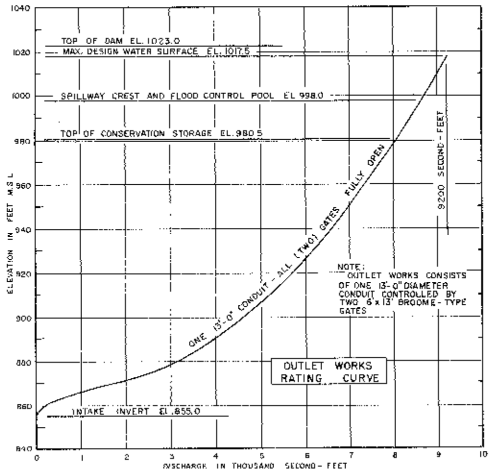


FIG. 1

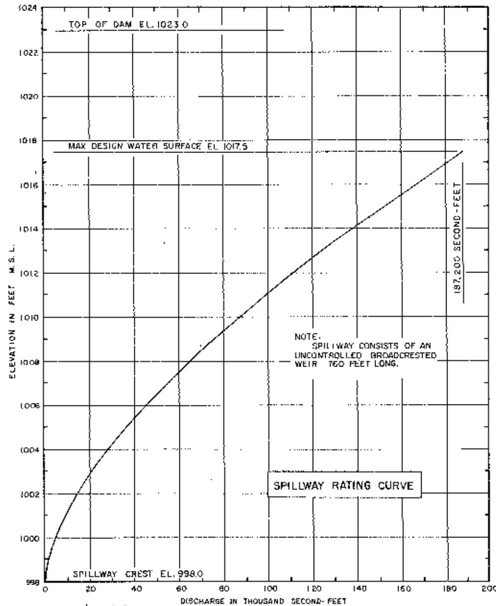


FIG. 2

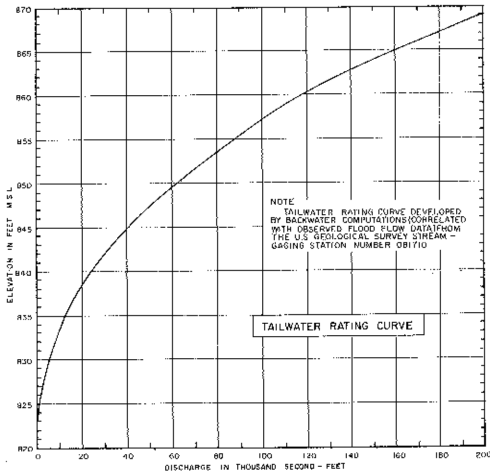
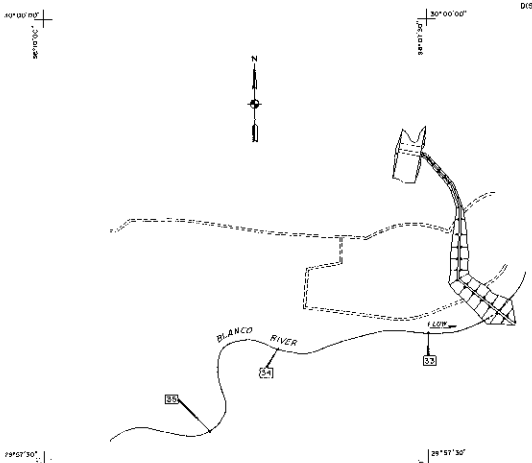


FIG. 3



PLAN

SCALE OF MILES

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

EDWARDS UNDERGROUND RESERVOIR

BLANCO RIVER

GENERAL HYDRAULIC DATA

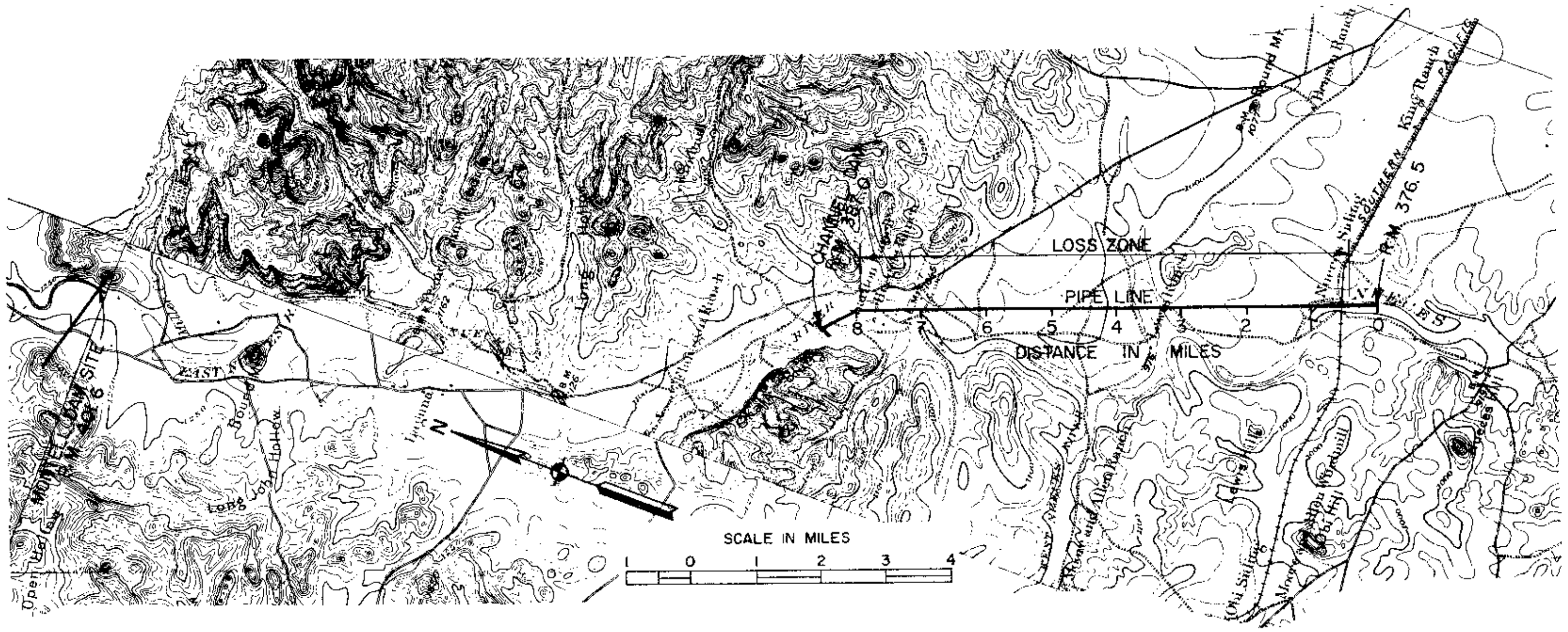
CLOPTIN CROSSING DAM & RESERVOIR

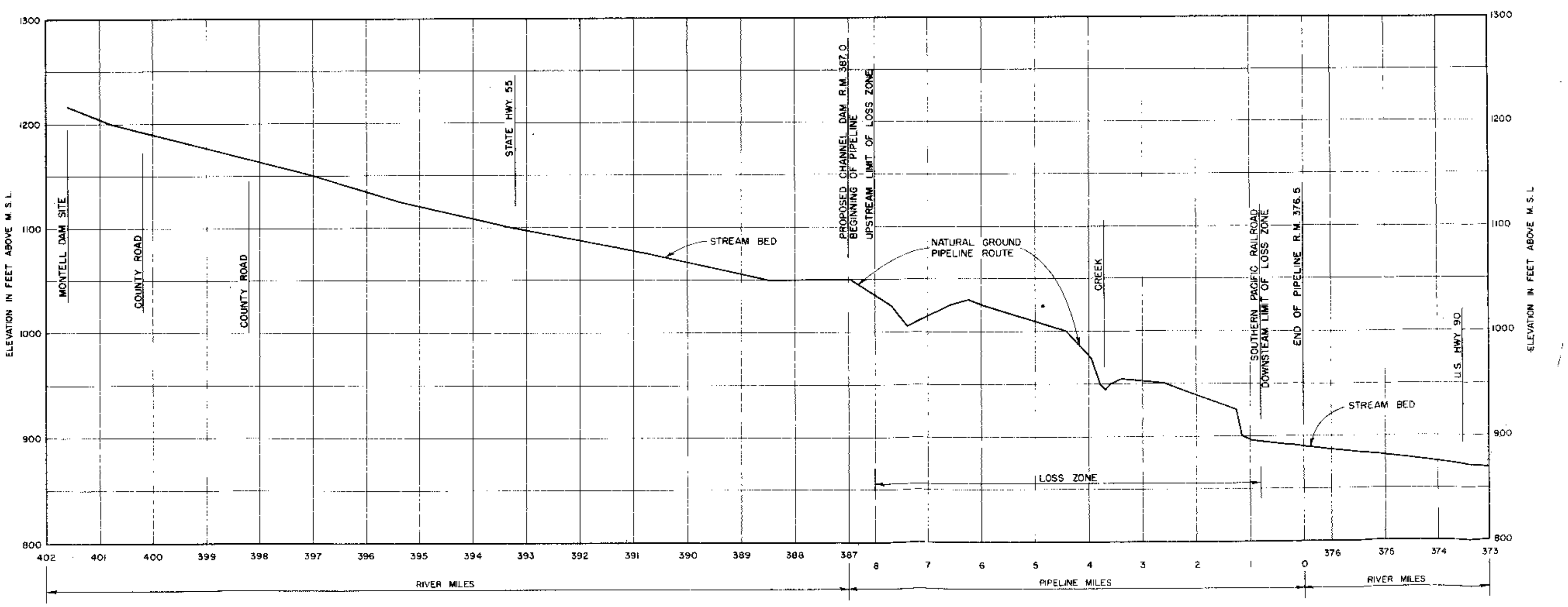
SCALED AS SHOWN

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, HYDRAULIC DESIGN SECT.	DRAWN BY A.H.F. / CHECKED BY O.T.K.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD 707-2

CORPS OF ENGINEERS U.S. ARMY





GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS

EDWARDS UNDERGROUND RESERVOIR

NUECES RIVER

PIPELINE FOR WATER SUPPLY

SCALES AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	C. F. Swenson, ENGINEER, CHIEF, ENGINEERING DIVISION	LT. COL., CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF, GENERAL INVESTIGATIONS SECTION	DRAWN BY T.L.W. / CHECKED BY R.M.G.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / FILE GUAD. 707-2

PLATE 61

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APPENDIX III

GEOLOGY

SURVEY REPORT
ON
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO AND NUECES RIVERS
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APPENDIX III

GEOLOGY

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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.

SURVEY REPORT
ON
EDWARDS UNDERGROUND RESERVOIR
GUADALUPE, SAN ANTONIO AND NUECES RIVERS
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APPENDIX III

GEOLOGY

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.

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 1 - 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	480	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	55	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.
		Fredericksburg	Edwards and associated limestone: Klamichi 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	190 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

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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.

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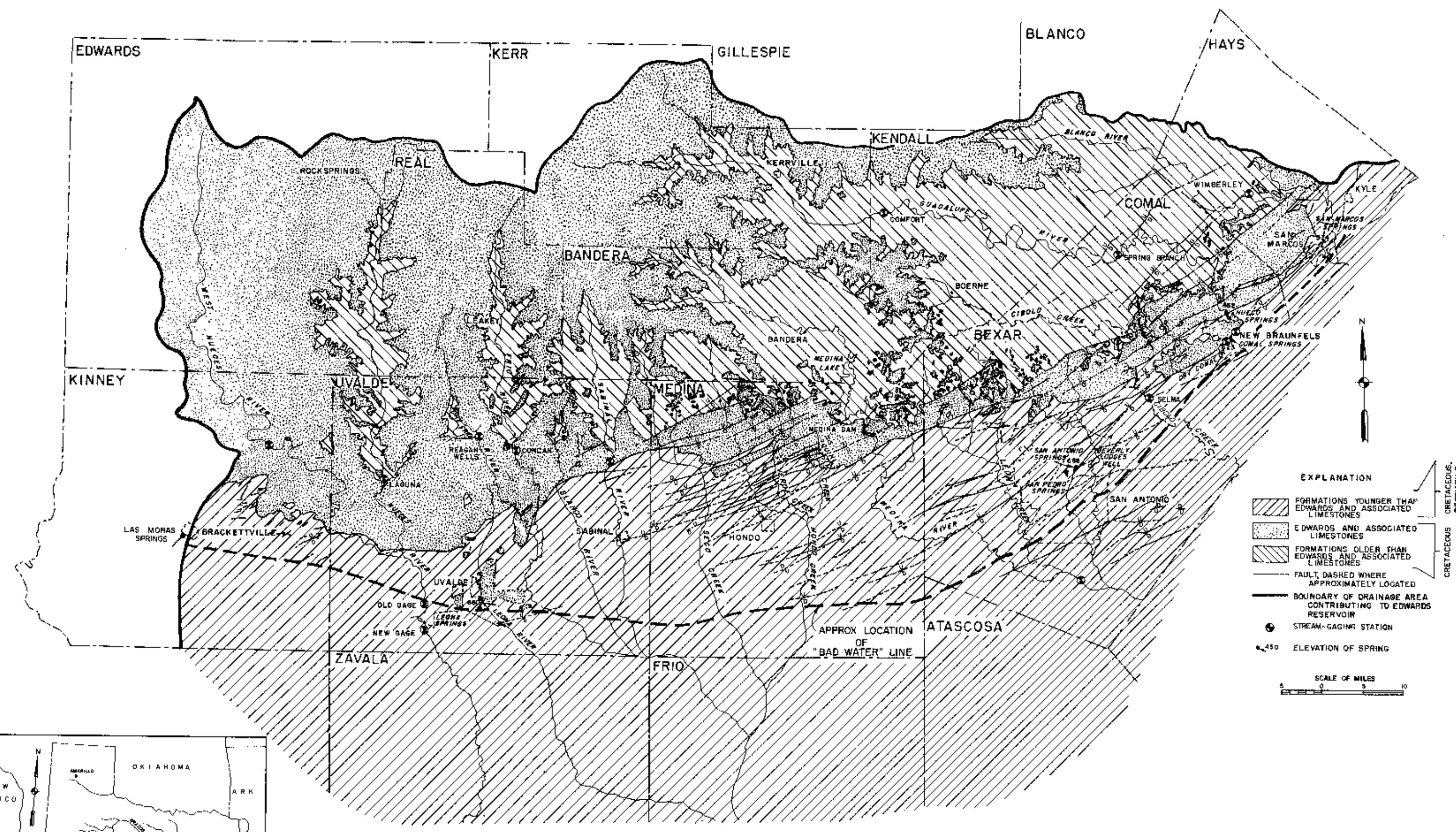
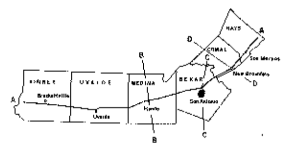


VICINITY MAP

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

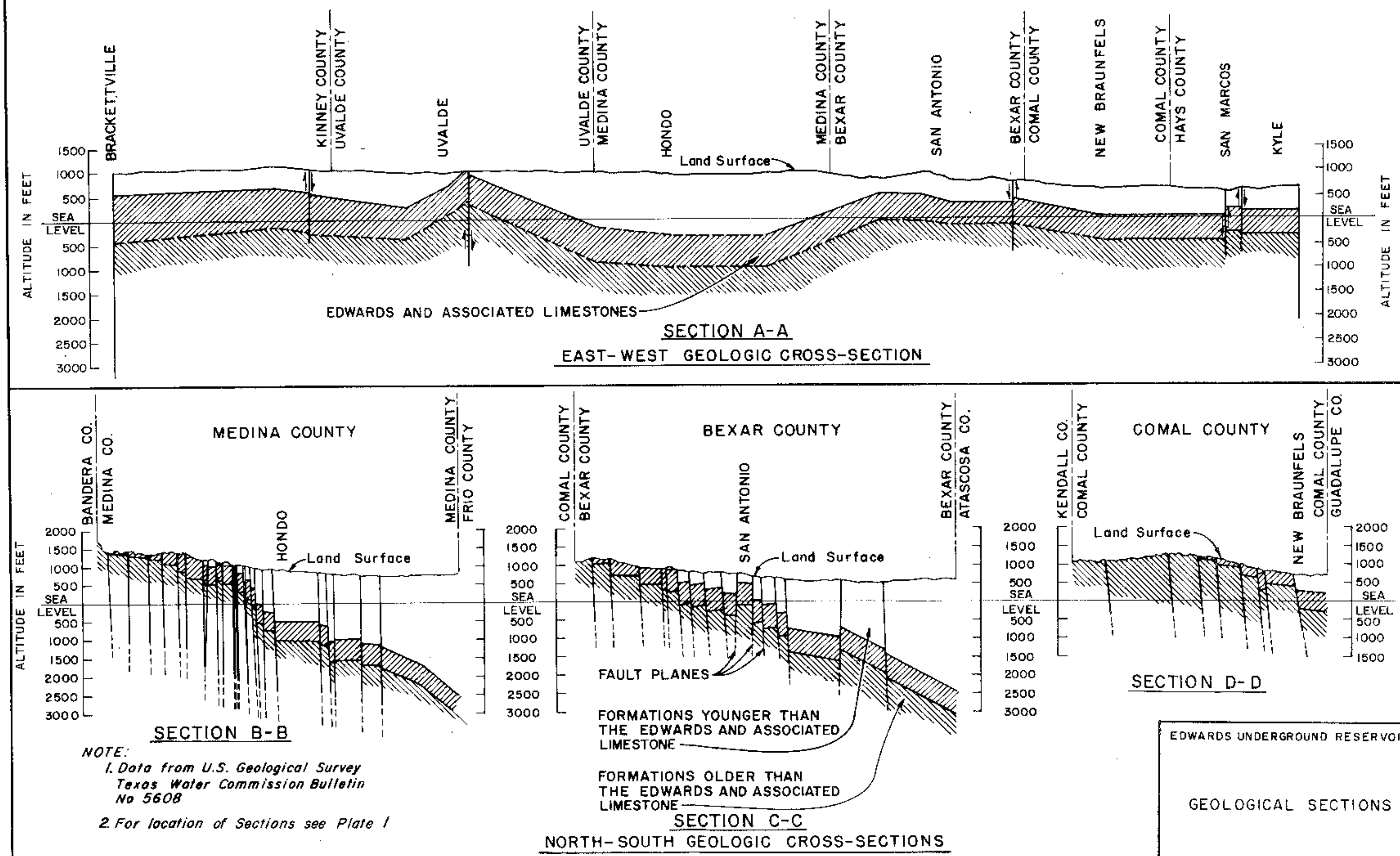
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR

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 CORPS OF ENGINEERS DISTRICT ENGINEER
PREPARED A. M. Hull ENGINEER	DRAWN BY / CHECKED BY	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE GUAD 707-2

PLATE 1



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

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. <u>Guadalupe River Basin</u>.- 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 24/ 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. <u>"Bad-Water" Line</u>.- 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.

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:

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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.

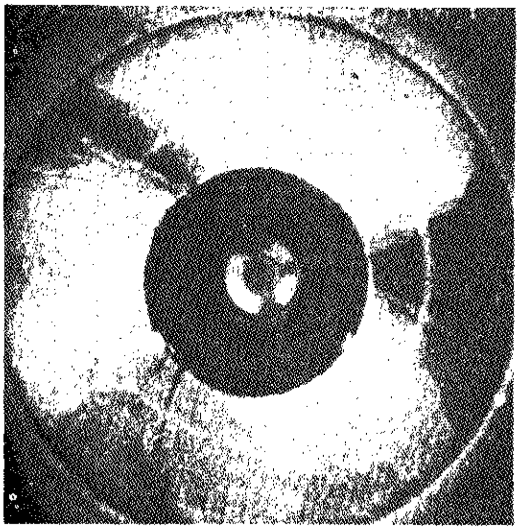
22. The Edwards limestone, as revealed by the cores, is a hard, dense, lithographic to subcrystalline limestone, generally highly broken and solutioned. Several reef zones, as well as chert lenses and nodules, were noted and the rock did not appear to be uniformly permeable. Favored flow paths, developed 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.

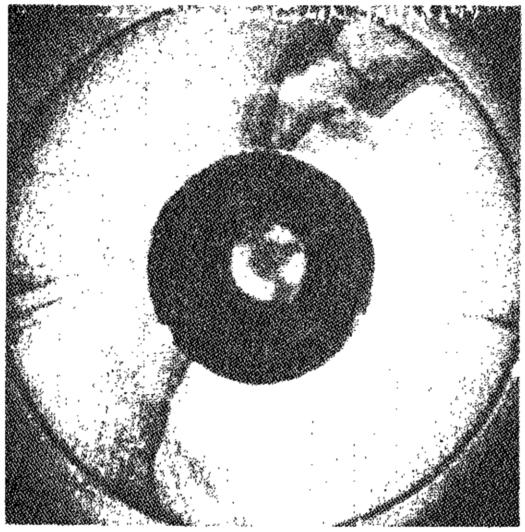
24. Present plans now call for a recorder to be installed in the well for use by the U. S. Geological Survey and the Edwards Underground Water District in their continuing study of the aquifer. An E-log of the hole is shown on plate 5.

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.

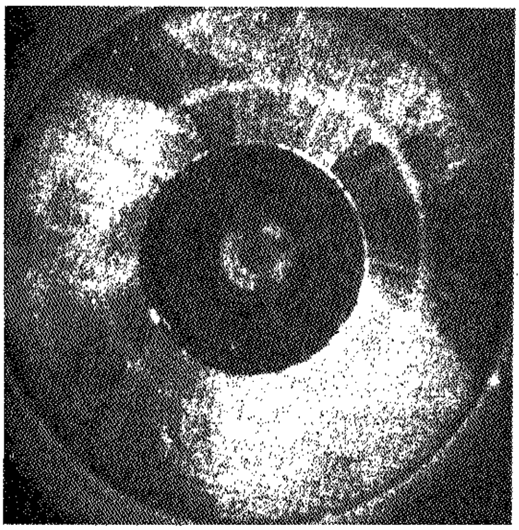
The Bore Hole Camera is an 8-mm moving picture camera included in a stainless steel tube 2-3/4 inches in diameter and 34 inches long. A cable is attached to one end by which it is lowered into the bore hole with a special lowering device. The lower end of the tube contains a transparent quartz window 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.



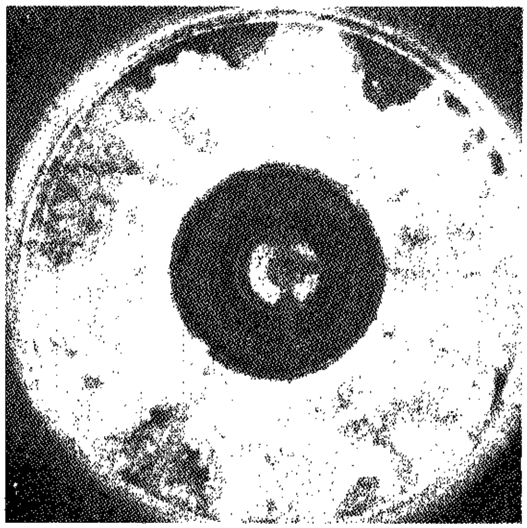
DEPTH 328.0. ARROW IN CENTER OF PHOTO POINTS TO THE NORTH (MAGNETIC). LIMB TO RIGHT OF ARROW DENOTES EAST SIDE. NOTE THE LARGE OPEN FRACTURE ALONG EAST SIDE OF HOLE.



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.

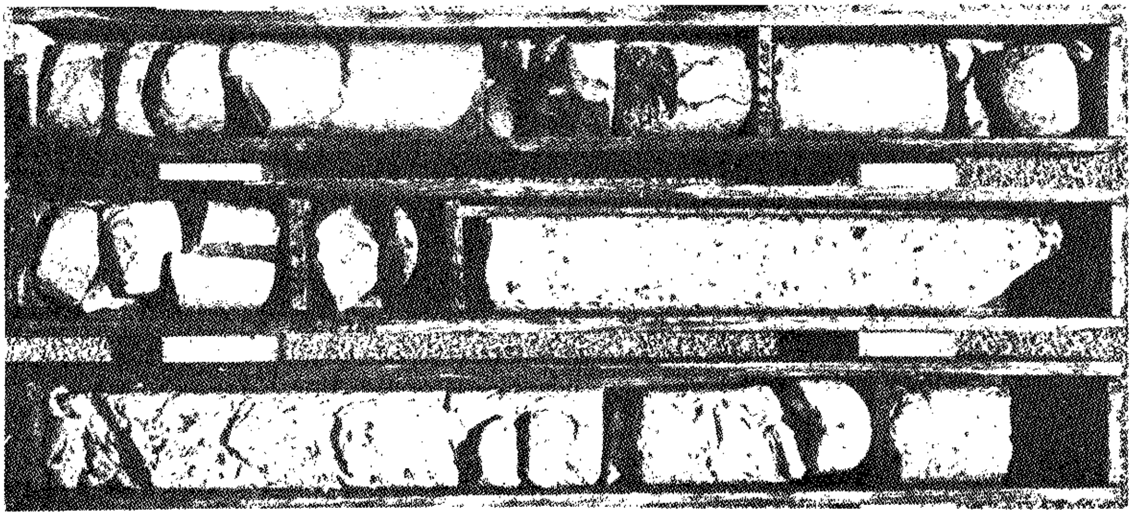


DEPTH 460.3. ROCK IS HIGHLY SOLUTIONED; NOTE OXIDE STAINS AND SOLUTION CAVITIES.

FIGURE I

BORE HOLE PHOTOS
EDWARDS EXPLORATION BORING

EDWARDS UNDERGROUND RESERVOIR

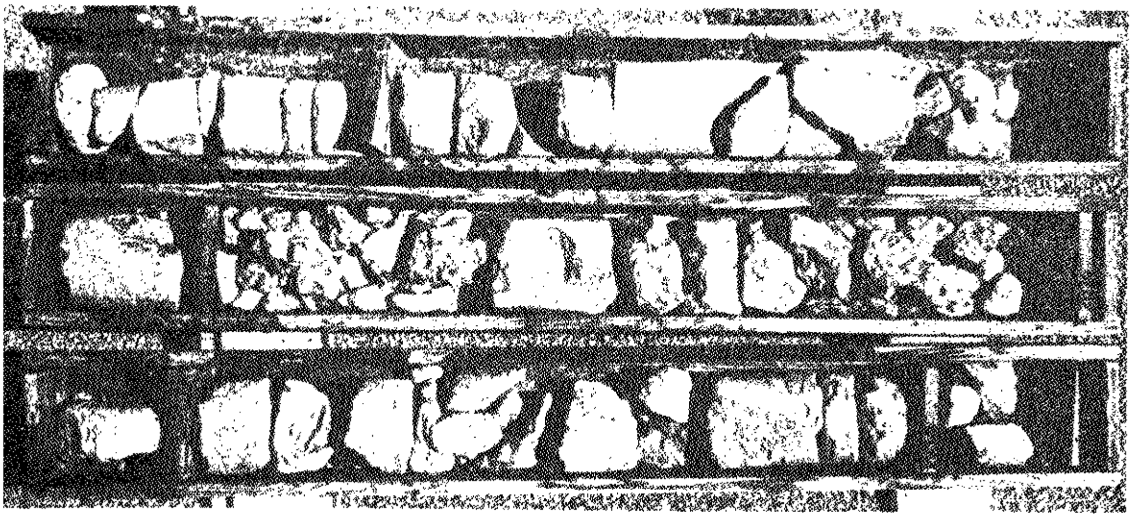


Box I through 3; 238.8 to 255.0. Georgetown - Edwards contact is at 243.8, near top of second box. Note reef limestone from 248.7. Depth increases from upper left to lower right.

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

FIGURE 2

CORE FROM EDWARDS CORE BORING

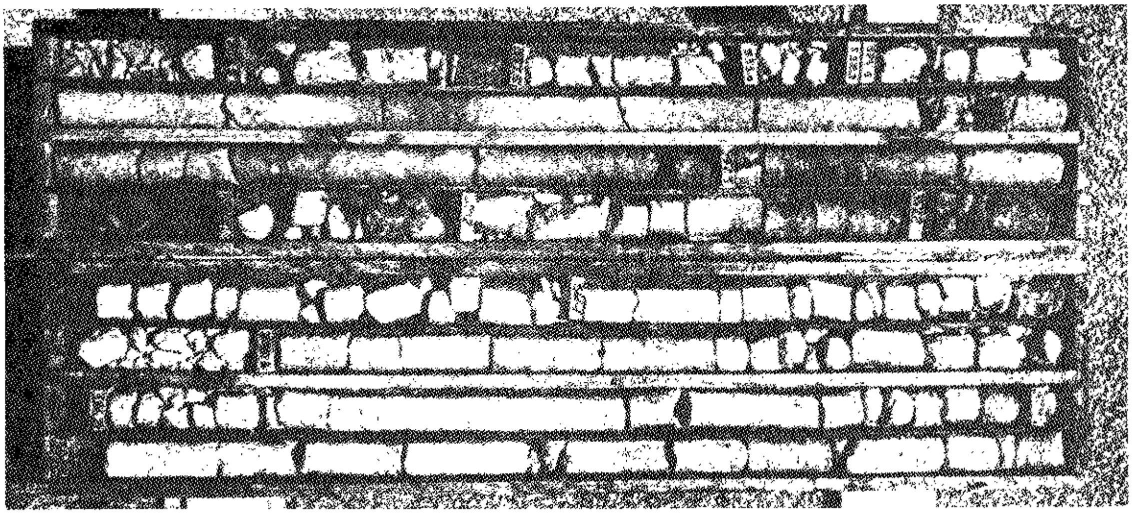


Box 7 through 9 ; 270.2 to 296.3. Considerable core loss in this interval. Rock highly broken and solutioned.

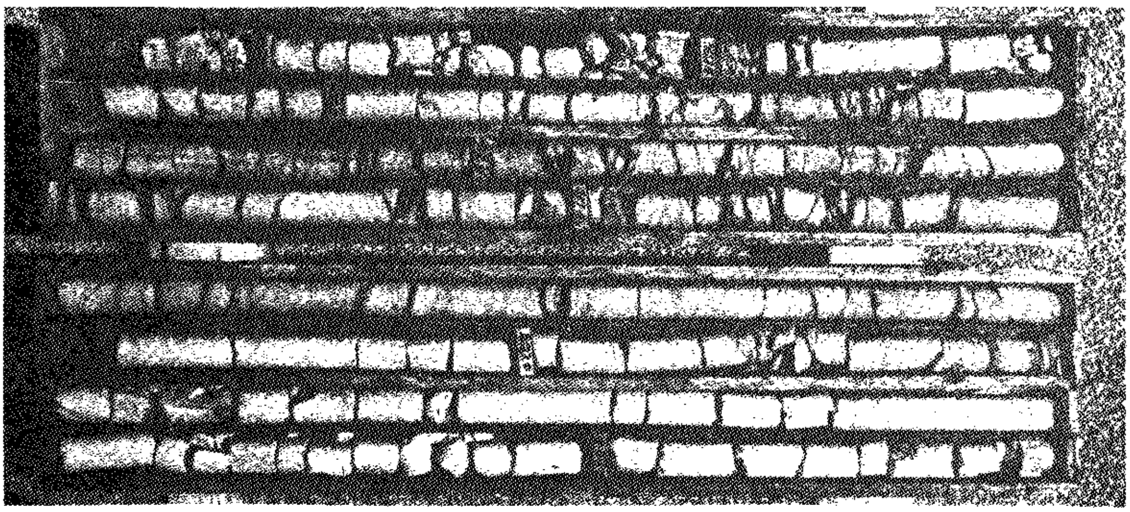
Box 10 through 13 ; 298.9 to 317.9. Rock bit used from about 296.3 to 298.9. Rock is very hard and generally highly fractured and solutioned in last three boxes.

FIGURE 3

CORE FROM EDWARDS CORE BORING



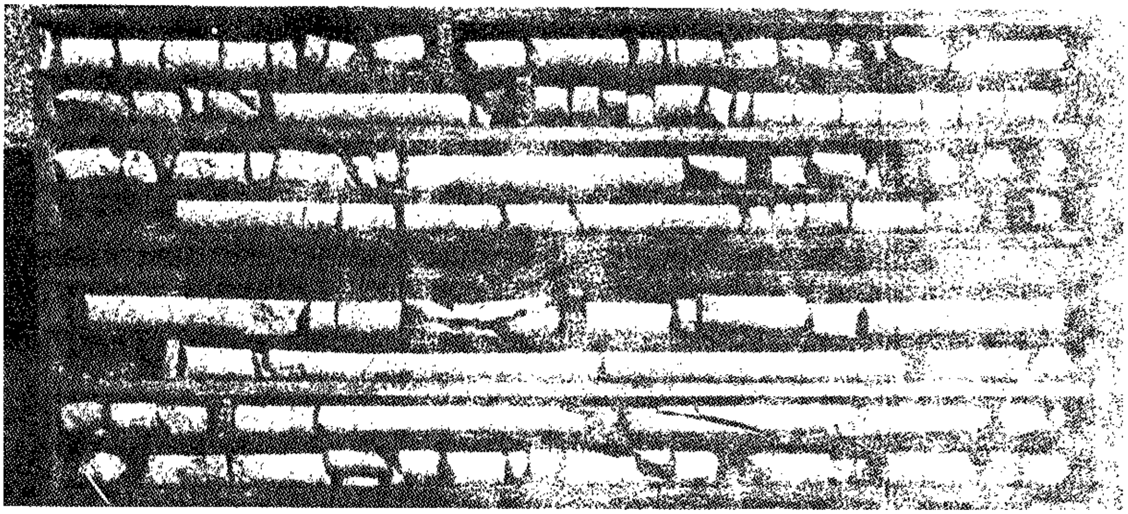
Box 14 and 15; 321.5 to 394.6. Core reduced from 6" to 2". Depth increases from upper right to lower left. Used rock bit from 317.9 to 321.5 and from 325.9 to 332.3. Generally very poor core recovery. Note scattered chert from 359.2 to 360.3.



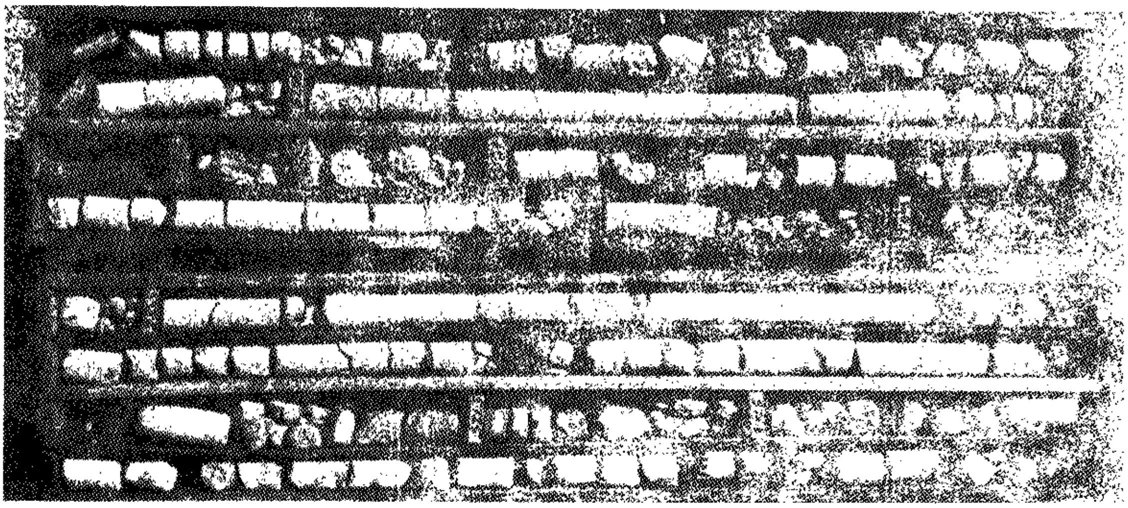
Box 16 and 17; 394.6 to 439.6. Core from 405.0 to 426.2 identified as "Dr. Burton's Ammonite Bed" by Shell Oil Co.

FIGURE 4

CORE FROM EDWARDS CORE BORING



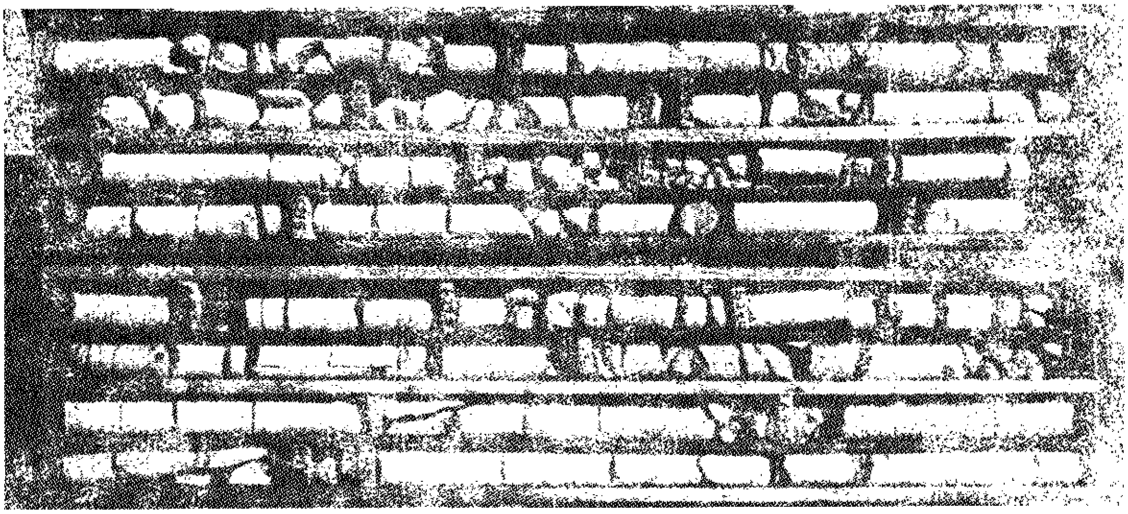
Box 18 and 19; 439.6 to 484.2. Chert nodule at 447.3. Cavity reported from 483.0 to 484.4. Note vertical and near vertical fractures.



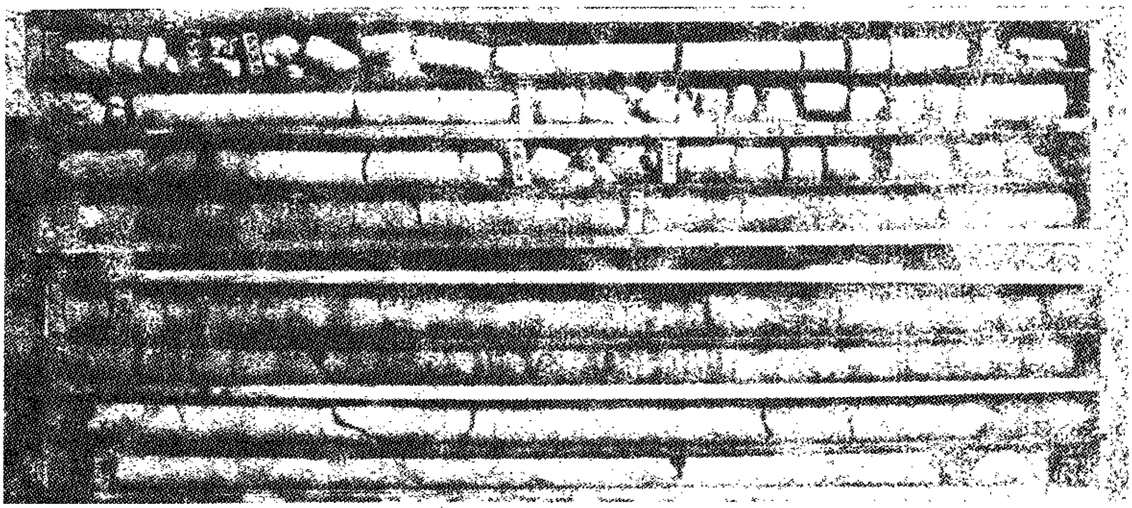
Box 20 and 21; 484.2 to 593.3. Very heavy core loss in this interval. Core in box 20 represents all that was recovered in 66.7 feet of hole. Highly solutioned with cavities up to 2'.

FIGURE 5

CORE FROM EDWARDS CORE BORING



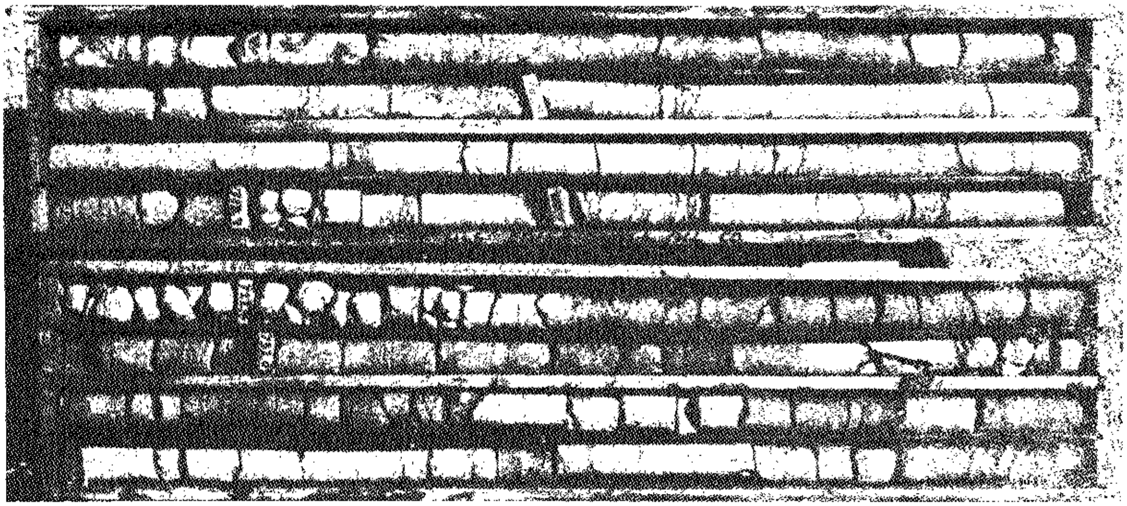
Box 22 and 23; 593.3 to 649.0. Physical characteristics of rock improves considerably at 640.0.



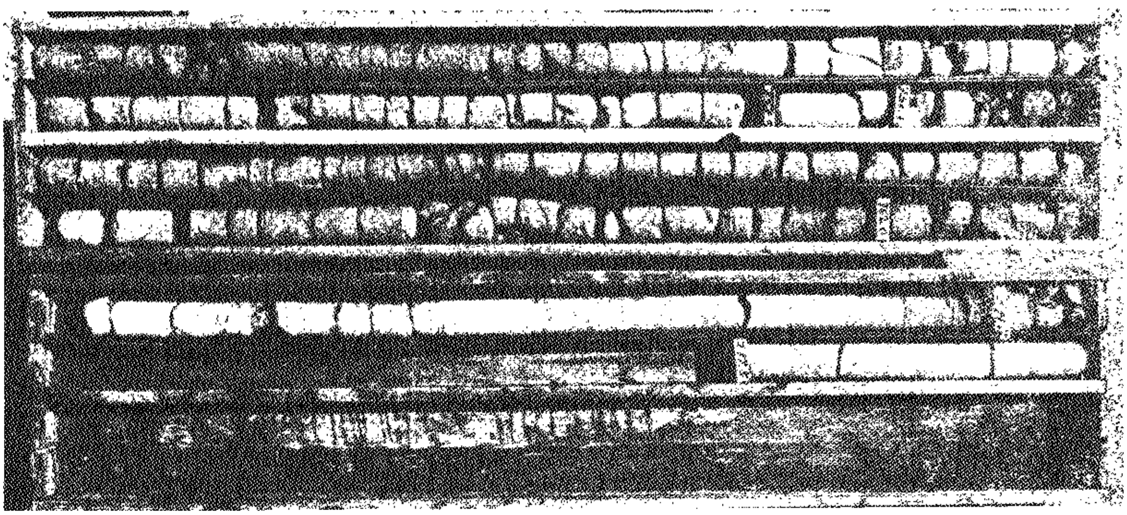
Box 24 and 25; 649.0 to 691.9. Rock below 660.6 is lithologically and hydrologically similar to the Glen Rose. Contact was originally chosen at that depth.

FIGURE 6

CORE FROM EDWARDS CORE BORING



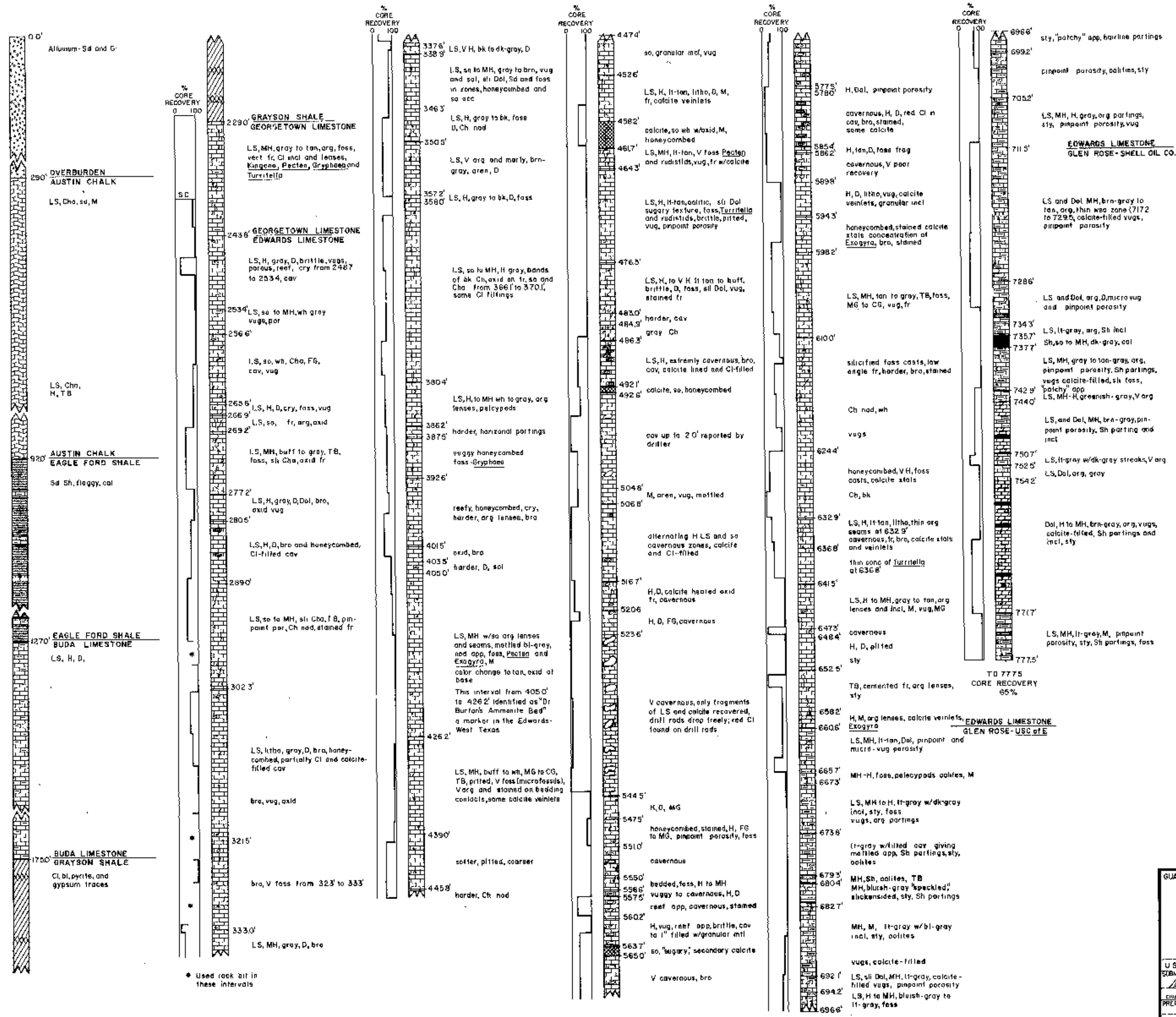
Box 26 and 27; 691.9 to 742.3. Edwards - Glen Rose contact, as selected by representatives of Shell Oil Co., is at 711.5. Interbedded limestone and dolomite below 711.5.



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 Solutional
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: 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
DRAWN BY J L
CHECKED BY M G S
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2

PLATE 3

CORPS OF ENGINEERS

U.S. ARMY

207

BORE HOLE PHOTO LOG		Boring No.: Edwards Core Boring
Edwards Underground Reservoir	Location: Selma, Texas	
15 October 1963	Hole size: 1-1/2" & 8.0	Condition of Borehole: Fair to Poor
Depth photographed: 238.0 - 480.0	Water depth: Above 238.0	Water condition: Good
0	0	242.0

Depth Range	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 1/16-inch partially open, strike trends N30°W and N40°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 N-S, N45°W, dip 40°-50°NW 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.
260.5-267.7	Highly vuggy zone.
268.6-279.2	Fracture zone, multiple, weathered, vuggy, hairline, tight to partially open. 270.4-270.7 rock is broken and weathered, some rock missing, strike trends N30°E, N65°E and N60°E, dip trends 80°SE and vertical.
274.5-274.7	Rock broken, some rock missing.
275.2-276.3	Vuggy zone.
278.3-279.4	Disturbed zone, the rock is weathered, vuggy, broken, fractured, and chipped out from wall of the hole.
280.1-290.0	Disturbed zone, rock appears highly weathered and vuggy. 280.1-285.0 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	Some 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 - 294.4. Major strike trend N45°E, dip vertical.
295.6-295.?	Highly weathered and vuggy zone, some rock missing.
298.3-298.9	Fracture, hairline, tight, strike N-S, dip 55°E.
299.2-300.1	Fracture, hairline, tight to partially open, strike N15°E, dip 55°SE.
302.6-302.8	Fracture appears open, approximately 1/16-inch, strike N-S, dip 30°W.
303.5-304.5	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 60°NE.
309.7-311.1	Highly weathered, vuggy zone.
311.5-312.5	Vuggy zone.
311.9-312.2	Fracture hairline, tight, strike N-S, dip 60°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 N80°W, N20°E, dip trends 45°SW and vertical. Sandy material noted in some of the vugs and fractures, probably drill cutting.
316.1-326.7	Fracture and broken zone, rock is weathered, vuggy and broken some rock missing to 317.3, hairline, tight fractures continue to 318.4 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. 321.0-326.0 the rock is not wholly broken back and fractured but is partially in place. Grout noted from 317.2-322.8.
32?.7-327.4	Rock is vuggy and iron stained.
327.0-328.5	Badly broken zone, no orientation.
329.0-329.7	Badly broken zone, no orientation.
330.2-331.3	Badly broken zone, no orientation.
331.6-332.4	Fracture zone, fracture appears to be associated with an open iron stained joint striking N50°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 fracture. Strike NS, dip 60°E.

Depth Range	Description
333.7-335.3	Badly broken zone, no orientation.
335.3-335.9	Highly weathered, vuggy, iron stained rock.
335.9-336.8	Broken and fractured zone, some rock missing, no orientation.
336.0-346.0	Weathered, iron stained, vuggy limestone.
358.0-358.3	Joint, surrounding rock broken, iron stained, no orientation.
358.9-360.4	Broken zone, rock is broken away from the walls of the hole, heavily iron stained.
360.7-360.8	Joint, hairline, appears open, heavily iron stained. Strike N35°E, dip 45°SE. Rock has a smeared appearance due to iron staining.
363.?-363.8	Horizontal joint upon 1/2-inch, the rock is badly stained and broken.
[illegible]	Rock is broken away from the walls with some fractures noted, heavily iron stained.
3?0.0-3?0.8	Joint, 1/16-inch open, heavily iron stained, some rock broken, strike N50°E, dip 60°SE.
[illegible]	Joint, 1/2-inch open, heavily iron stained, strike N65°E, dip 35°SE.
[illegible]	Joint 1/8-inch open, heavily iron stained, some rock broken strike N50°E, dip 60°SE.
367.0-368.?	Joint 1/32-inch open, heavily iron stained, strike approximately NS, dip 65°W.
368.2-368.3	Joint, appears open, rock broken, heavily iron stained, no orientation.
368.6-369.?	Joint, appears open, some rock broken, strike N45°W, dip about 35°SW.
369.0-370.9	Broken zone, heavily iron stained, rock broken away from the walls, no orientation.
373.5-373.?	Disturbed 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 heavily iron stained. Strike N70°E, dip 45°SE.
375.?-3??.?	Broken and fractured zone, some rock broken back from the walls of the hole, one fracture is hairline, open, some staining noted, strike N50°E, dip vertical.
378.?	Horizontal, open, iron stained joint.
380.0-380.3	Broken zone, heavily iron stained, no orientation.
380.7	Joint, horizontal, appears open, heavily stained.
381.5-381.?	Low angle irregular, iron stained joint, open.
381.?-383.7	Broken zone, some rock missing, highly iron stained, no orientation.
384.0-384.3	As above.
385.?-385.9	Horizontal joint, open, about 1/4-inch highly iron stained, some rock broken.
38?.?	As above (open about 1/2-inch).
386.?-386.6	Joint, open, highly iron stained, the rock is broken around the joint plane, strike N?°E, dip 30°SW.
386.5-386.?	Joint, open about 1/16-inch, highly iron stained, strike N50°E, unable to determine dip.
387.3	Horizontal, open, iron stained joint.
387.?-387.?	Joint, open, 1/32-inch, iron stained, strike N60°E, dip 45°SE.
388.1	Horizontal, open, 1/16-inch, iron stained joint.
388.?-393.4	Hairline, iron stained joint leading to a 4.5 foot cavity. An additional portion of rock would show up out of focus back in the cavity.
394.0-394.?	Joint open 1/16-inch, highly iron stained, strike N30°E, dip 60°SE.
394.?-395.?	Broken zone, the rock is highly iron stained and shows no orientation.
396.?-396.8	Vertical joint, rock broken away from walls at 396.7-397.4 and 397.? - 398.8, strike NS, dip vertical, highly iron stained.
399.3-399.6	Broken zone, no orientation.
400.?-400.8	Broken zone, no orientation.
401.5-402.?	Broken zone, no orientation.
402.?-40?.?	Broken zone, no orientation.
404.7-405.?	Broken zone, no orientation.
405.6	Horizontal joint, open, iron stained.
406.8	Horizontal joint, open, iron stained.
407.?	Horizontal joint, open, iron stained.
408.0-408.4	Joint appears open and iron stained.
408.?	Horizontal joint, open, iron stained.
408.7-408.8	Joint, low angle, appears open and iron stained.
410.5-410.8	Disturbed zone, iron staining noted.
412.0-412.?	Broken zone, iron stained.
416.2-416.3	As above.

Depth Range	Description
424.2-424.3	Joint, tight, strike EW, unable to determine dip.
424.6	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.
433.1-434.7	Hairline, tight, fracture zone.
435.4	Joint, horizontal, open, iron stained.
435.4	Joint, horizontal, open, iron stained.
441.7-443.1	Joint, complex, tight to partially open, highly iron stained, some rock broken, strike N85°E, dip vertical.
445.3-445.5	Joint, tight to partially open, highly iron stained.
447.6-447.5	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.
453.1-454.0	Multiple joints, hairline, tight to 1/32-inch open, highly iron stained, strike trends N15°E, N35°E, and N60°E, dip trends 60°SE, 30°SE, and 60°SE.
455.0-455.3	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.
457.8	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.
465.6-466.2	Joint, hairline, tight, strike N50°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 N80°E and NW that changes to N80°E then to N70°E, dip vertical.
472.5-478.3	Multiple, complex, joint zone bounding a broken zone at 477.1 - 478.0. The joints range from hairline tight to 1/32-inch open, highly iron stained with some of the surrounding rock being broken. (Cont'd)
472.5-478.3 (Cont'd)	Strike trends N45°E to N70°E to EW, dip trends about vertical. No orientation within the broken zone or the 0.5 foot section below 477.1 - 478.3.
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
[signature] ENGINEER, CHIEF PROJECT PLANNING BRANCH	[signature] ENGINEER, CHIEF, ENGINEERING DIVISION	[signature] COL CORPS OF ENGINEERS, DISTRICT ENGINEER
PREPARED [signature] ENGINEER, CHIEF FOUNDATION & MATERIALS BR	DRAWN BY T. LAMB; CHECKED BY M.E.D.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE GUAD 707-2

PLATE 4

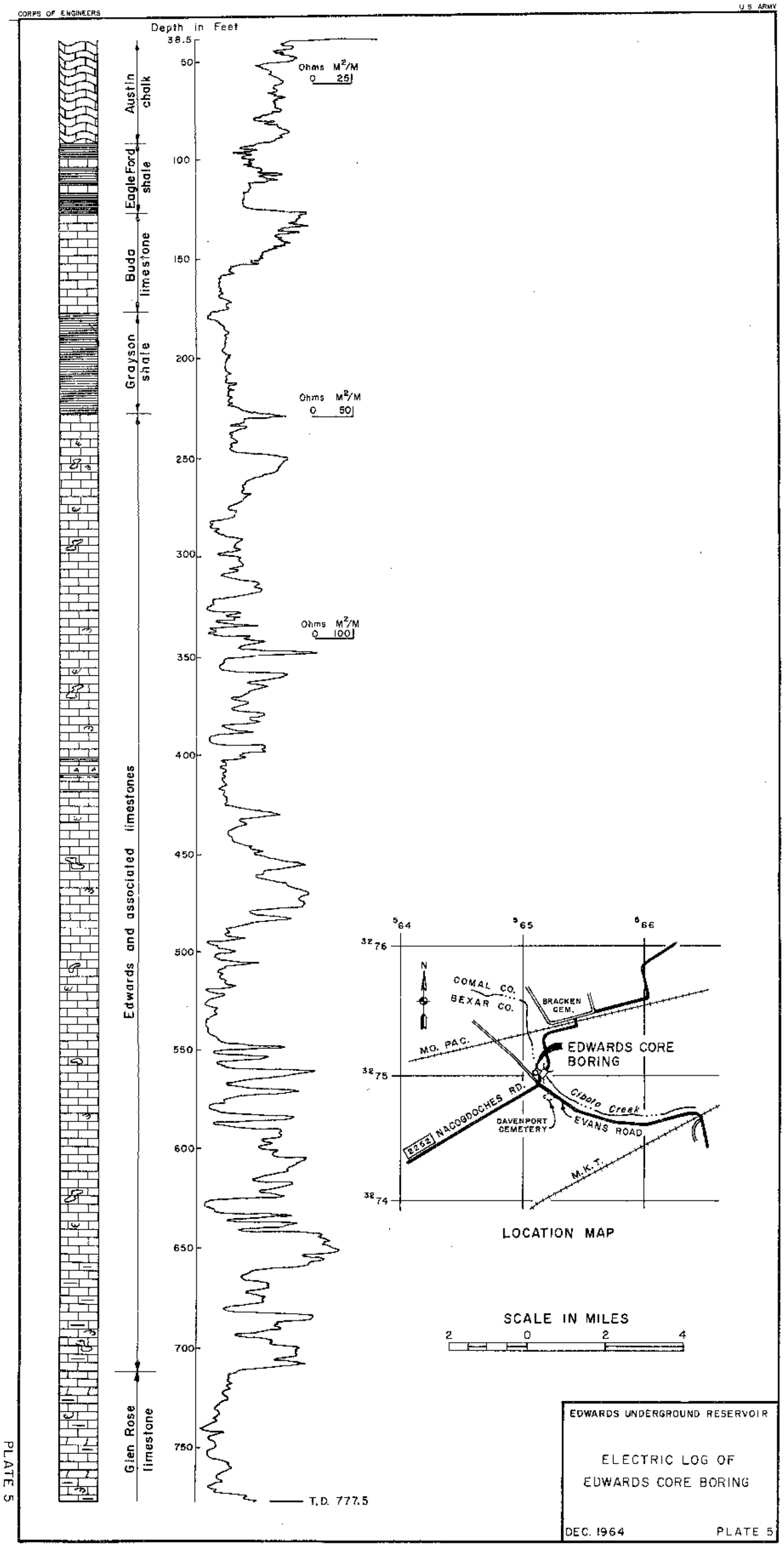

CORPS OF ENGINEERS
U.S. ARMY
Depth in Feet
Austin chalk
Eagle Ford shale
Buda limestone
Grayson shale
Edwards and associated limestones
Glen Rose limestone
Ohms M²/M 0 25
Ohms M²/M 0 50
Ohms M²/M 0 100
T.D. 777.5
COMAL CO.
BEXAR CO.
BRACKEN CEM.
MO. PAC.
EDWARDS CORE BORING
NACOGDOCHES RD.
2252
DAVENPORT CEMETERY
Cibolo Creek
EVANS ROAD
M.K.T.
LOCATION MAP
SCALE IN MILES
EDWARDS UNDERGROUND RESERVOIR
ELECTRIC LOG OF EDWARDS CORE BORING
DEC. 1964
PLATE 5

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/

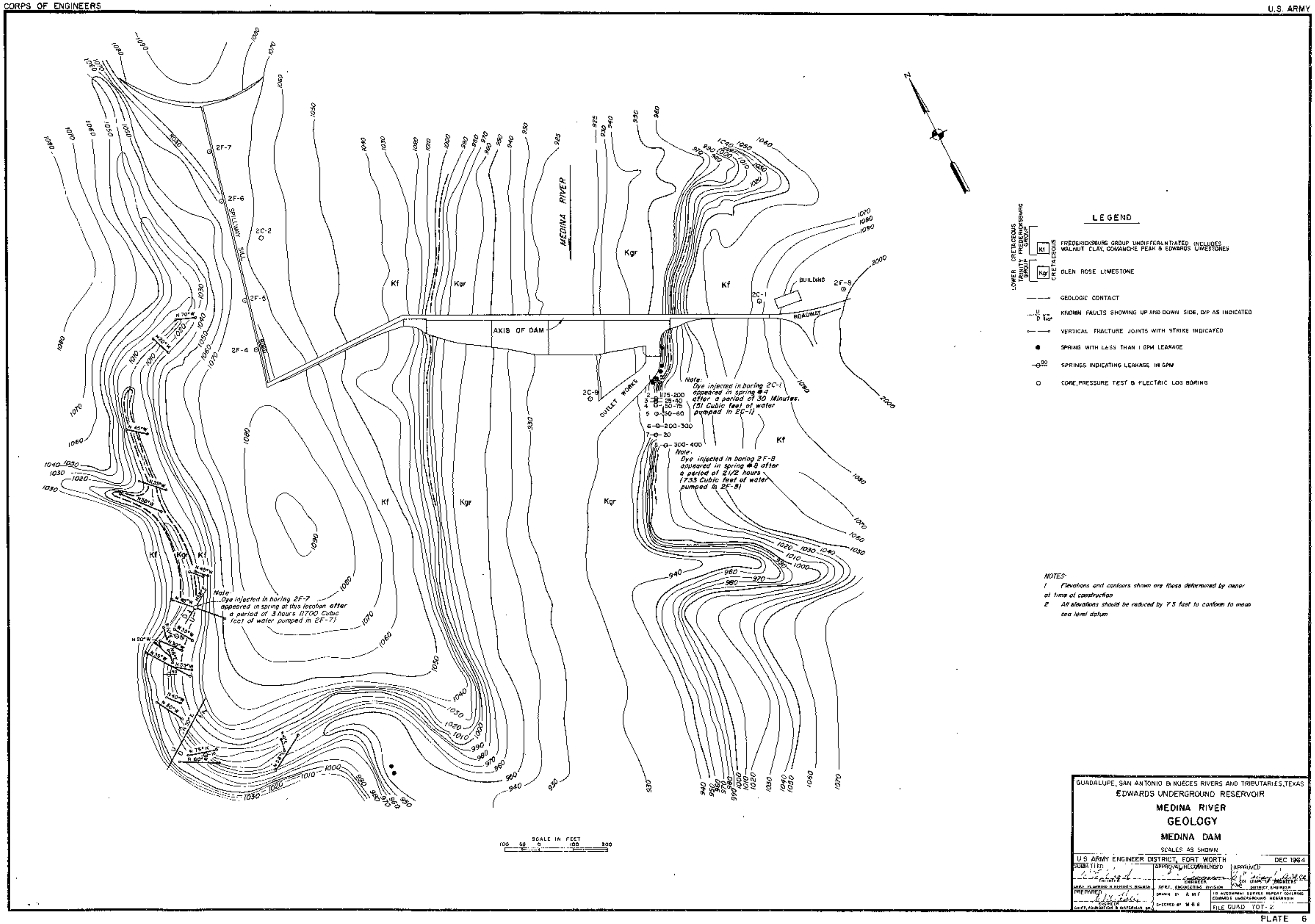
b. General Geology.- Medina Dam is founded on the Glen Rose limestone, Walnut clay, Comanche Peak limestone, and Edwards limestone. The Glen Rose, an argillaceous, thin- to medium-bedded limestone with thin interbeds of clay and shale, crops out in the river valley and in the canyon walls to about elevation 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.

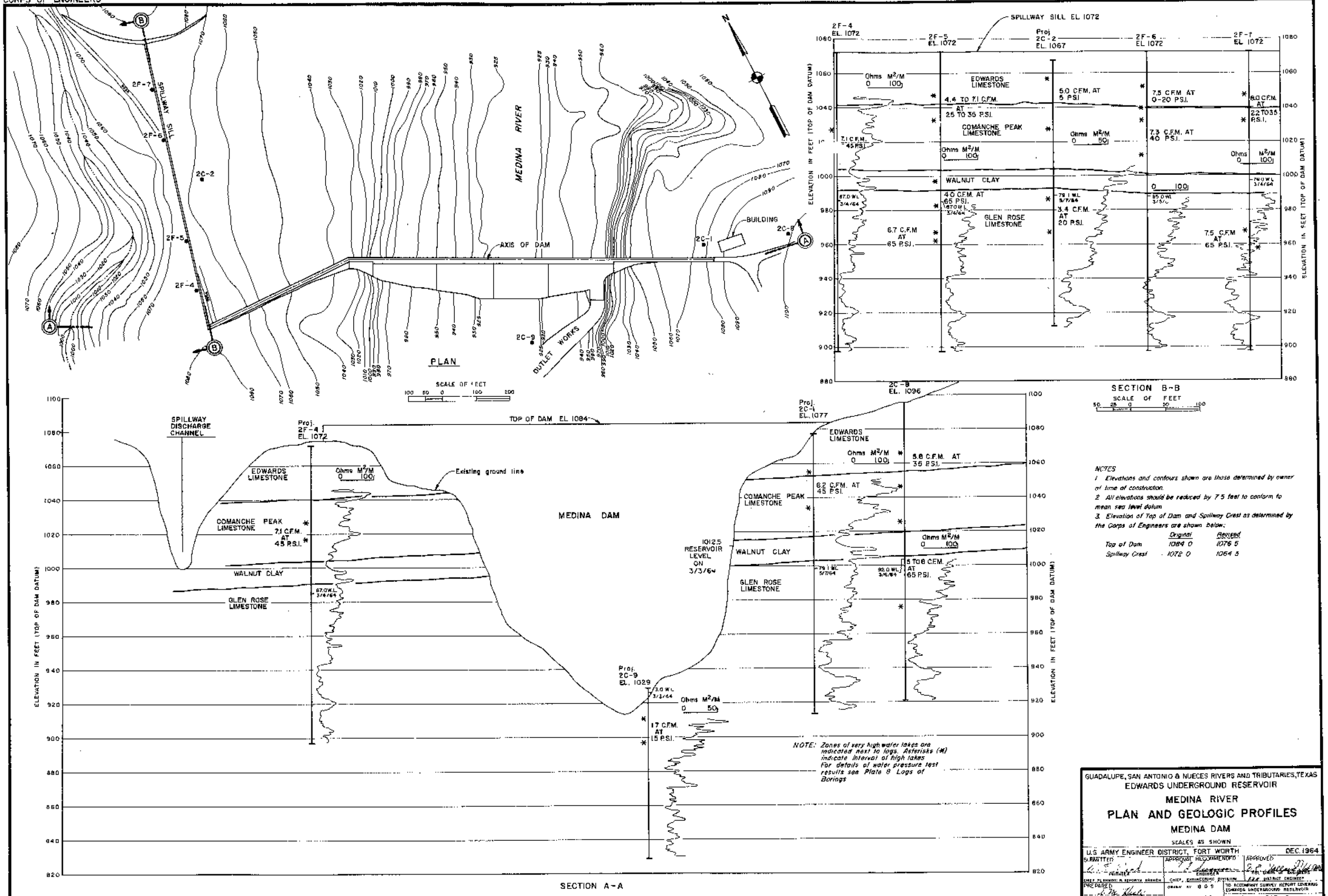
c. Investigations.- The feasibility of reducing leakage from Medina Reservoir has been explored by (1) geologic mapping, (2) core and "fishtail" borings, (3) electric logs, (4) water pressure tests, and (5) dye injection tests. The geology and structure were mapped in the vicinity of the dam and in the 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.


CORPS OF ENGINEERS
U.S. ARMY
MEDINA RIVER
AXIS OF DAM
SPILLWAY SILL
OUTLET WORKS
BUILDING
ROADWAY
Note: Dye injected in boring 2C-1 appeared in spring #4 after a period of 30 Minutes. (51 Cubic feet of water pumped in 2C-1)
Note: Dye injected in boring 2F-8 appeared in spring #8 after a period of 2 1/2 hours (733 Cubic feet of water pumped in 2F-8)
Note: Dye injected in boring 2F-7 appeared in spring at this location after a period of 3 hours (1700 Cubic feet of water pumped in 2F-7)
LEGEND
LOWER CRETACEOUS
FREDERICKSBURG GROUP
TRINITY GROUP
CRETACEOUS
Kf FREDERICKSBURG GROUP UNDIFFERENTIATED INCLUDES WALNUT CLAY, COMANCHE PEAK & EDWARDS LIMESTONES
Kgr GLEN ROSE LIMESTONE
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
SCALE IN FEET
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
APPROVAL RECOMMENDED
APPROVED
ENGINEER
CHIEF, ENGINEERING DIVISION
DISTRICT ENGINEER
PREPARED
DRAWN BY A.M.F.
CHECKED BY M.B.B.
FILE GUAD 707-2
PLATE 6

CORPS OF ENGINEERS

U.S. ARMY



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.D.S. — CHECKED BY M.C.B.

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD 707-2

PLATE 7

213

CORPS OF ENGINEERS

U.S. ARMY

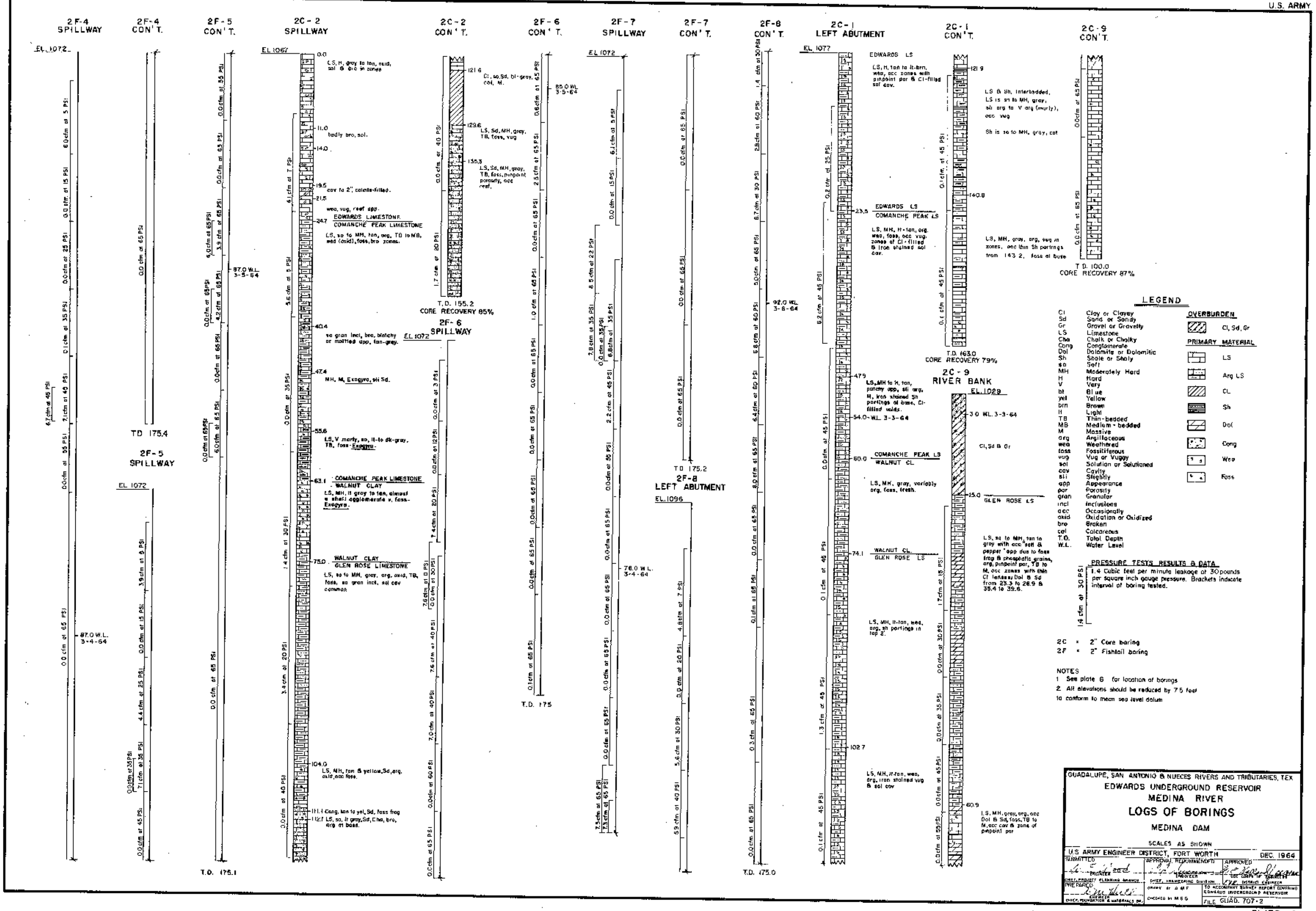


PLATE 8

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.

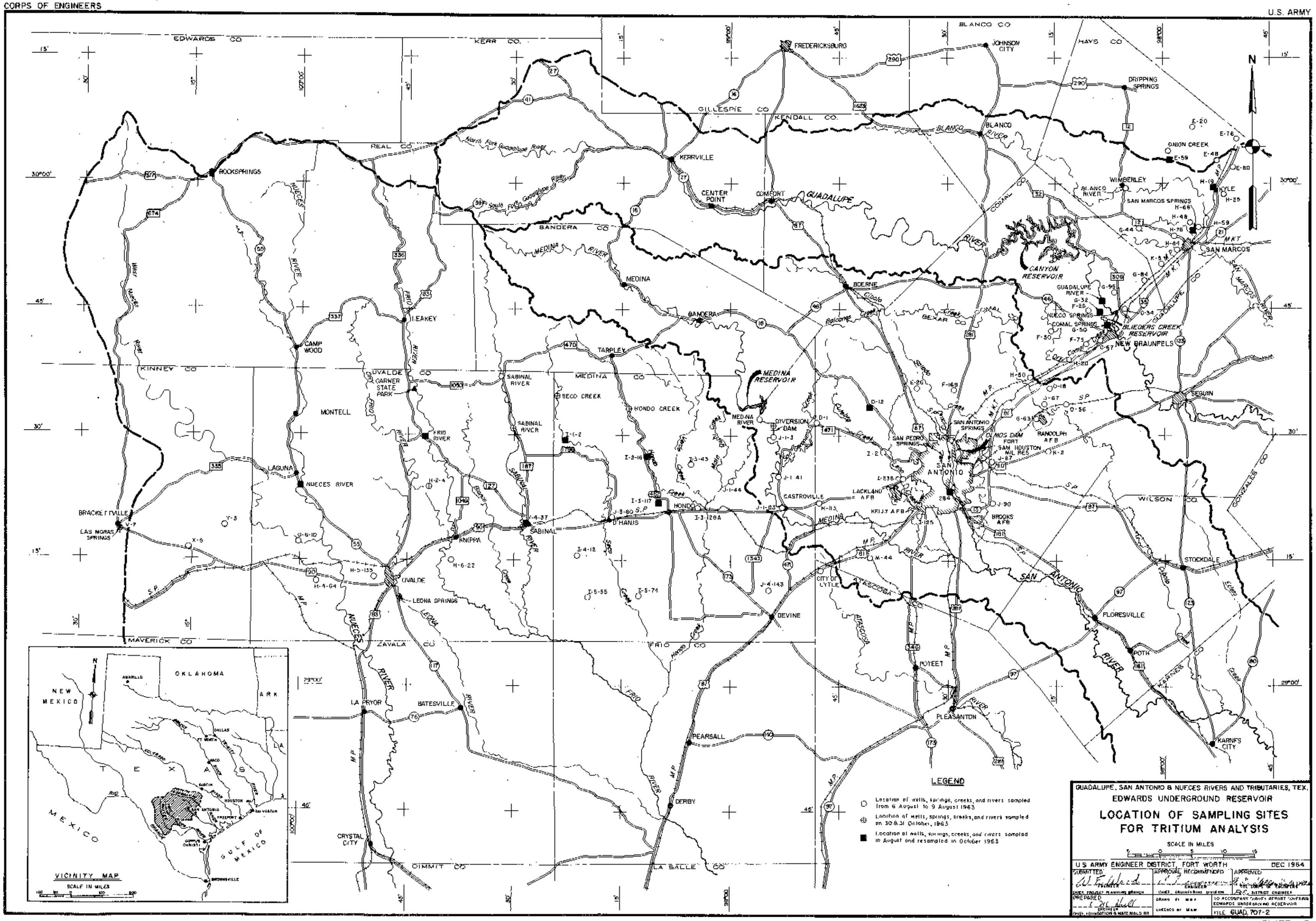
28. To learn how effective tritium can be in studying the movement of water in the Edwards Underground Reservoir, the Fort Worth District entered into a contract with Isotopes, Inc., of Westwood, New Jersey, in early 1963 to perform a localized pilot test program using natural tritium measurements. The 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

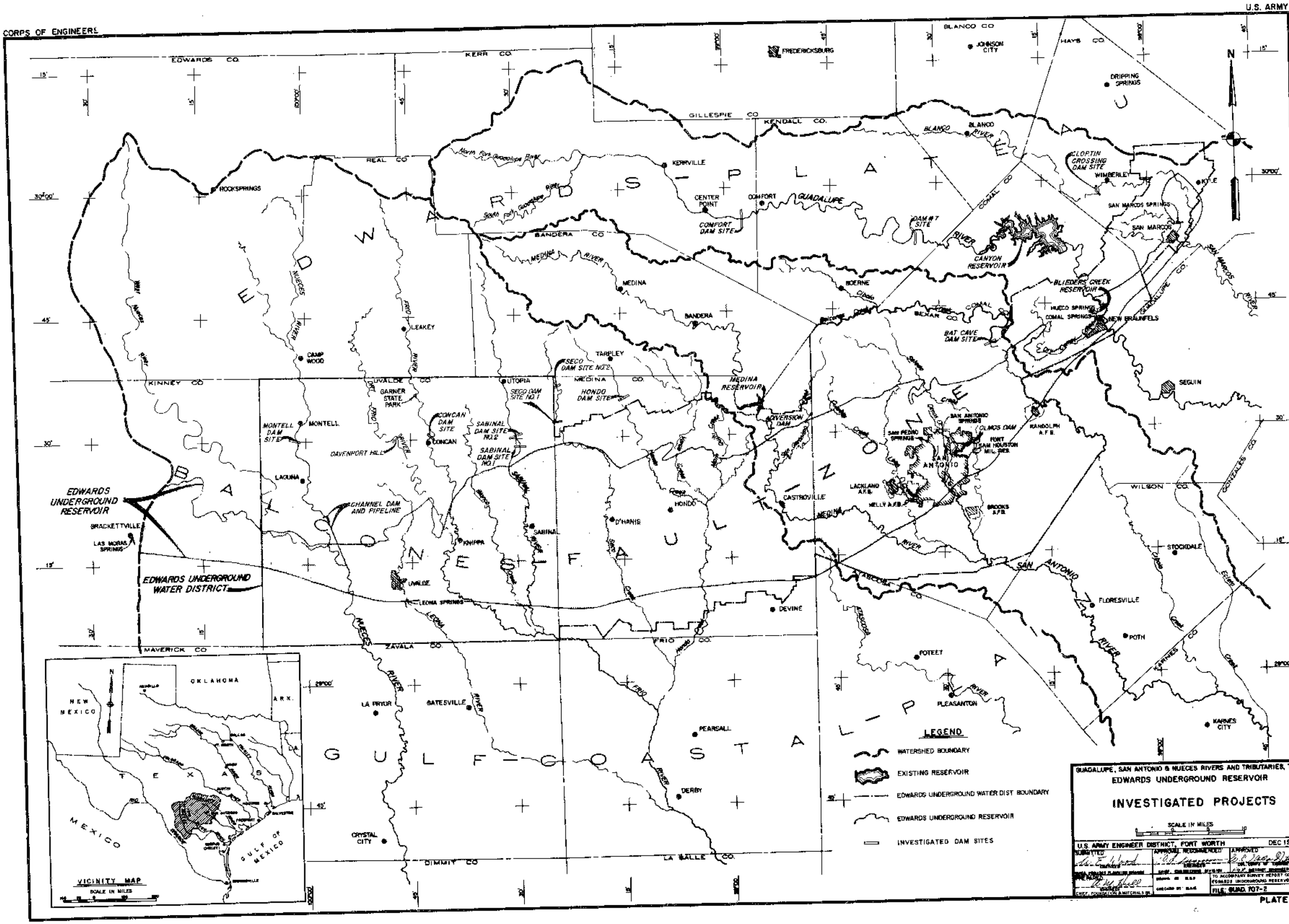

LEGEND
Location of wells, springs, creeks, and rivers sampled from 6 August to 9 August 1963
Location of wells, springs, creeks, and rivers sampled on 30 & 31 October, 1963
Location of wells, springs, creeks, and rivers sampled in August and resampled in October 1963
GUADALUPE, SAN ANTONIO & NUECES RIVERS 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
FILE GUAD. 707-2
VICINITY MAP
NEW MEXICO
OKLAHOMA
TEXAS
MEXICO
GULF OF MEXICO
SAN ANTONIO
NEW BRAUNFELS
SAN MARCOS
SEGUIN
UVALDE
HONDO
BOERNE
KERRVILLE
FREDERICKSBURG
BANDERA
DEVINE
PLEASANTON
FLORESVILLE
MEDINA RESERVOIR
CANYON RESERVOIR

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.


U.S. ARMY
CORPS OF ENGINEERS
EDWARDS CO.
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REAL CO.
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LA SALLE CO.
FREDERICKSBURG
JOHNSON CITY
DRIPPING SPRINGS
BLANCO
KERRVILLE
CENTER POINT
COMFORT
COMFORT DAM SITE
DAM #7 SITE
CLOPTIN CROSSING DAM SITE
WIMBERLEY
KYLE
SAN MARCOS SPRINGS
SAN MARCOS
CANYON RESERVOIR
BLIEDERS CREEK RESERVOIR
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
BAT CAVE DAM SITE
SEGUIN
ROCKSPRINGS
LEAKEY
CAMP WOOD
MEDINA
BANDERA
BOERNE
TARPLEY
SECO DAM SITE NO.2
SECO DAM SITE NO.1
HONDO DAM SITE
MEDINA RESERVOIR
DIVERSION DAM
UTOPIA
GARNER STATE PARK
MONTELL
MONTELL DAM SITE
CONCAN DAM SITE
CONCAN
SABINAL DAM SITE NO.2
SABINAL DAM SITE NO.1
DAVENPORT HILL
LAGUNA
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
OLMOS DAM
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
SAN ANTONIO
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
CASTROVILLE
HONDO
D'HANIS
SABINAL
KNIPPA
EDWARDS UNDERGROUND RESERVOIR
BRACKETTVILLE
LAS MORAS SPRINGS
CHANNEL DAM AND PIPELINE
UVALDE
LEONA SPRINGS
EDWARDS UNDERGROUND WATER DISTRICT
DEVINE
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
PEARSALL
DERBY
CRYSTAL CITY
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
MEDINA RIVER
NUECES RIVER
FRIO RIVER
SAN ANTONIO RIVER
LEONA RIVER
E D W A R D S - P L A T E A U
B A L C O N E S - F A U L T - Z O N E
G U L F - C O A S T A L - P L A I N
LEGEND
WATERSHED BOUNDARY
EXISTING RESERVOIR
EDWARDS UNDERGROUND WATER DIST BOUNDARY
EDWARDS UNDERGROUND RESERVOIR
INVESTIGATED DAM SITES
OKLAHOMA
NEW MEXICO
ARK.
LA.
TEXAS
MEXICO
GULF OF MEXICO
VICINITY MAP
SCALE IN MILES
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEX.
EDWARDS UNDERGROUND RESERVOIR
INVESTIGATED PROJECTS
SCALE IN MILES
U.S. ARMY ENGINEER DISTRICT, FORT WORTH
DEC 1964
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD. 107-2
PLATE 10

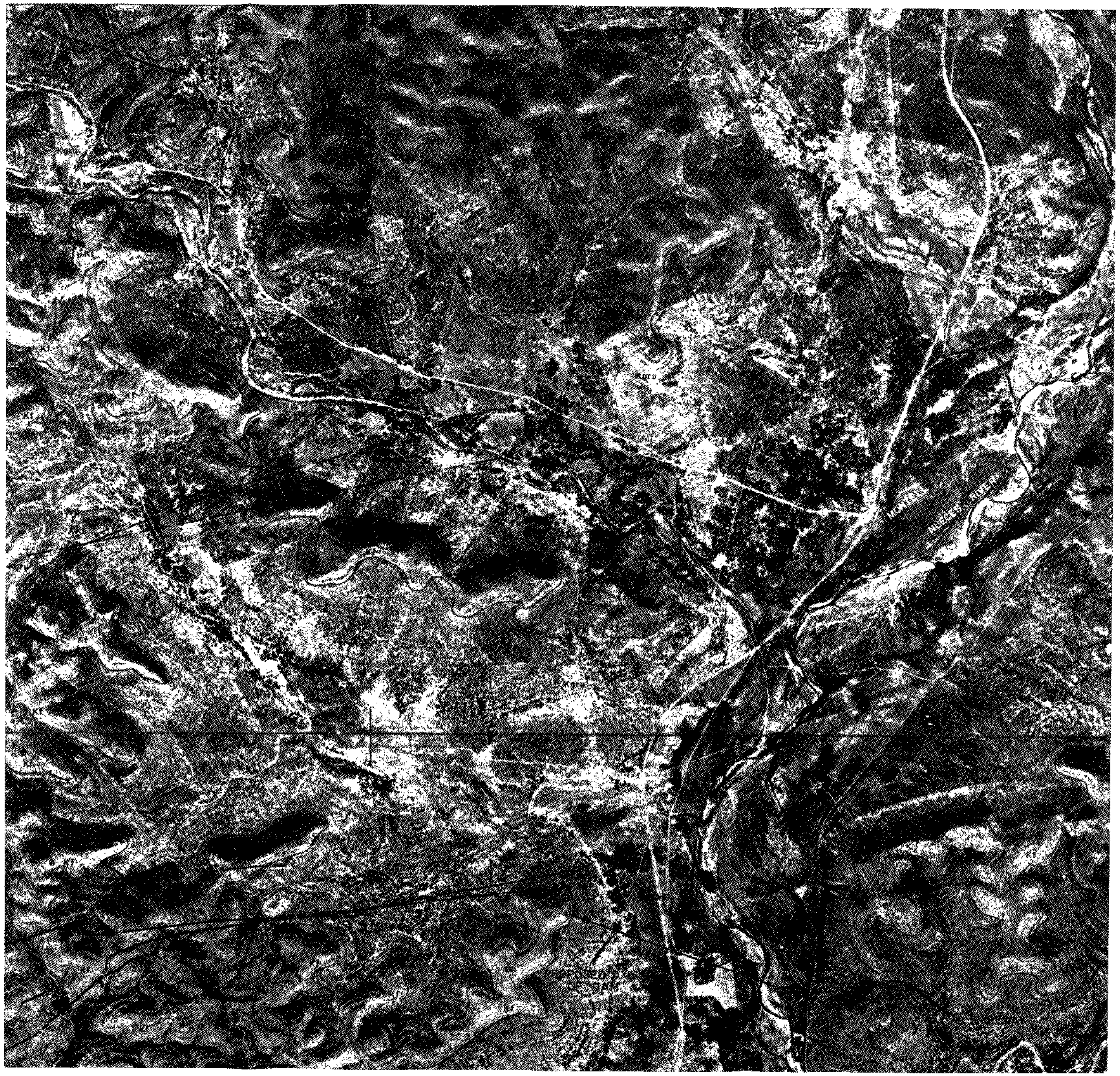
MONTELL DAM SITE - NUECES RIVER

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



LEGEND

CRETACEOUS

Kf	Fredericksburg Group undifferentiated. Includes Kiomichi, Edwards & Comanche 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: 70/ 2

PLATE 11

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.

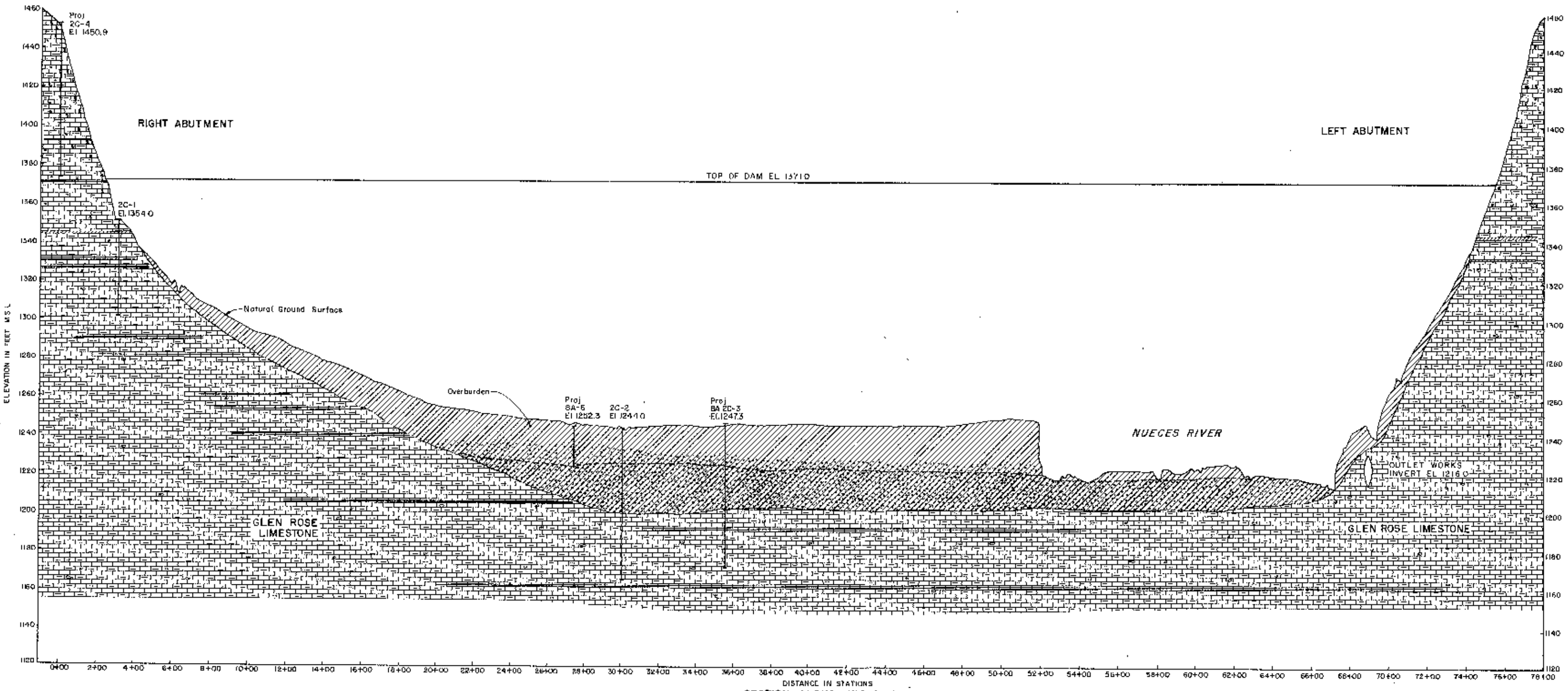
b. There are no known faults cutting the dam axis. A fracture zone, located north of the right abutment, is traceable for a considerable distance, but will not affect the dam foundation.

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.

CORPS OF ENGINEERS

U. S. ARMY



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.

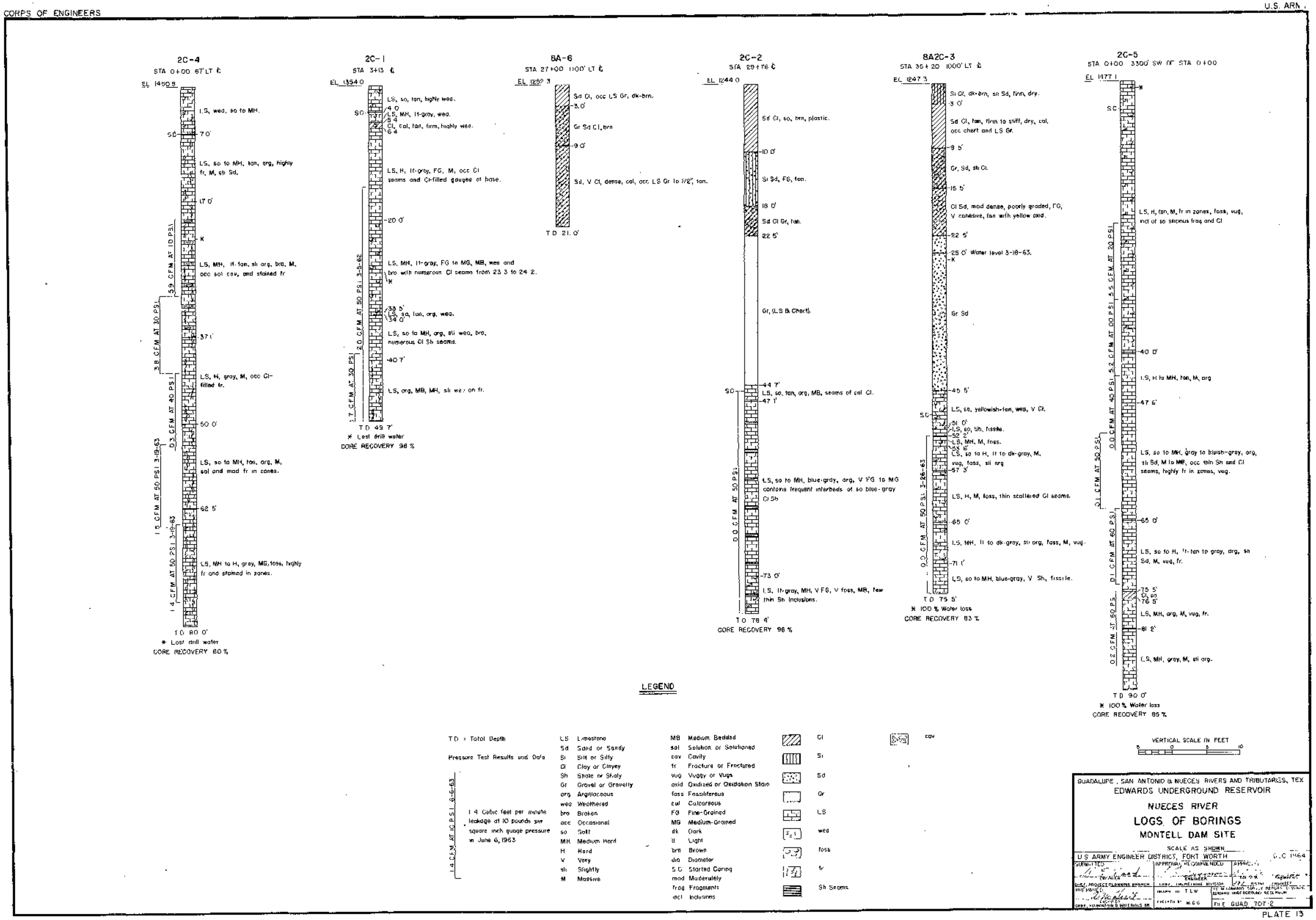
GUADALUPE, SAN ANTONIO & NUECES RIVERS AND TRIBUTARIES, TEXAS
EDWARDS UNDERGROUND RESERVOIR
NUECES RIVER

GEOLOGIC PROFILE
MONTELL DAM SITE

SCALES AS SHOWN

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

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


CORPS OF ENGINEERS
U.S. ARMY
2C-4
STA 0+00 67' LT ℄
EL 1450.9
LS, wea, so to MH.
LS, so to MH, tan, arg, highly fr, M, sli Sd.
LS, MH, lt-tan, sli arg, bro, M, occ sol cav, and stained fr
LS, H, gray, M, occ Cl-filled fr.
LS, so to MH, tan, arg, M, sol and mod fr in zones.
LS, MH to H, gray, MG, foss, highly fr and stained in zones.
T D 80.0'
* Lost drill water
CORE RECOVERY 80 %
2C-1
STA 3+13 ℄
EL 1354.0
LS, so, tan, highly wea.
LS, MH, lt-gray, wea.
Cl, cal, tan, firm, highly wea.
LS, H, lt-gray, FG, M, occ Cl seams and Cl-filled gouges at base.
LS, MH, lt-gray, FG to MG, MB, wea and bro with numerous Cl seams from 23.3 to 24.2.
LS, so, tan, arg, wea.
LS, so to MH, arg, sli wea, bro, numerous Cl Sh seams.
LS, arg, MB, MH, sli wea on fr.
T D 49.7'
* Lost drill water
CORE RECOVERY 98 %
8A-6
STA 27+00 1100' LT ℄
EL 1292.3
Sd Cl, occ LS Gr, dk-brn.
Gr Sd Cl, brn
Sd, V Cl, dense, cal, occ LS Gr to 1/2", tan.
T D 21.0'
2C-2
STA 29+76 ℄
EL 1244.0
Sd Cl, so, brn, plastic.
Si Sd, FG, tan.
Sd Cl Gr, tan.
Gr, (LS & Chert).
LS, so, tan, arg, MB, seams of cal Cl.
LS, so to MH, blue-gray, arg, V FG to MG contains frequent interbeds of so blue-gray Cl Sh
LS, lt-gray, MH, V FG, V foss, MB, few thin Sh inclusions.
T D 78.4'
CORE RECOVERY 98 %
8A2C-3
STA 35+20 1000' LT ℄
EL 1247.3
Si Cl, dk-brn, sli Sd, firm, dry.
Sd Cl, tan, firm to stiff, dry, cal, occ chert and LS Gr.
Gr, Sd, sli Cl.
Cl Sd, mod dense, poorly graded, FG, V cohesive, tan with yellow oxid.
25.0' Water level 3-18-63.
Gr Sd
LS, so, yellowish-tan, wea, V Cl.
LS, so, Sh, fissile.
LS, MH, M, foss.
LS, so to H, lt to dk-gray, M, vug, foss, sli arg
LS, H, M, foss, thin scattered Cl seams.
LS, MH, lt to dk-gray, sli arg, foss, M, vug.
LS, so to MH, blue-gray, V Sh, fissile.
T D 75.5'
* 100 % Water loss
CORE RECOVERY 83 %
2C-5
STA 0+00 3300' SW OF STA 0+00
EL 1477.1
LS, H, tan, M, fr in zones, foss, vug, incl of so siliceous frag and Cl
LS, H to MH, tan, M, arg
LS, so to MH, gray to bluish-gray, arg, sli Sd, M to MB, occ thin Sh and Cl seams, highly fr in zones, vug.
LS, so to H, lt-tan to gray, arg, sli Sd, M, vug, fr.
LS, MH, arg, M, vug, fr.
LS, MH, gray, M, sli arg.
T D 90.0'
* 100 % Water loss
CORE RECOVERY 85 %
LEGEND
T D = Total Depth
Pressure Test Results and Date
1.4 Cubic feet per minute leakage at 10 pounds per square inch guage pressure in June 6, 1963
LS Limestone
Sd Sand or Sandy
Si Silt or Silty
Cl Clay or Clayey
Sh Shale or Shaly
Gr Gravel or Gravelly
arg Argillaceous
wea Weathered
bro Broken
occ Occasional
so Soft
MH Medium Hard
H Hard
V Very
sli Slightly
M Massive
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
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
FILE GUAD. 707-2
PLATE 13

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.

CORPS OF ENGINEERS

U S ARMY

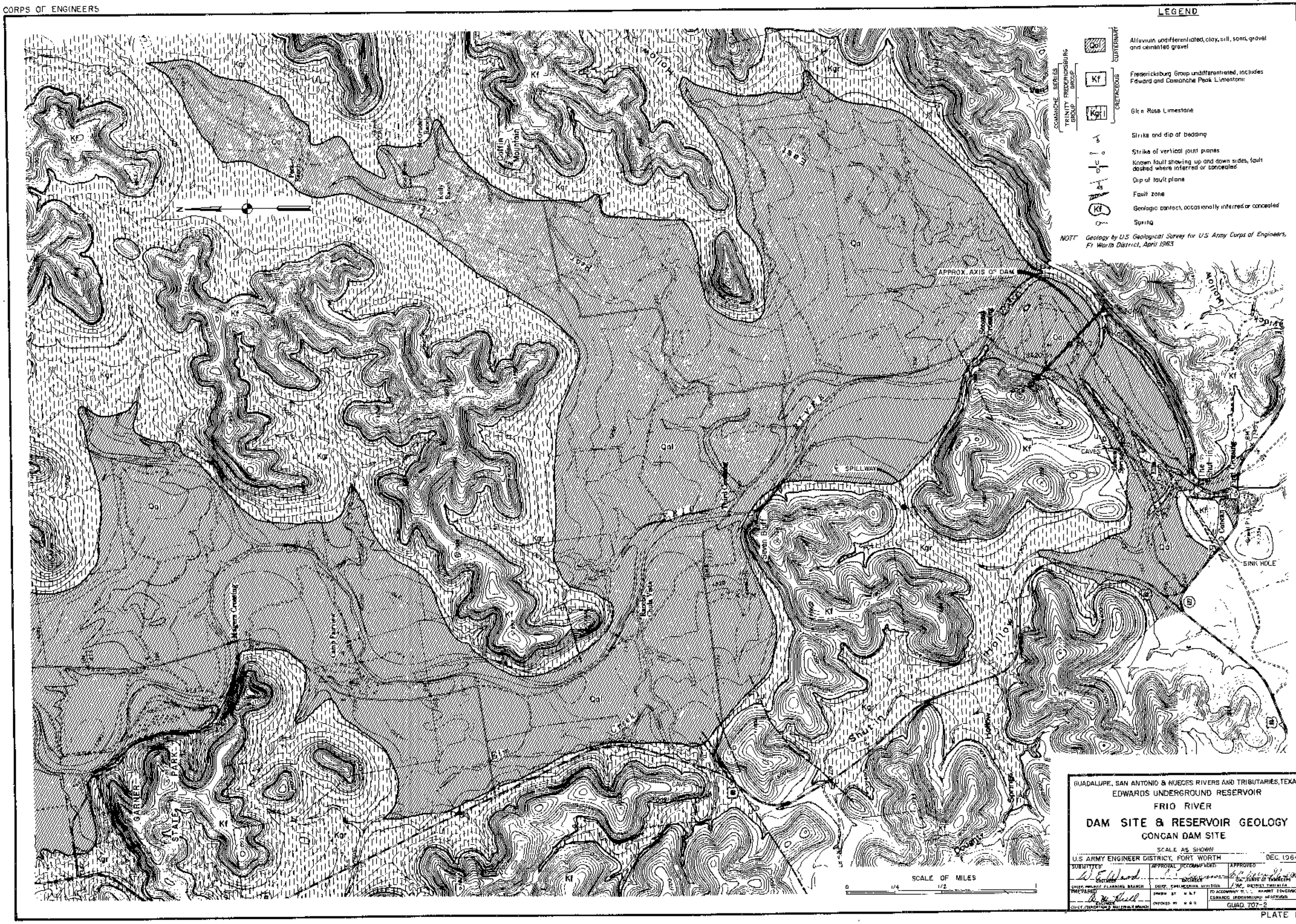
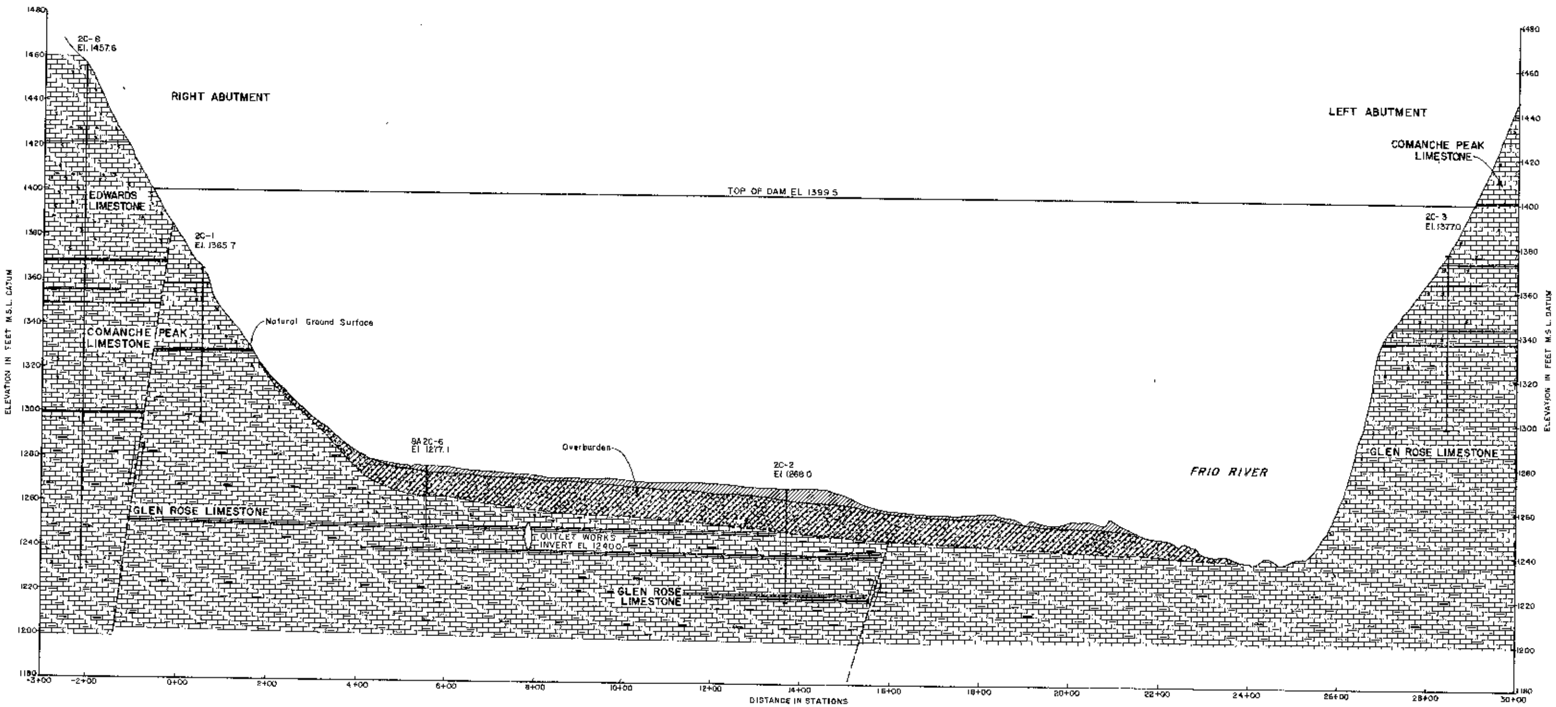


PLATE 14



SECTION ALONG AXIS OF DAM

LEGEND

OVERBURDEN

- Sandy Clay, tan
- Gravel, Sand and Clay

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
- Shale-dark-gray, soft, clayey
- Weathering
- Chert
- 2C 2" Core boring
- 8A 8" Auger boring
- Inferred fault, arrows show direction of movement.

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: ENGINEER, CHIEF, PROJECT PLANNING BRANCH	APPROVAL RECOMMENDED: ENGINEER, CHIEF, ENGINEERING DIVISION	APPROVED: COL. CORPS OF ENGINEERS, DIST. ENGINEER
PREPARED: ENGINEER, CHIEF, FOUNDATION & MATERIALS BRANCH	DRAWN BY V.J.M. / CHECKED BY M.C.D.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR / HKE QUAD 707-2

PLATE 15

CORPS OF ENGINEERS U.S ARMY

LEGEND

PRIMARY STRATA

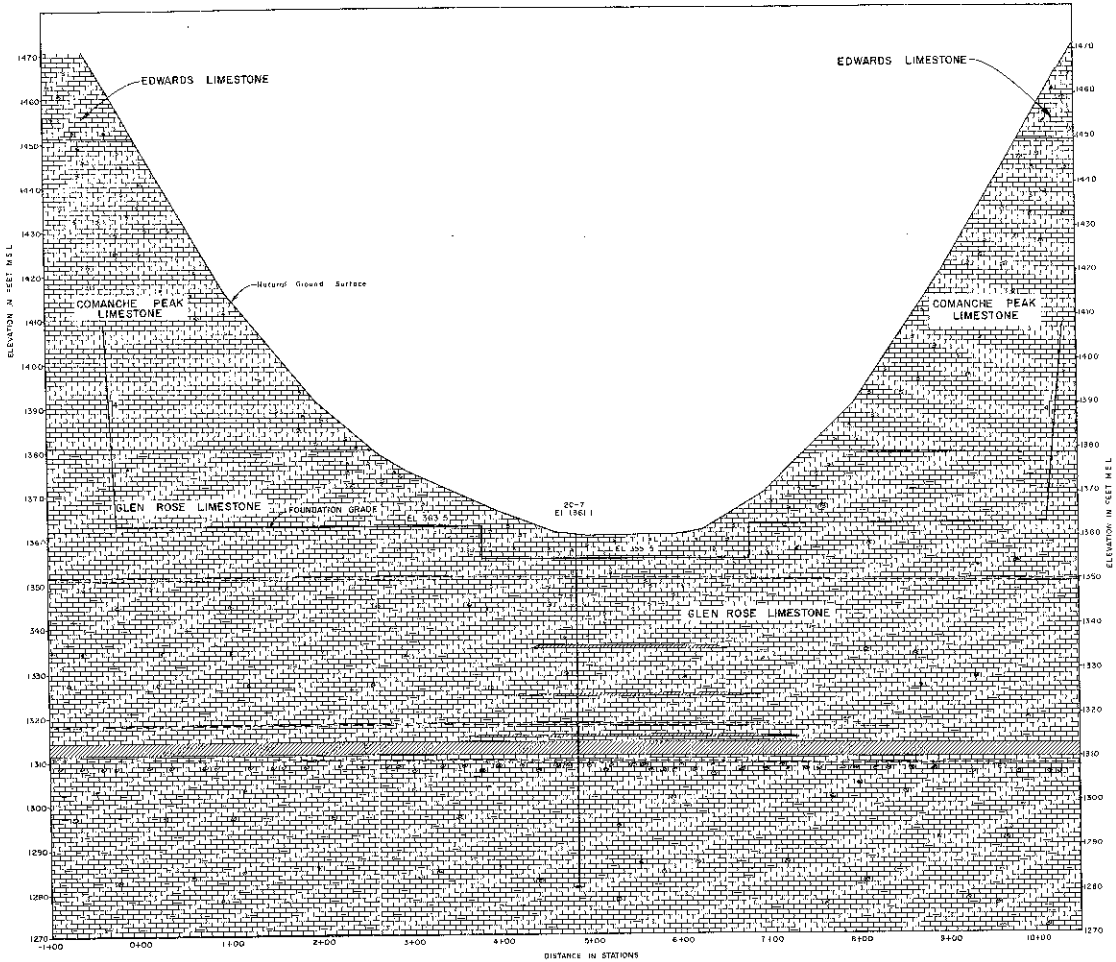
- Edwards Limestone - Moderately hard to hard, gray, medium to massive bedded, vuggy and solutioned, scattered chert nodules
- Comanche Peak Limestone - Moderately hard to hard, gray, nodular, fossiliferous, vuggy
- Glen Rose Limestone Soft to moderately hard, tan to tan-gray, thin to medium-bedded, 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 (Kugers Crossing).



SPILLWAY
(LOOKING EAST)

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

GEOLOGIC SECTION

CONCAN DAM SITE

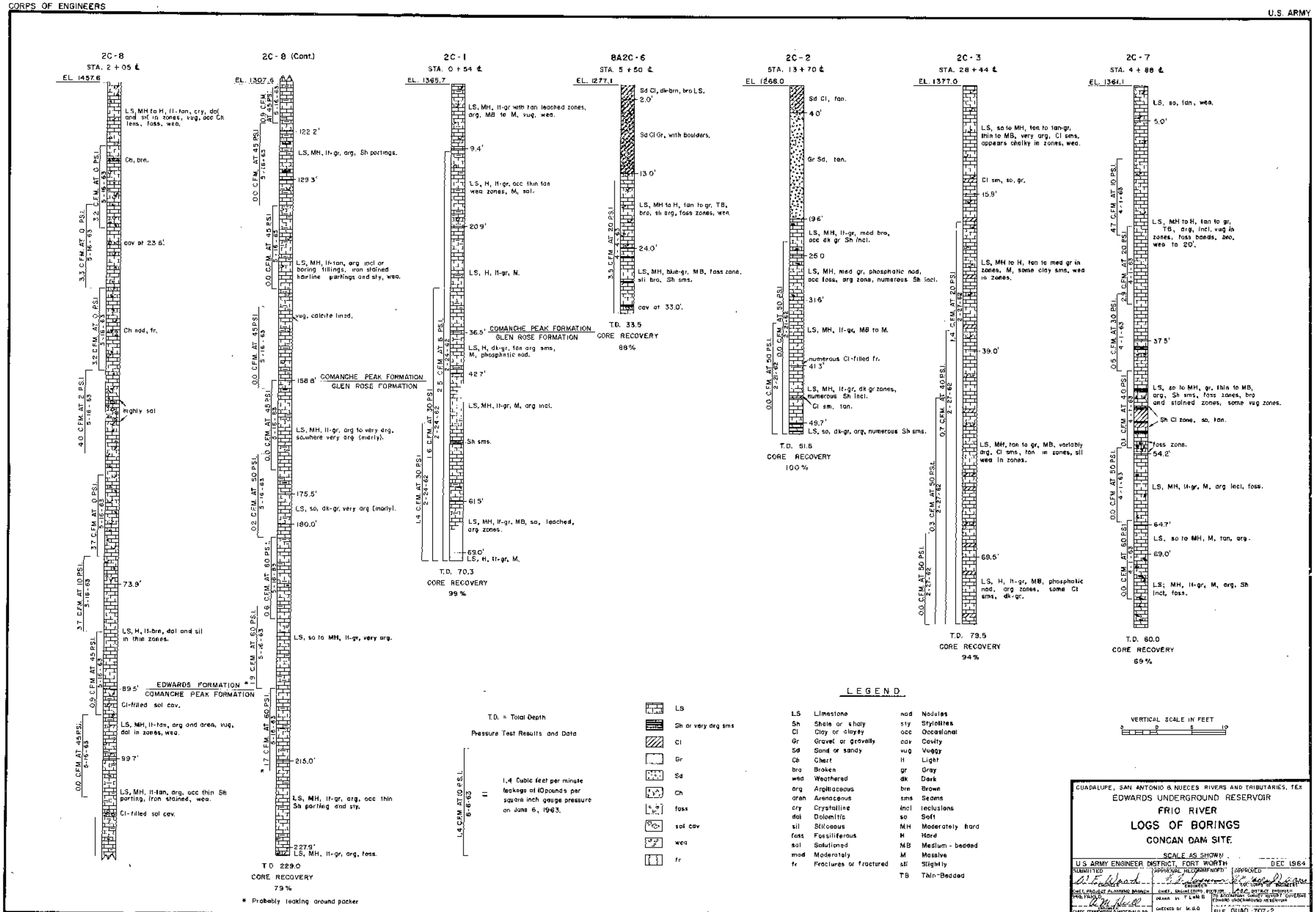
SCALES AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, Engineer, Chief, Project Planning Branch	Engineer, Chief, Engineering Division	Lt. Col. Corps of Engineers, District Engineer
PREPARED: A. M. Hull, 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

PLATE 16

CORPS OF ENGINEERS U.S. ARMY



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
FILE GUAD. 707-2

PLATE 17

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.

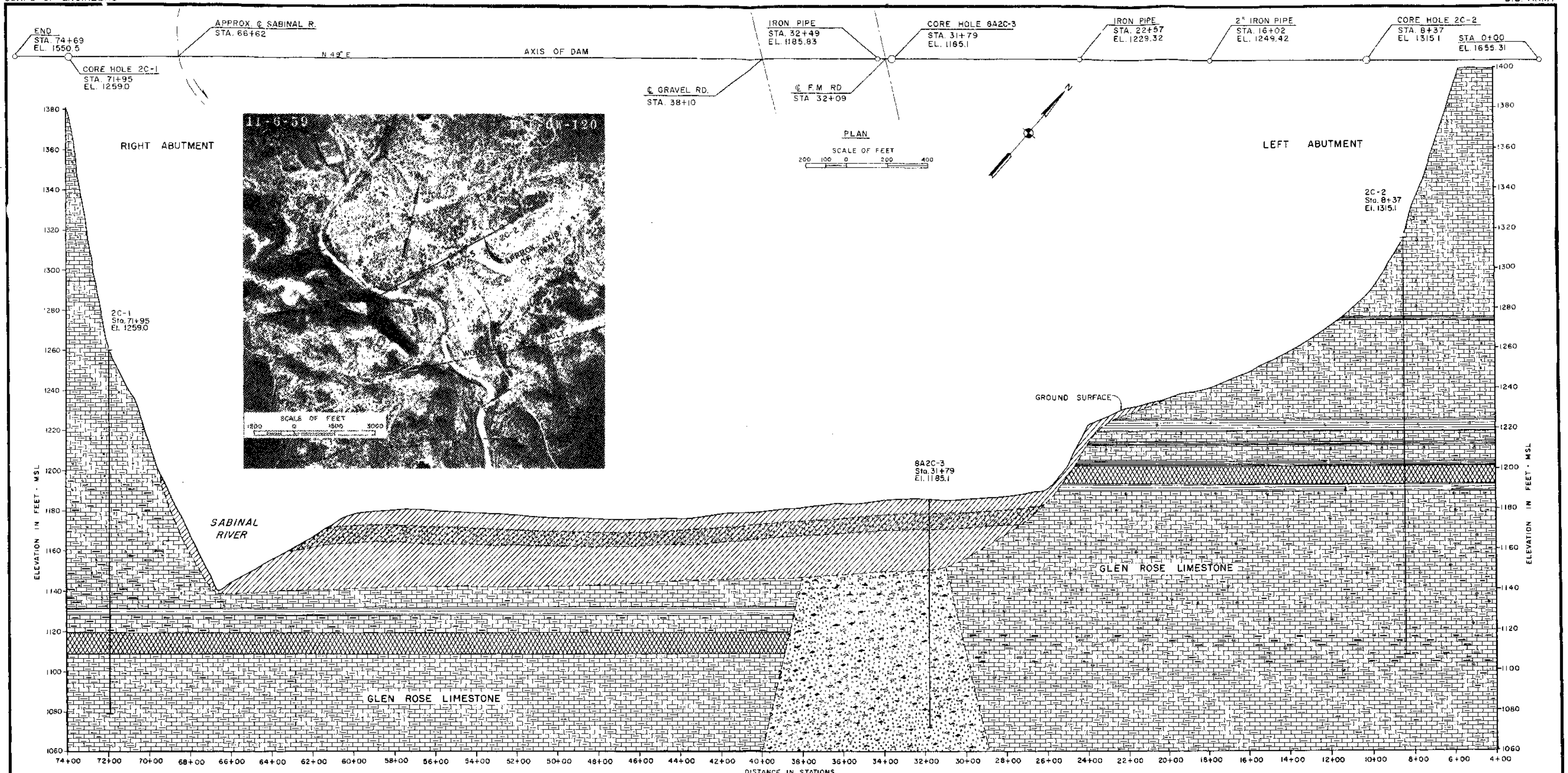
61. STRUCTURAL GEOLOGY.- The Balcones fault zone, a belt of intense faulting extending northeast-southwest across Uvalde County, is the principal structural feature in the area. The Geological Survey 25/ reports that in the northeastern part of the county, the total vertical displacement across the zone 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



SECTION 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
- s = 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 W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	APPROVAL RECOMMENDED C. R. Swenson, ENGINEER, CHIEF, ENGINEERING DIVISION	APPROVED [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

PLATE 18

83-939 O-72-Vol. 2 (Face p. 240)

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

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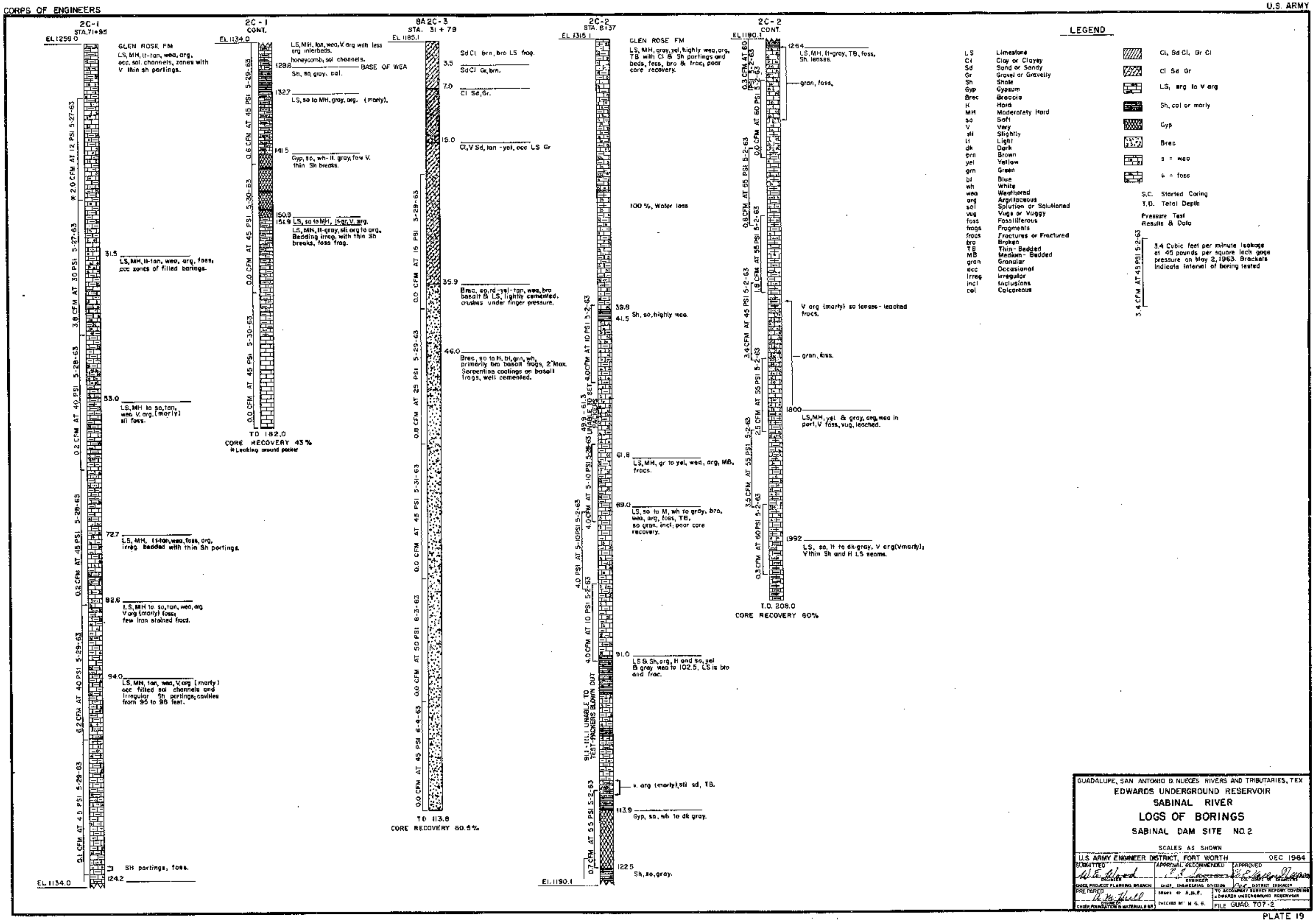
potentially serious leakage condition exists in the limestone and gypsum comprising both abutments, and along the periphery of the referenced intrusive. The highly soluble gypsum bed encountered at the site will require special foundation treatment.

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.


CORPS OF ENGINEERS
U.S. ARMY
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, sol.
132.7
LS, so to MH, gray, arg. (marly).
141.5
Gyp, so, wh- lt. gray, few V. thin Sh breaks.
150.9
151.9
LS, so to MH, lt-gr, V arg.
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
8A2C-3
STA. 31+79
EL 1185.1
Sd Cl brn, bro LS frag.
3.5
Sd Cl 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%
2C-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
91.1-111.1 UNABLE TO TEST-PACKERS BLOWN OUT
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
s = wea
6 = foss
S.C. Started Coring
T.D. Total Depth
Pressure Test Results & Data
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
3.4 CFM AT 45 PSI 5-2-63
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
FILE GUAD. T07-2
PLATE 19

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/.

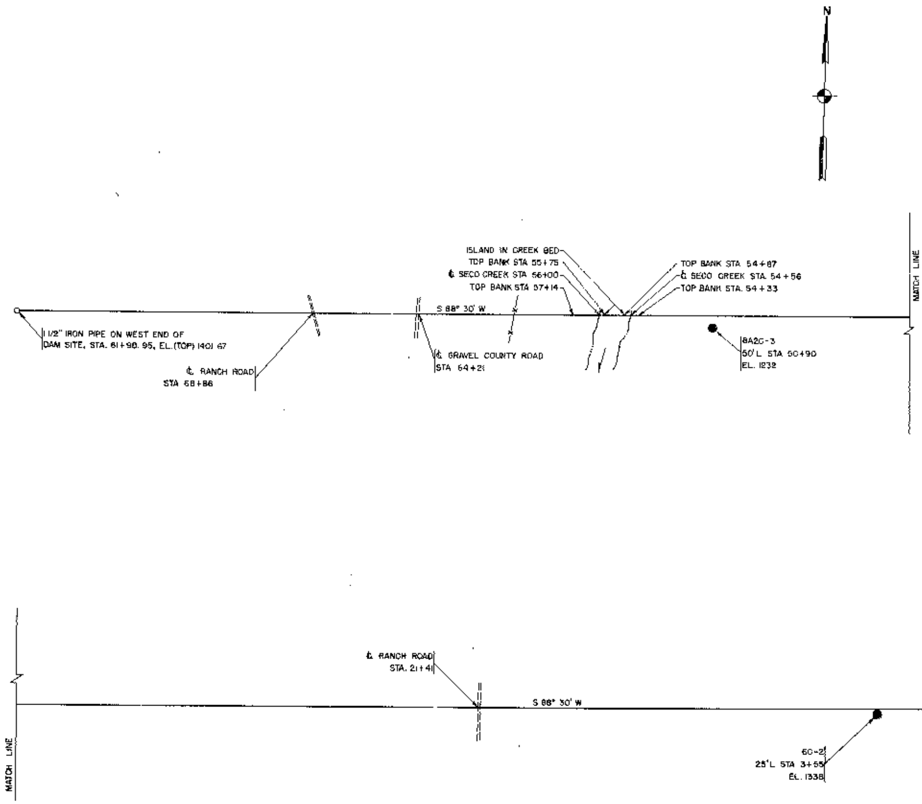
79. CONSTRUCTION MATERIALS.- From the present investigation it is not believed that a sufficient quantity of alluvium is available for an earthfill embankment, but the quantity may be adequate for impervious core or blanket use. Material for a random rockfill embankment is available from the Glen Rose 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

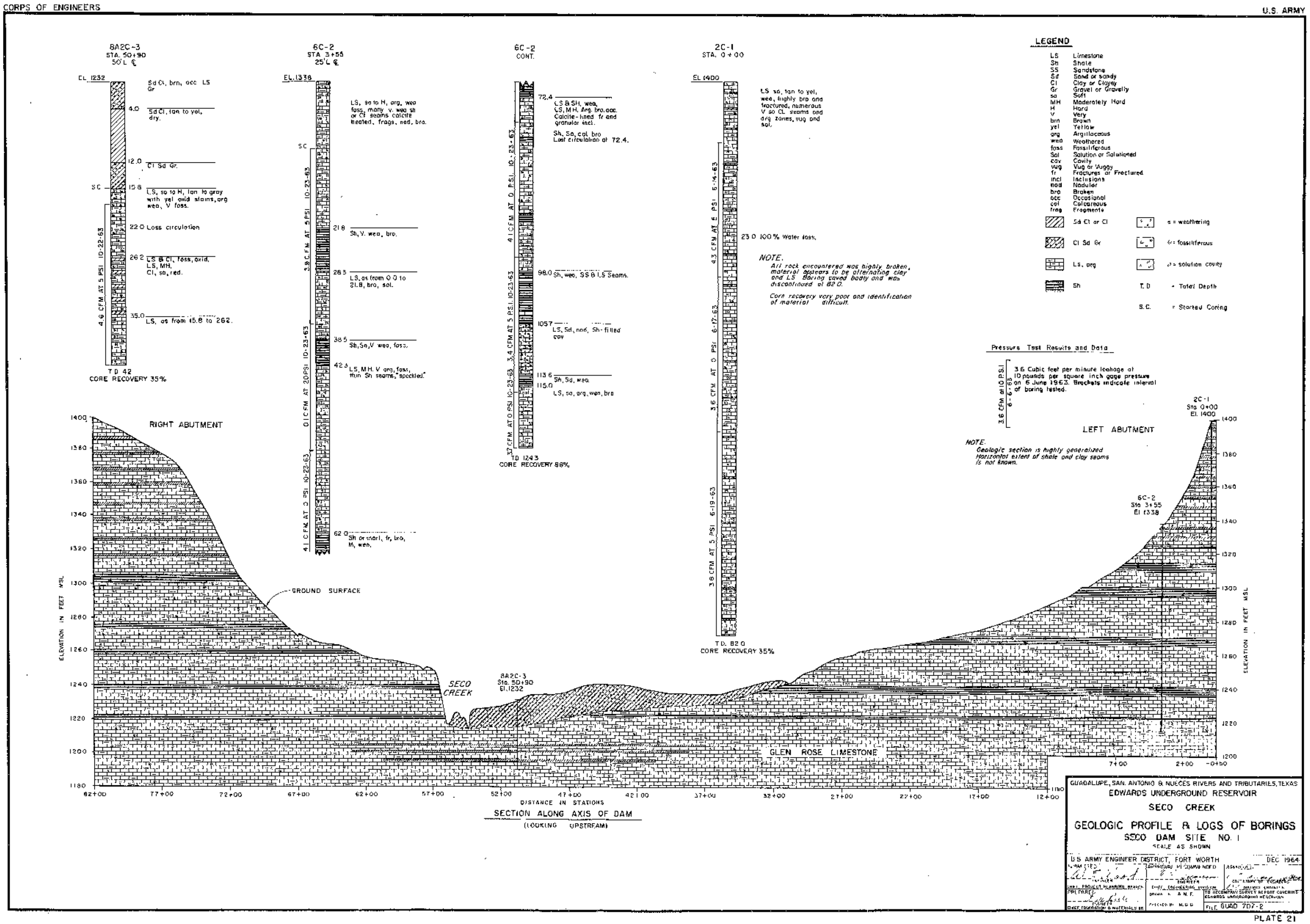
PLAN OF ALIGNMENT

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, DISTRICT ENGINEER
PREPARED: ENGINEER, CHIEF FOUNDATION & MATERIALS BR.	DRAWN BY T.L.P. CHECKED BY M.G.S.	TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR; FILE GUAD T07-2


CORPS OF ENGINEERS
U.S. ARMY
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
TD 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, Sa, V wea, foss.
42.3 LS, MH, V arg, foss, thin Sh seams, "speckled."
62.0 Sh or marl, fr, bro, M, wea.
3.8 CFM AT 5 PSI 10-23-63
0 I CFM AT 20 PSI 10-23-63
4.1 CFM AT 0 PSI 10-23-63
6C-2
CONT.
72.4 LS & SH, wea, LS, MH, Arg. bro, occ. Calcite-lined fr and granular incl.
Sh, Sa, cal. bro
Lost circulation at 72.4.
98.0 Sh, wea, SS & LS Seams.
105.7 LS, Sd, nod, Sh-filled cav
113.6 Sh, Sd, wea.
115.0 LS, so, arg, wea, bro
4.1 CFM AT 0 PSI 10-23-63
3.4 CFM AT 5 PSI 10-23-63
3.7 CFM AT 0 PSI 10-23-63
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.
4.3 CFM AT 5 PSI 6-14-63
3.6 CFM AT 0 PSI 6-17-63
3.8 CFM AT 5 PSI 6-19-63
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 CFM at 10 P.S.I. 6-6-63
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
8A2C-3
Sta. 50+90
El. 1232
6C-2
Sta 3+55
El 1338
2C-1
Sta 0+00
El. 1400
GLEN ROSE LIMESTONE
ELEVATION IN FEET MSL
1400
1380
1360
1340
1320
1300
1280
1260
1240
1220
1200
1180
82+00
77+00
72+00
67+00
62+00
57+00
52+00
47+00
42+00
37+00
32+00
27+00
22+00
17+00
12+00
7+00
2+00
-0+50
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
SUBMITTED
APPROVAL RECOMMENDED
APPROVED
ENGINEER
CHIEF, ENGINEERING DIVISION
DISTRICT ENGINEER
CHIEF, PROJECT PLANNING BRANCH
PREPARED
CHIEF, FOUNDATION & MATERIALS BR.
DRAWN BY A. N. F.
CHECKED BY N. G. G.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD 707-2
PLATE 21

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.

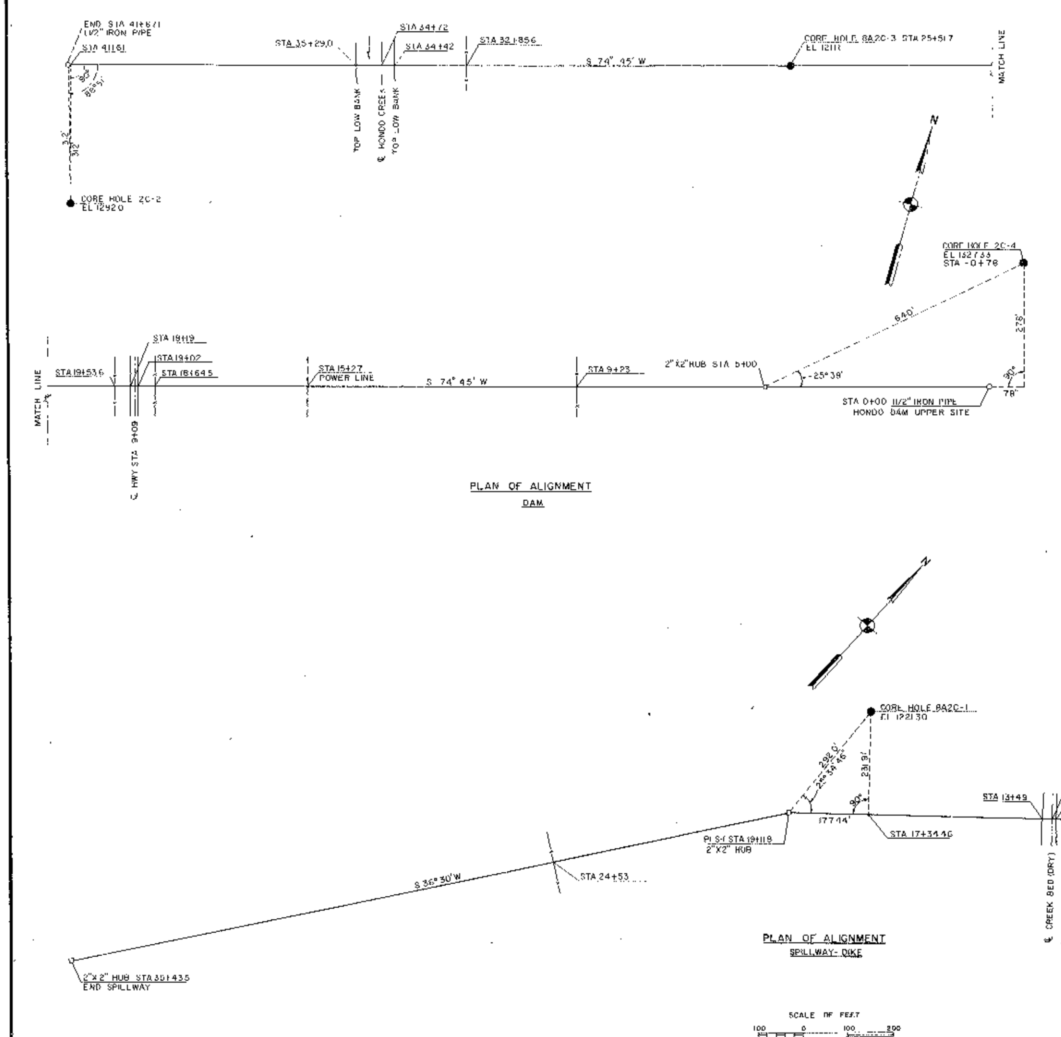
87. CONSTRUCTION MATERIALS.- Preliminary field investigations indicate that flood-plain alluvium, suitable for an impervious core, may be available in the broad flood plain contiguous to and upstream from the dam site. Boring 8A2C-3, located along the proposed dam axis in the valley, encountered 10.5 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.

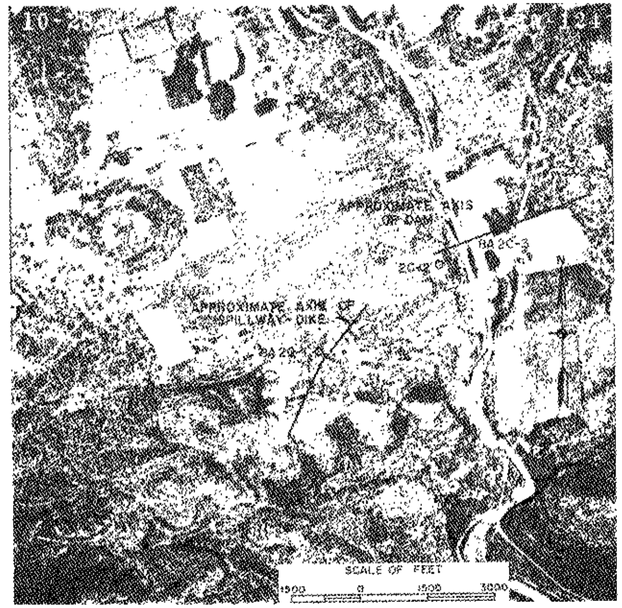
88. CONCLUSIONS AND RECOMMENDATIONS.- On the basis of the investigations completed at the site, the following conclusions are presented:

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

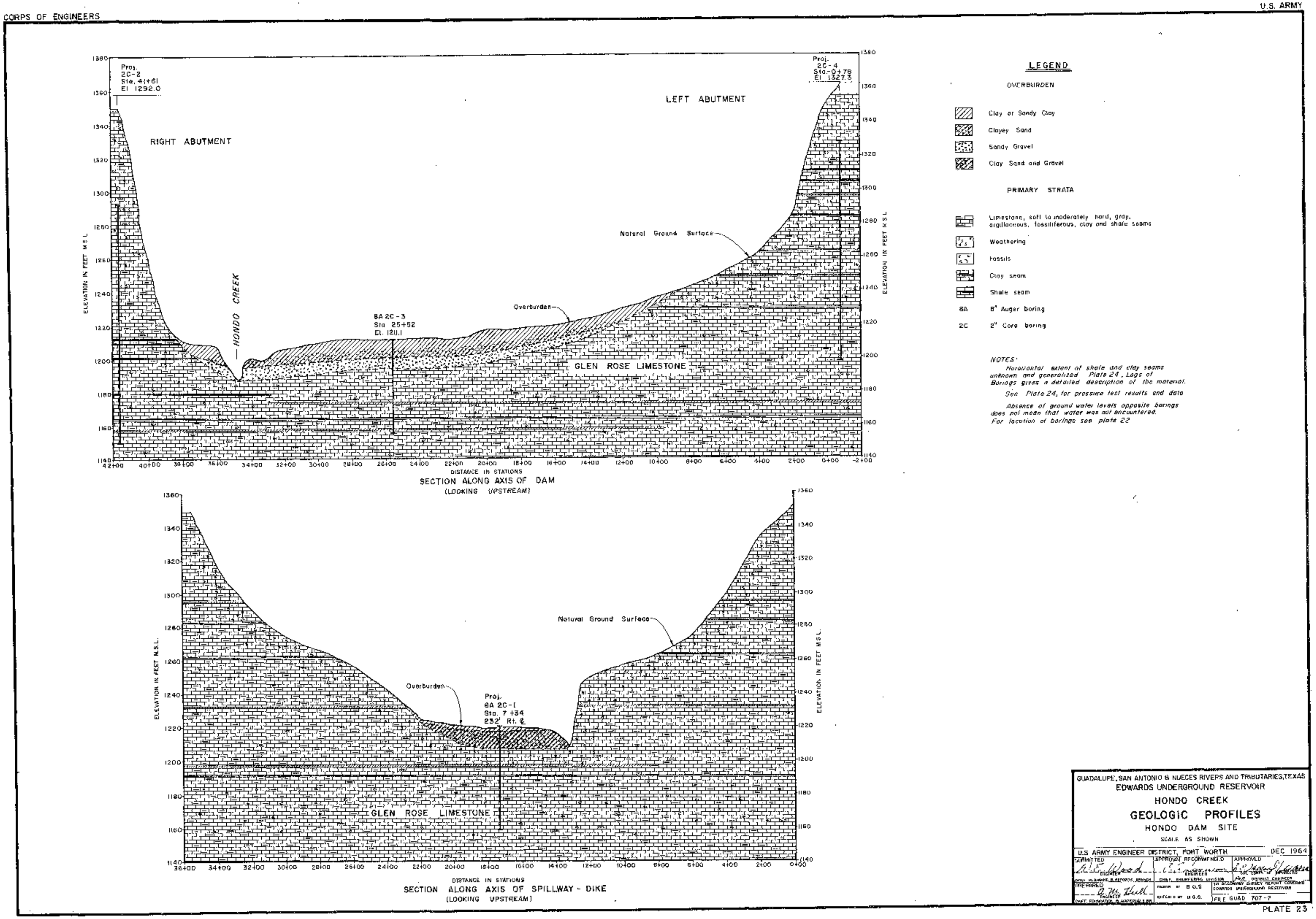
PLAN OF ALIGNMENT

HONDO DAM SITE

SCALE AS SHOWN

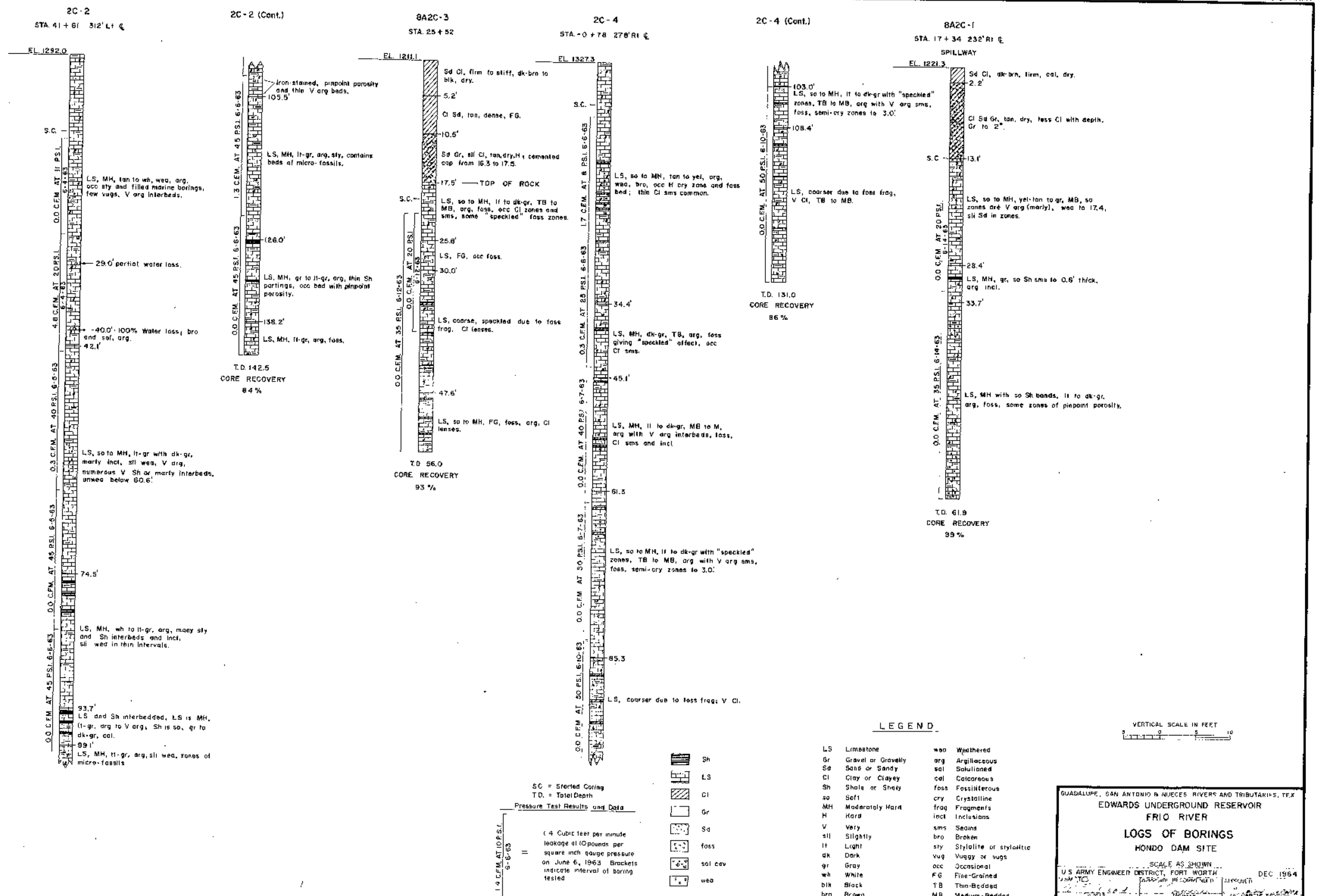
U.S. ARMY ENGINEER DISTRICT, FORT WORTH — DEC 1964

GUAD 707-2


CORPS OF ENGINEERS
U.S. ARMY
RIGHT ABUTMENT
LEFT ABUTMENT
Proj. 2C-2 Sta. 41+61 El 1292.0
Proj. 2C-4 Sta. 0+78 El 1327.3
HONDO CREEK
8A 2C-3 Sta 25+52 El. 1211.1
Overburden
Natural Ground Surface
GLEN ROSE LIMESTONE
ELEVATION IN FEET M.S.L.
DISTANCE IN STATIONS
SECTION ALONG AXIS OF DAM
(LOOKING UPSTREAM)
Proj. 8A 2C-1 Sta. 7+34 232' Rt. ℄
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
PREPARED
DRAWN BY B G.S
CHECKED BY U.G.S.
FILE GUAD 707-7
PLATE 23

CORPS OF ENGINEERS U.S. ARMY

260



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

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

EDWARDS UNDERGROUND RESERVOIR

FRIO RIVER

LOGS OF BORINGS

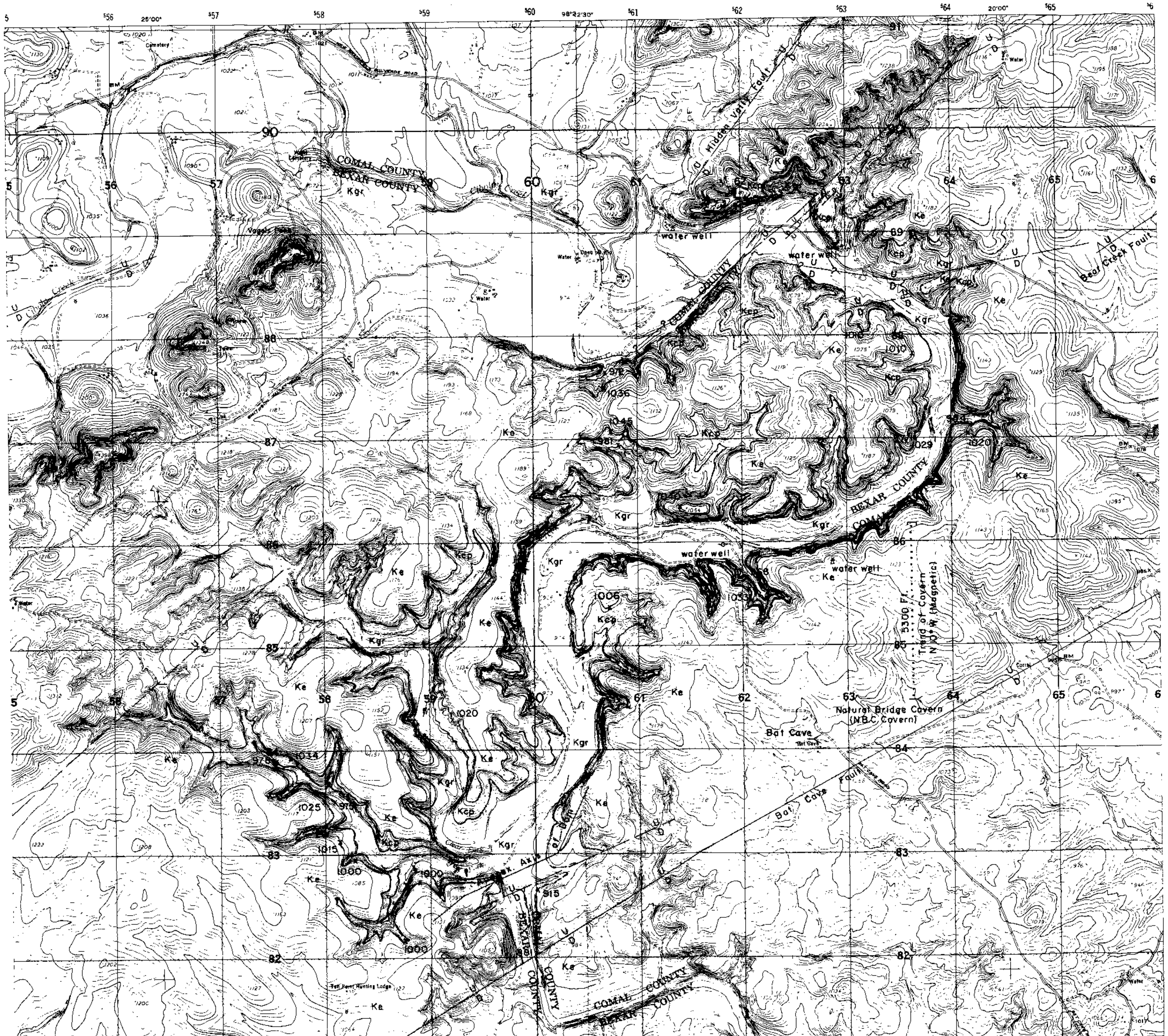
HONDO DAM SITE

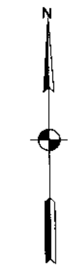
SCALE AS SHOWN

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

FILE GUAD. 707-2

PLATE 24





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 W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	APPROVAL RECOMMENDED ENGINEER, CHIEF, ENGINEERING DIVISION	APPROVED COL CORPS OF ENGINEERS, FOR 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

PLATE 25

83-939 O-72-Vol. 2 (Face p. 260)

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.

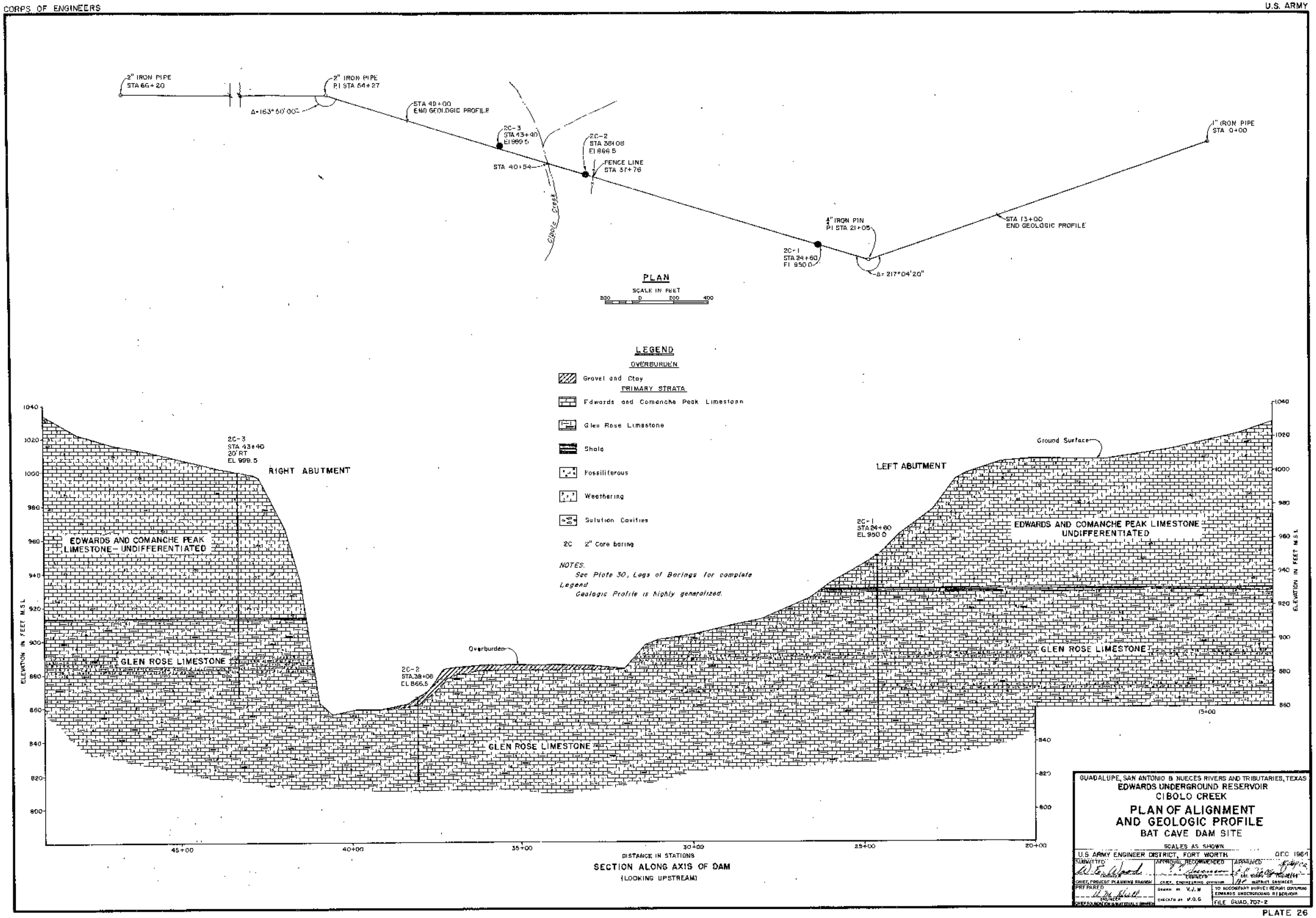
d. Faulting.- The proposed Bat Cave Dam site is located in an area of intense faulting and may possibly include minor faulting contiguous to or intersecting the proposed alignment. Geologic contacts, determined from the abutment core holes, showed the Comanche Peak-Glen Rose contact at elevation 912.5 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.



CORPS OF ENGINEERS
U.S. ARMY
2" IRON PIPE
STA 66+20
2" IRON PIPE
P.I. STA 54+27
Δ=163°50'00"
STA 49+00
END GEOLOGIC PROFILE
2C-3
STA 43+40
El 999.5
STA 40+54
2C-2
STA 38+08
El 866.5
FENCE LINE
STA 37+76
Cibolo Creek
1" IRON PIPE
STA 0+00
STA 13+00
END GEOLOGIC PROFILE
3/4" IRON PIN
P.I. STA 21+05
2C-1
STA 24+60
El 950.0
Δ=217°04'20"
PLAN
SCALE IN FEET
200 0 200 400
LEGEND
OVERBURDEN
Gravel and Clay
PRIMARY STRATA
Edwards and Comanche Peak Limestone
Glen Rose Limestone
Shale
Fossiliferous
Weathering
Solution Cavities
2C 2" Core boring
NOTES:
See Plate 30, Logs of Borings for complete Legend
Geologic Profile is highly generalized.
2C-3
STA 43+40
20' RT
EL 999.5
RIGHT ABUTMENT
LEFT ABUTMENT
Ground Surface
EDWARDS AND COMANCHE PEAK LIMESTONE- UNDIFFERENTIATED
EDWARDS AND COMANCHE PEAK LIMESTONE UNDIFFERENTIATED
2C-1
STA 24+60
EL 950.0
GLEN ROSE LIMESTONE
Overburden
2C-2
STA 38+08
EL 866.5
GLEN ROSE LIMESTONE
GLEN ROSE LIMESTONE
ELEVATION IN FEET M.S.L.
1040
1020
1000
980
960
940
920
900
880
860
840
820
800
45+00
40+00
35+00
30+00
25+00
20+00
15+00
DISTANCE IN STATIONS
SECTION ALONG AXIS OF DAM
(LOOKING UPSTREAM)
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
SUBMITTED
ENGINEER
CHIEF, PROJECT PLANNING BRANCH
APPROVAL RECOMMENDED
ENGINEER
CHIEF, ENGINEERING DIVISION
APPROVED
DISTRICT ENGINEER
PREPARED
ENGINEER
DRAWN BY V.J.M.
CHECKED BY V.G.G.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE GUAD. 707-2
PLATE 26

CORPS OF ENGINEERS U.S. ARMY

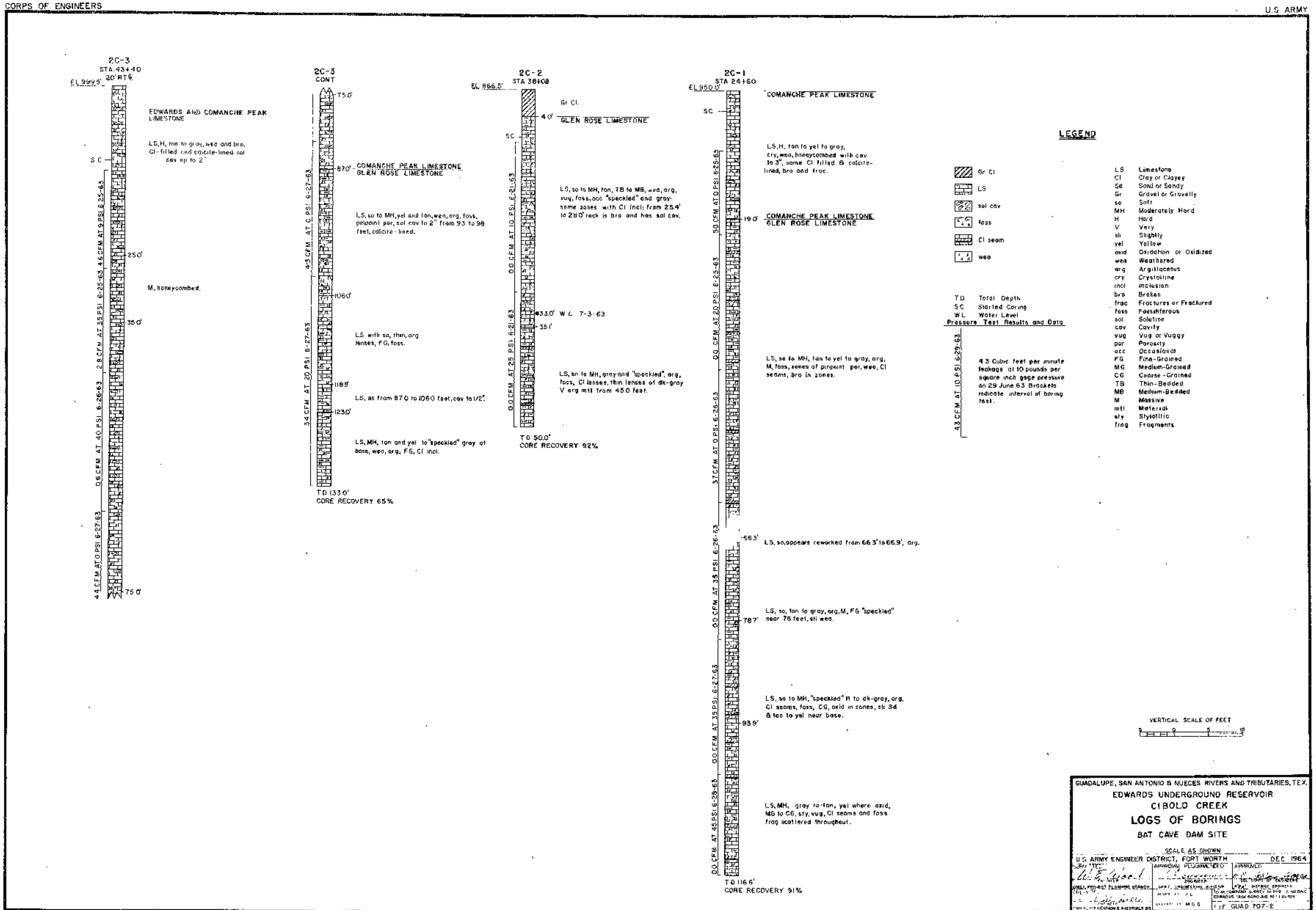
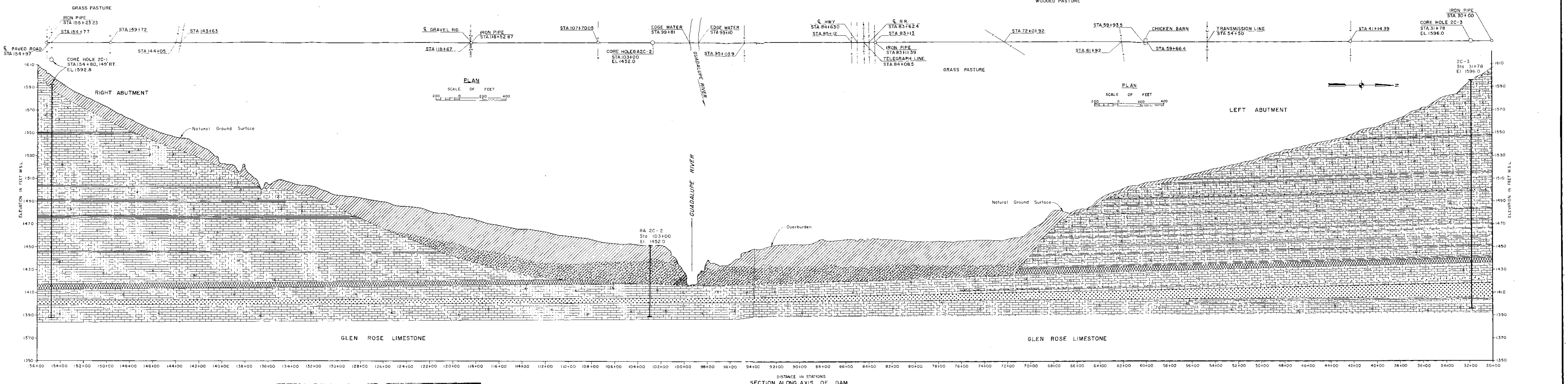
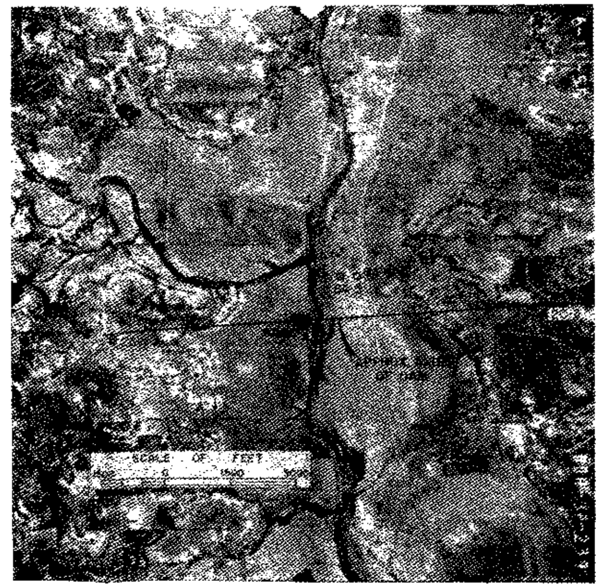


PLATE 27

266



SECTION ALONG AXIS OF DAM
(LOOKING UPSTREAM)



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: COL CORPS OF ENGINEERS, 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

PLATE 28

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.

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.

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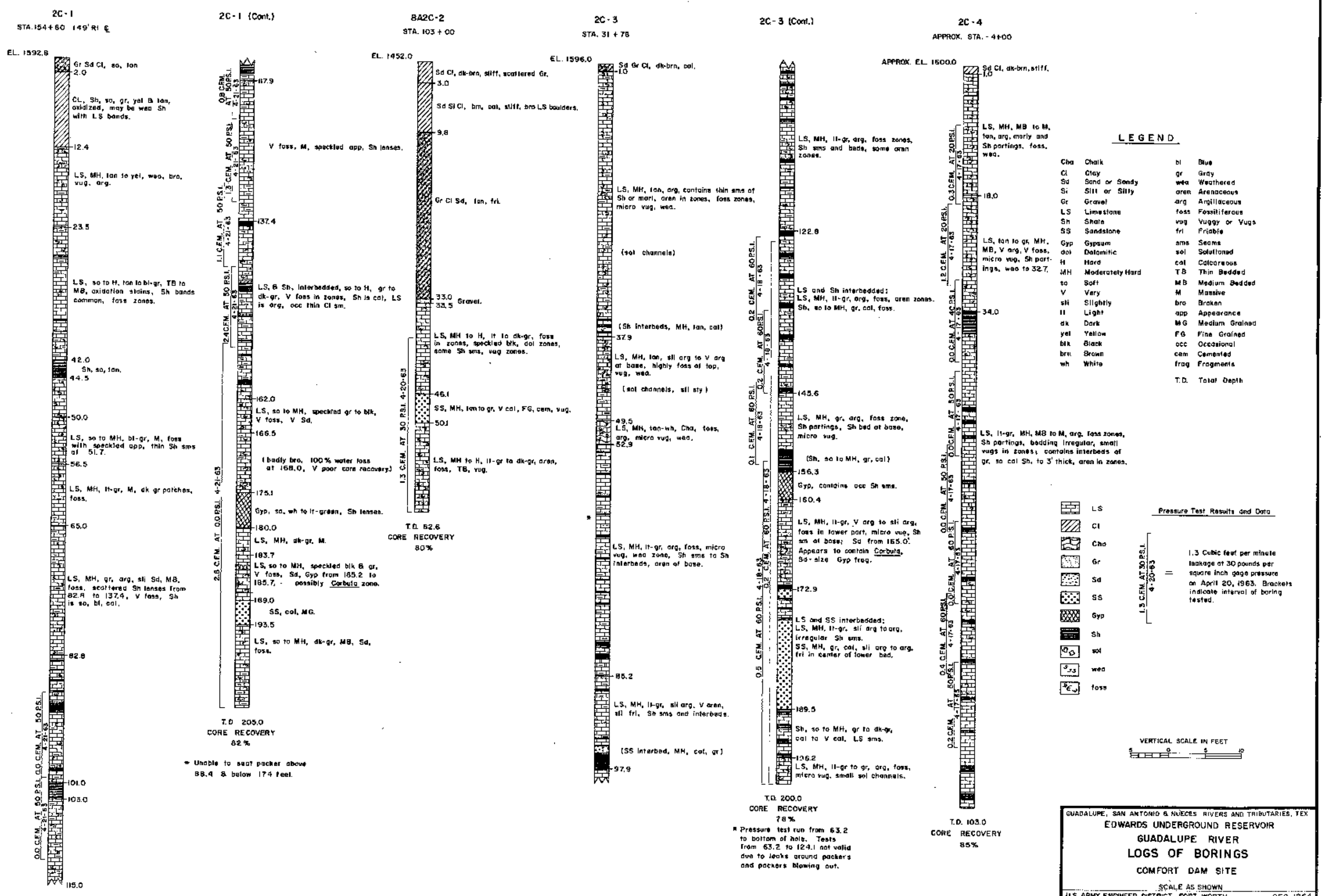
CORPS OF ENGINEERS

U.S. ARMY



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 — CHIEF, PROJECT PLANNING BRANCH; APPROVAL RECOMMENDED — CHIEF, ENGINEERING DIVISION; APPROVED — DISTRICT ENGINEER

PREPARED — CHIEF, FOUNDATION & MATERIALS BR.; DRAWN BY T. LAMB; CHECKED BY M.G.G.; TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD. 707-2

PLATE 29

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

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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 floodplain 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.

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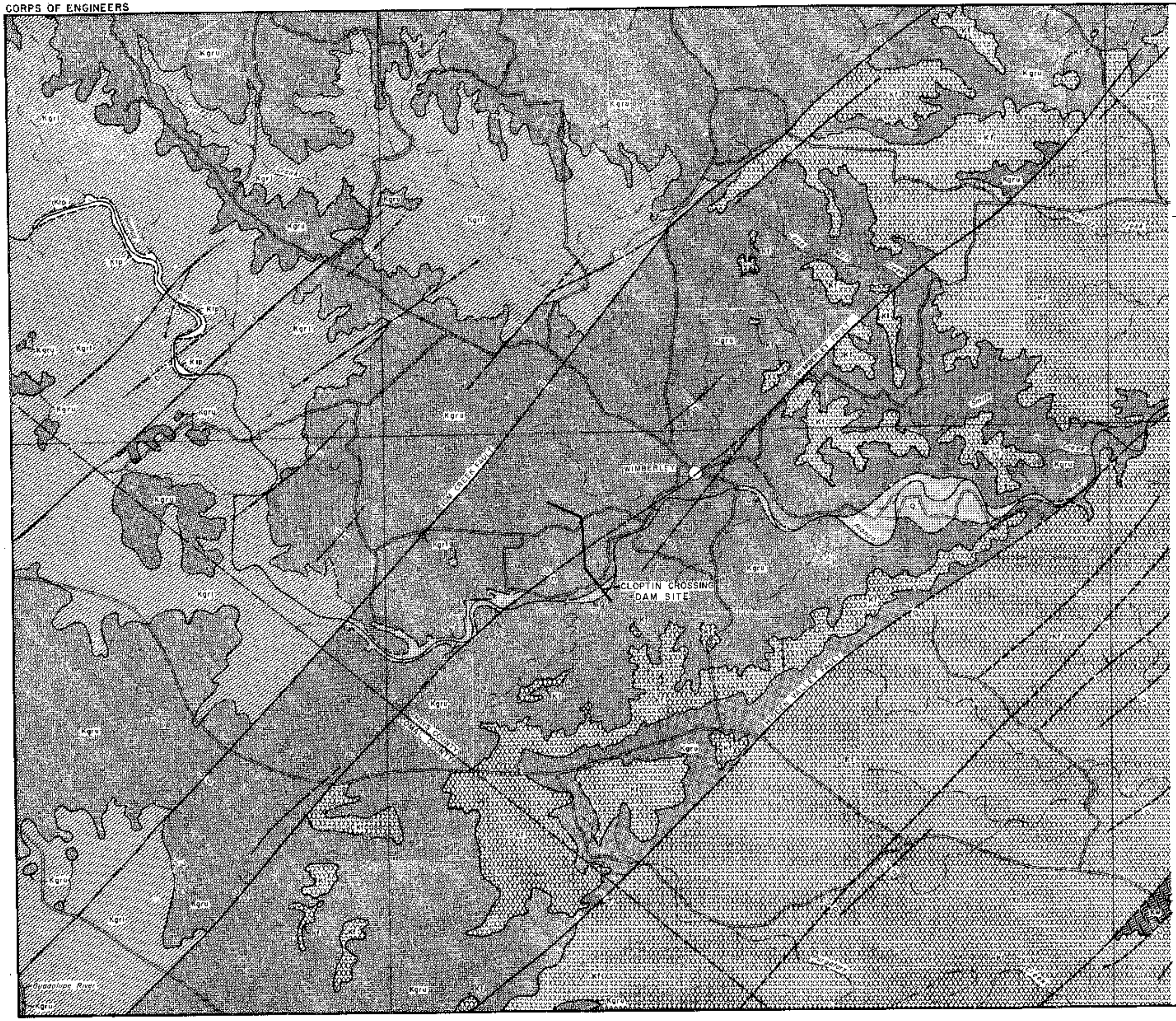


SYSTEM	SERIES	GROUP	FORMATION	DEPOSITIONAL THICKNESS (FEET)		GENERAL LITHOLOGIC DESCRIPTION
CRETACEOUS	COMANCHE	WASHITA	BUDA LIMESTONE	30-60		Tan and gray massive hard nodular limestone
			GRAYSON SHALE	40-60		Blue-gray to tan gypsiferous, ferruginous calcareous shale
			GEORGETOWN LIMESTONE	30-50		Light-gray 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
			GLEN ROSE LIMESTONE: LOWER MEMBER			
			TRAVIS PEAK FORMATION: HENSELL MEMBER	85±		Fine grained siltstone, and argillaceous limestones
			TRAVIS PEAK FORMATION: COW CREEK LIMESTONE MEMBER	60-70		Massive detrital limestone
			TRAVIS PEAK FORMATION: 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 Resources 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, FOUNDATIONS & MATERIALS BR.

DRAWN BY C M P

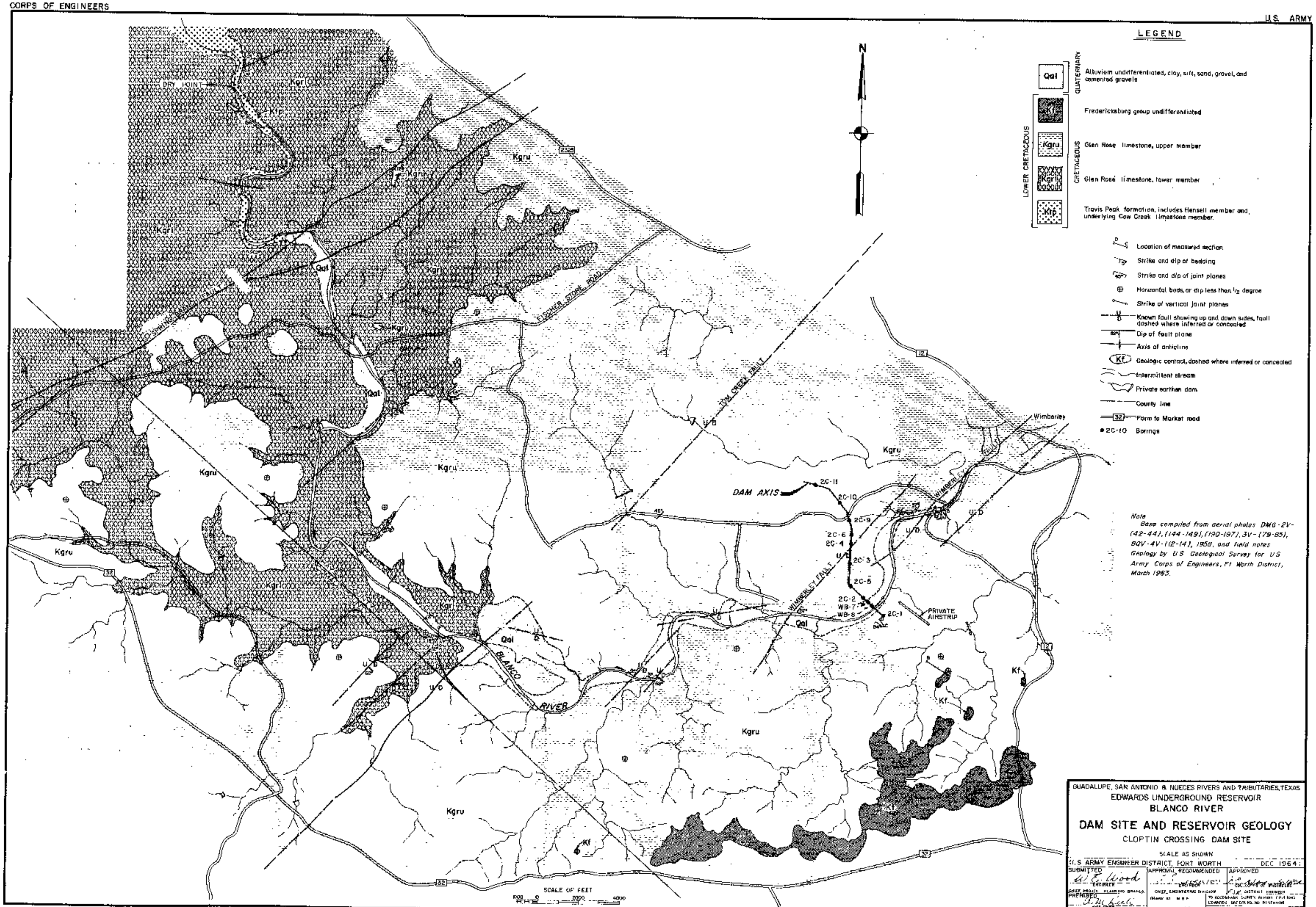
CHECKED BY M R G

TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR

FILE GUAD 707-2

CORPS OF ENGINEERS

U.S. ARMY



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

DAM SITE AND RESERVOIR GEOLOGY

CLOPTIN CROSSING DAM SITE

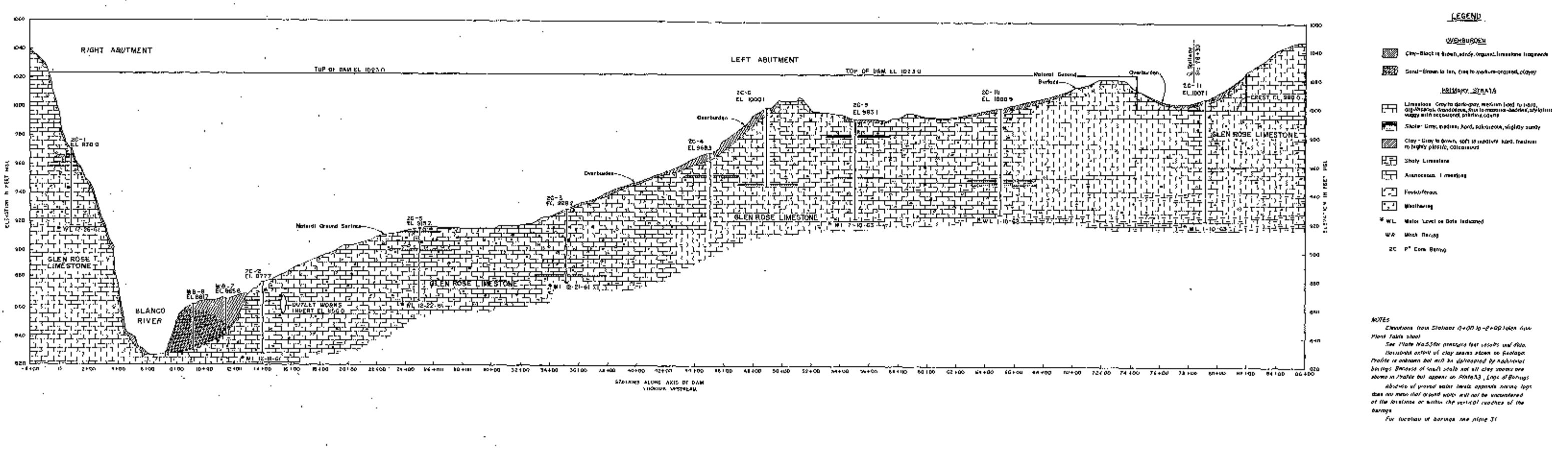
SCALE AS SHOWN

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

SUBMITTED	APPROVAL RECOMMENDED	APPROVED
W. E. Wood, ENGINEER, CHIEF, PROJECT PLANNING BRANCH	ENGINEER, CHIEF, ENGINEERING DIVISION	DISTRICT ENGINEER
PREPARED ENGINEER, CHIEF, FOUNDATION & MATERIALS BR	DRAWN BY M.B.P. CHECKED BY M.G.G.	FILE GUAD 707-2

PLATE 31

287



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

FILE GUAD 307-9

PLATE 32

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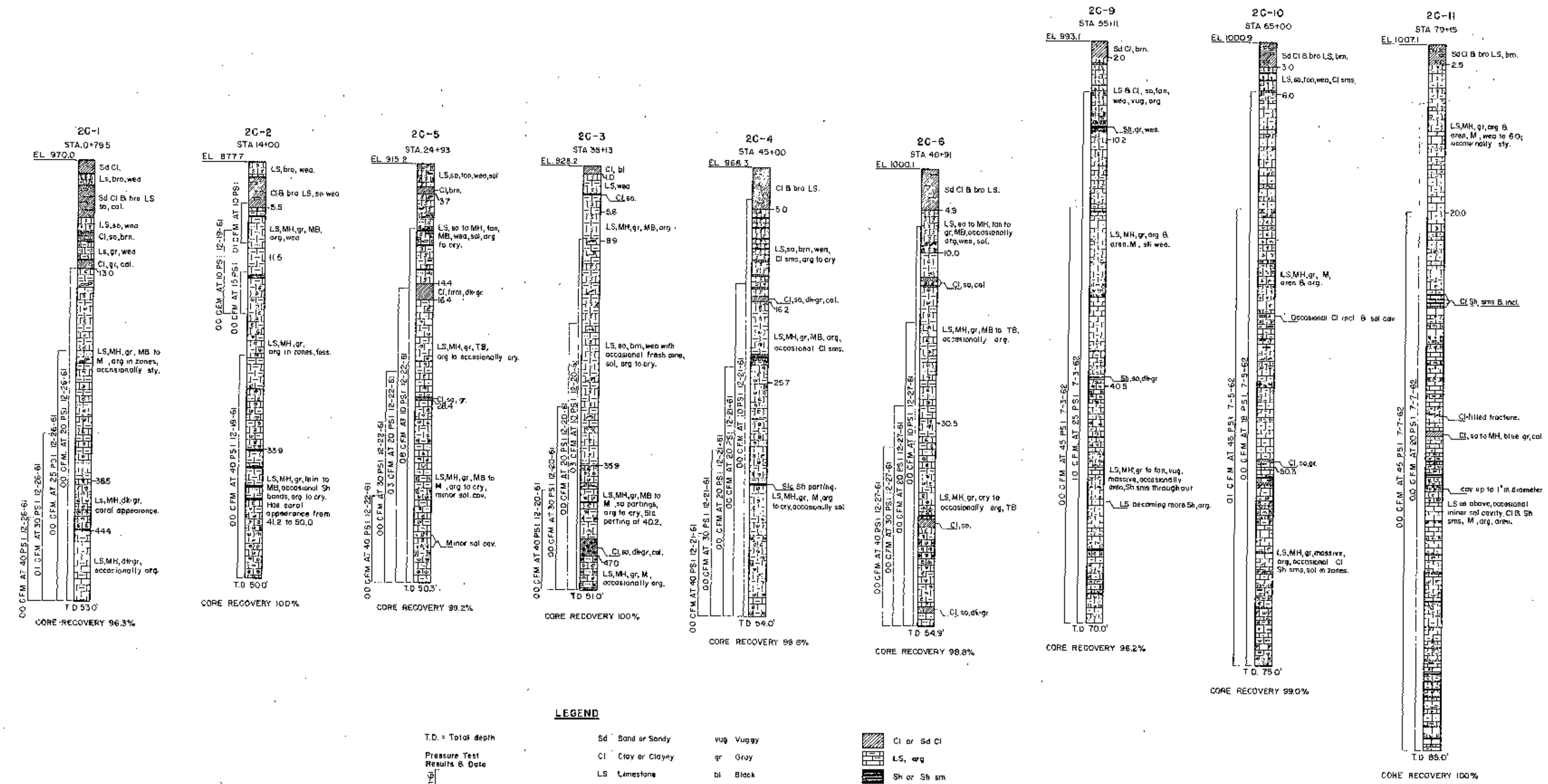


LEGEND

T.D. = Total depth

Pressure Test Results & Date

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 — 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: A.O.W.
CHECKED BY: M.G.S.
TO ACCOMPANY SURVEY REPORT COVERING EDWARDS UNDERGROUND RESERVOIR
FILE: GUAD 707-2

PLATE 33

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.

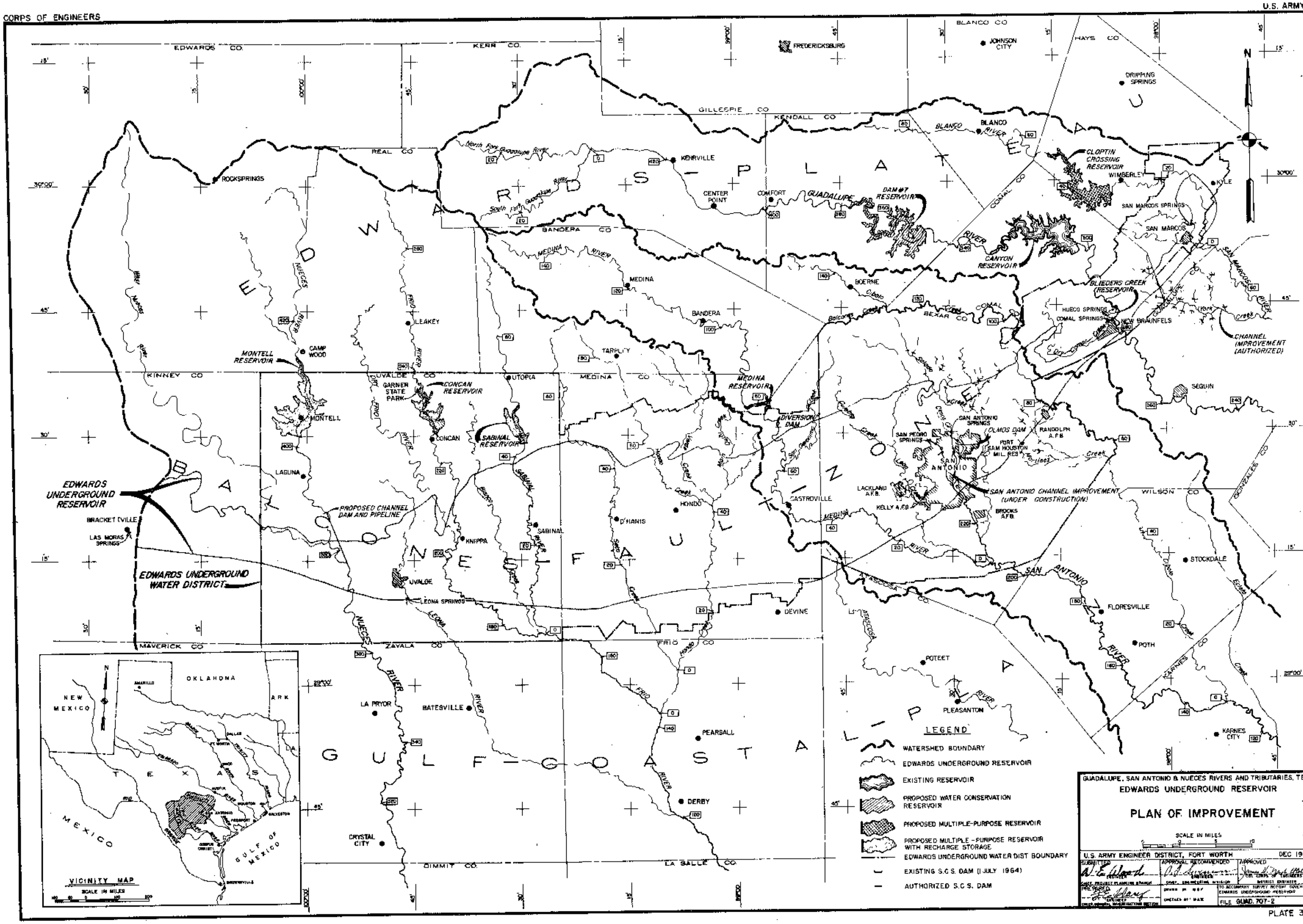
124. FOUNDATION CONDITIONS.- Dam No. 7 will be founded on the Cow Creek and Hensell members of the Travis Peak formation and the lower member of the Glen Rose formation. The Cow Creek and Hensell members occur as inliers in the streambed while the lower member of the Glen Rose forms the valley walls 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.



CORPS OF ENGINEERS
U.S. ARMY
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
PLATE 34
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
FORT SAM HOUSTON MIL. RES.
RANDOLPH A.F.B.
LACKLAND A.F.B.
KELLY A.F.B.
BROOKS A.F.B.
SAN ANTONIO
SAN ANTONIO SPRINGS
SAN PEDRO SPRINGS
HUECO SPRINGS
COMAL SPRINGS
NEW BRAUNFELS
SAN MARCOS SPRINGS
SAN MARCOS
WIMBERLEY
KYLE
BLANCO
JOHNSON CITY
DRIPPING SPRINGS
FREDERICKSBURG
KERRVILLE
CENTER POINT
COMFORT
BOERNE
BANDERA
MEDINA
TARPLEY
UTOPIA
LEAKEY
CAMP WOOD
ROCKSPRINGS
MONTELL
GARNER STATE PARK
CONCAN
LAGUNA
BRACKETTVILLE
LAS MORAS SPRINGS
KNIPPA
SABINAL
UVALDE
LEONA SPRINGS
D'HANIS
HONDO
CASTROVILLE
DEVINE
SEGUIN
STOCKDALE
FLORESVILLE
POTH
POTEET
PLEASANTON
KARNES CITY
LA PRYOR
BATESVILLE
PEARSALL
DERBY
CRYSTAL CITY
EDWARDS CO
KERR CO
GILLESPIE CO
BLANCO CO
HAYS CO
KENDALL CO
REAL CO
BANDERA 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
NUECES RIVER
FRIO RIVER
SABINAL RIVER
MEDINA RIVER
GUADALUPE RIVER
BLANCO RIVER
SAN MARCOS RIVER
SAN ANTONIO RIVER
VICINITY MAP
NEW MEXICO
OKLAHOMA
ARK
TEXAS
MEXICO
GULF OF MEXICO

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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

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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.

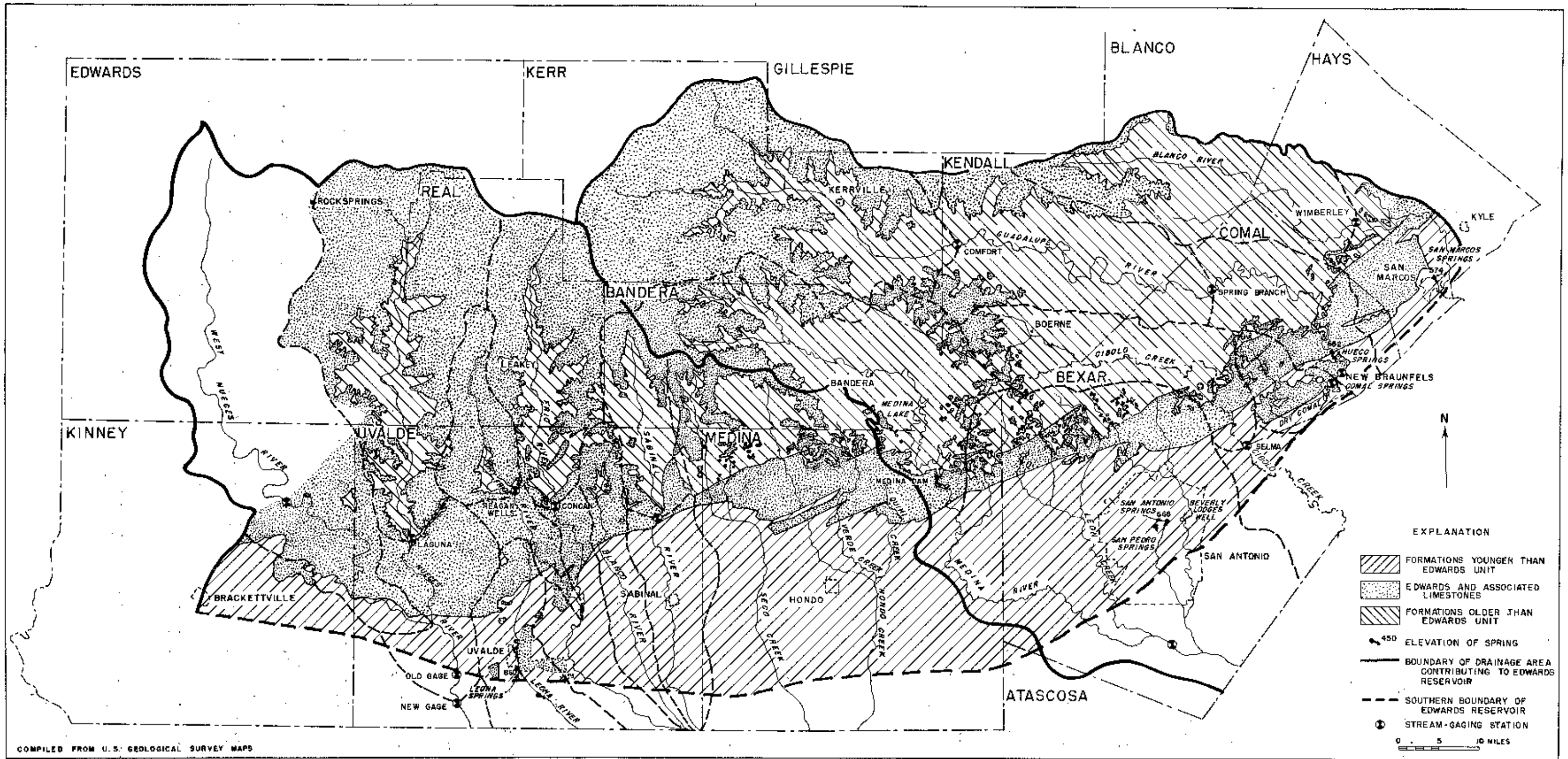

FIGURE 1.-GEOLOGIC MAP SHOWING EXTENT OF EDWARDS RESERVOIR AND AREA CONTRIBUTING RECHARGE.

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

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FIGURE 2

SCHEME OF SAMPLING OF EDWARDS UNDERGROUND RESERVOIR, TEXAS, FOR TRITIUM ANALYSIS

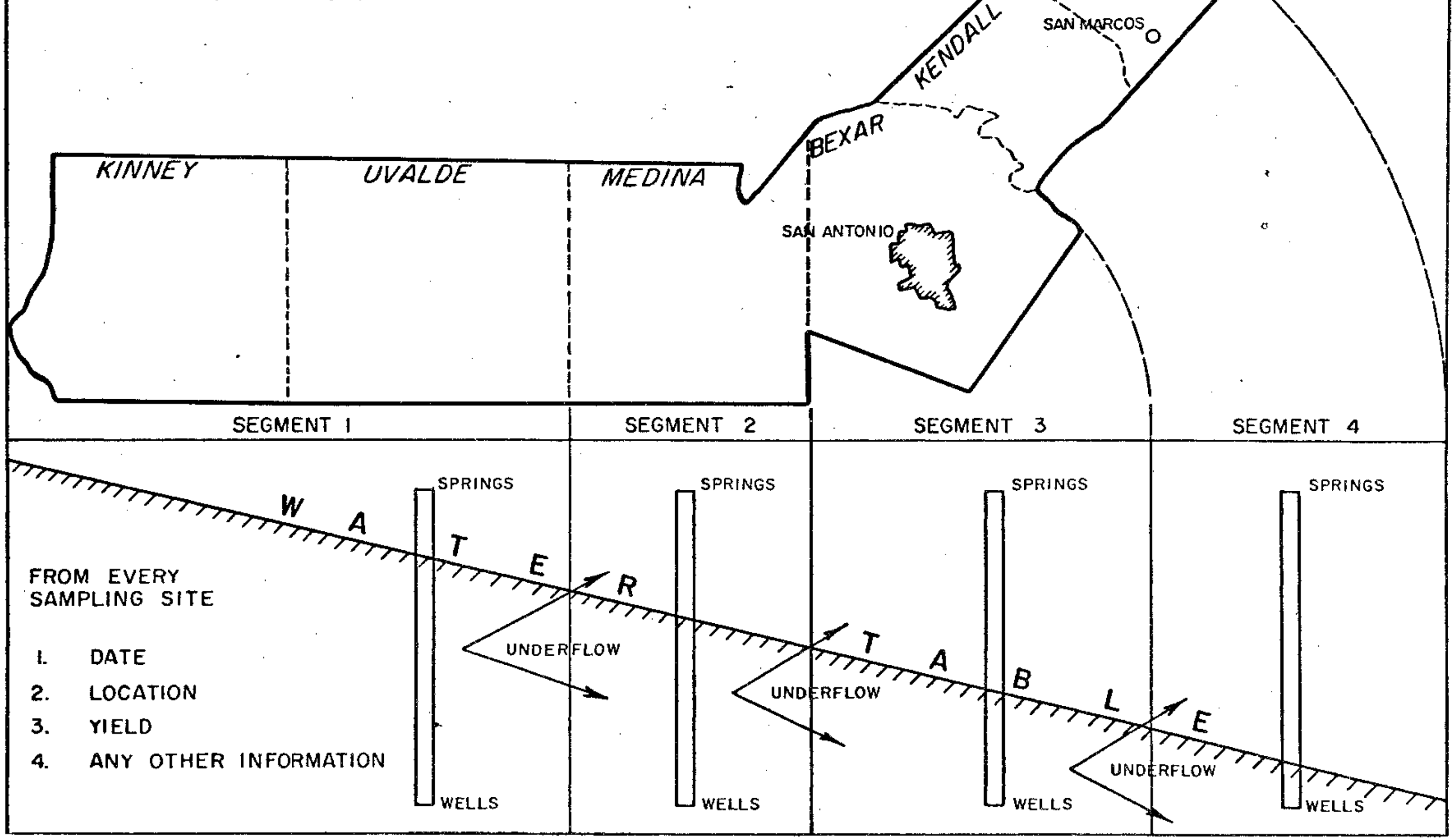

Table 2. Water Samples for Tritium Analysis from the Edwards Underground Reservoir, Texas, August and October 1963

Well No.	Description, Reference	Well Depth (feet)	Productive Depth (feet)	Yield (gpm)	Water Temp. (°F)	Sampling Period	Tritium Units (±10%)
Kinney County							
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
Uvalde County							
-	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. (^{o}F)	Sampling Period	Tritium Units ($\pm$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

County	River	River Flow Rates (gpm)* Aug 63	Oct 63	Tritium Activities (T.U.) 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.

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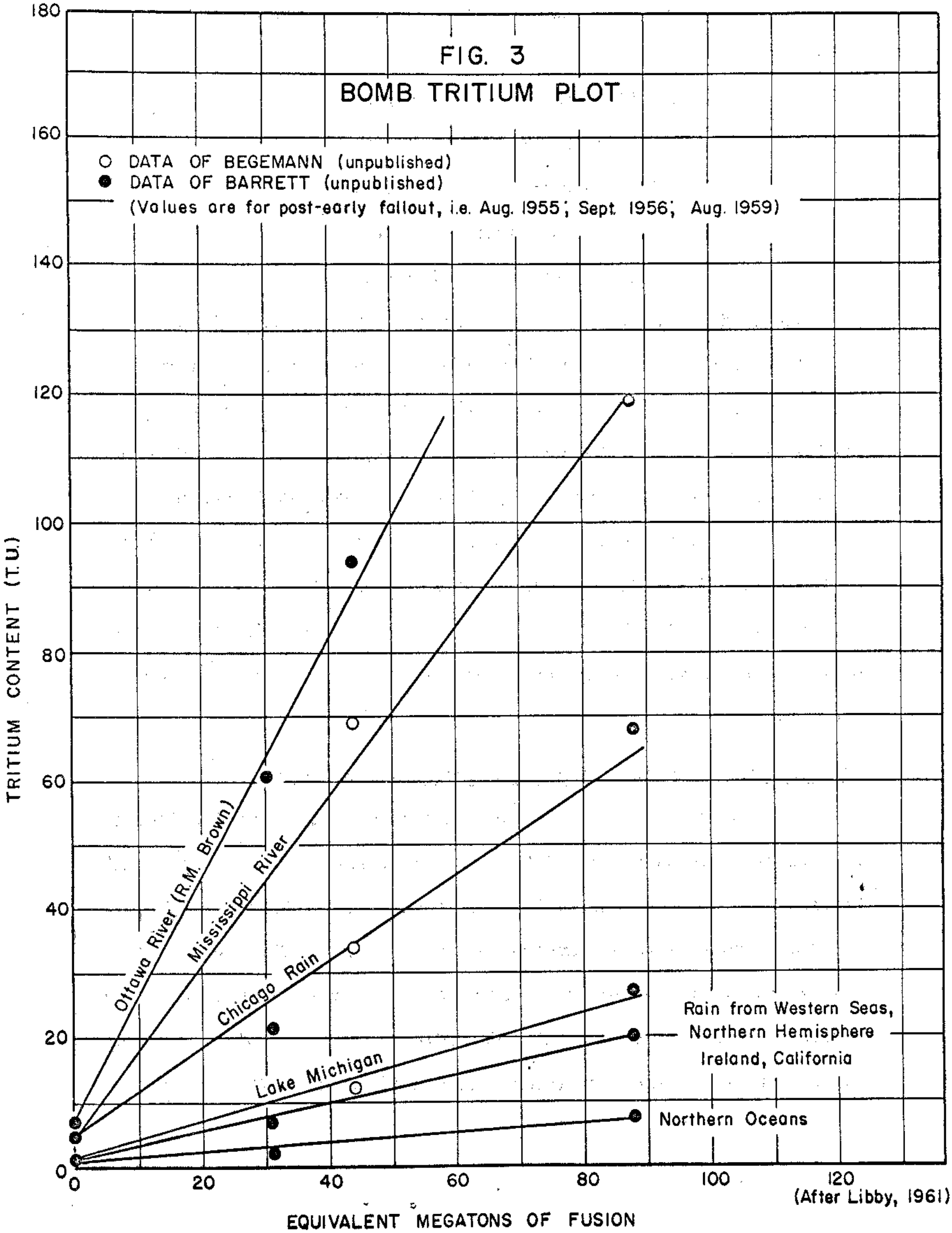
FIG. 3
BOMB TRITIUM PLOT
DATA OF BEGEMANN (unpublished)
DATA OF BARRETT (unpublished)
(Values are for post-early fallout, i.e. Aug. 1955; Sept. 1956; Aug. 1959)
Ottawa River (R.M. Brown)
Mississippi River
Chicago Rain
Lake Michigan
Rain from Western Seas, Northern Hemisphere Ireland, California
Northern Oceans
TRITIUM CONTENT (T.U.)
EQUIVALENT MEGATONS OF FUSION
0
20
40
60
80
100
120
140
160
180
(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	as gleaned from Figure 1, p. 4490
1961	~ 300	

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^{o}-50^{o}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

Year	Change in Stored Water	A) 600 ft. Thickness: Reservoir Volume (10^3 acre ft.)		A) 600 ft. Thickness: Tritium Activity (T.U.)	B) 1,750 ft. Thickness: Reservoir Volume (10^3 acre ft.)		B) 1,750 ft. Thickness: 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 (10^3 acre ft.)		A) Tritium Activity (T.U.)	B) 1,750 ft. Thickness: Reservoir Volume (10^3 acre 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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