San Antonio & Guadalupe River Basins Study

1974

Report to the U.S. Congress

City of San Antonio
Edwards Underground Water District
San Antonio River Authority
City Water Board
Guadalupe-Blanco River Authority

EDWARDS UNDERGROUND WATER DISTRICT
1615 NORTH ST. MARY'S
P. O. BOX 15830
SAN ANTONIO, TEXAS 78212

The Honorable O. C. Fisher
2407 Rayburn House Office Bldg.
Washington, D. C. 20515

The Honorable Henry B. Gonzalez
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The Honorable Abraham Kazen
1514 Longworth House Office Bldg.
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The Honorable Jake Pickle
231 Cannon House Office Bldg.
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The Honorable John Young
2419 Rayburn House Office Bldg.
Washington, D. C. 20515

Gentlemen:

The undersigned organizations are the local agencies charged with responsibility for water resource planning and development in most of the Guadalupe and San Antonio River Basins, some adjoining coastal areas, and the portion of the Nueces River Basin included in the Edwards Underground Water District. We have joined in writing you about our problems because of the complex inter-relationship that exists between the water resources of our respective areas and because each of you represents a part of the overall area.

As the San Antonio and Guadalupe Rivers join near the Gulf Coast, surface water developments in one basin inevitably affect interests in the other basin. Stream flow in both basins is affected by inflow to and withdrawals from the Edwards Underground Reservoir which traverses both basins (and also the Nueces River Basin) and contributes substantially to stream flow through discharges of large springs at San Marcos and New Braunfels and smaller springs elsewhere. This aquifer is the sole present source of municipal and industrial water supply for the San Antonio metropolitan area and is also used to supply substantial irrigation developments.

Numerous studies of the water problems and potentialities of our area have been made by our agencies and by State and Federal agencies. Some of the studies have been limited to one river basin or part of a basin while others have covered most or all of Texas. These studies generally have concluded that full development of the area's surface water resources is essential to meet future water needs and support future economic development and population growth. As a result, several reservoirs have been proposed for the purpose of securing such development.

For a variety of reasons, however, investigations made in recent years have been ineffective in advancing development of the water resources of our area. Localized proposals generally have been too limited in scope to permit adequate evaluation of their effect on other parts of the area. Broader based proposals covering the entire area generally have been advanced as elements of large-scale plans involving all or most of the rest of Texas requiring widespread unanimity of views and action not thus far attainable. Up until the present time there has been general reluctance to advance proposals involving coordinated and integrated use of ground and surface waters.

In our collective view all of the past investigations have been useful in promoting better understanding of our water problems and potentialities and in exploring alternative means of developing our water resources. We also believe, however, that they badly need updating and broadening to reflect current conditions and aspirations of the people of our area. In particular existing proposals need review in the light of the recent rapid growth of public interest in environmental and ecological considerations. We need to formulate a comprehensive long-term plan for coordinated integrated use of all of our water resources that will recognize every conceivable beneficial use of those resources and extract therefrom the maximum benefits obtainable for our entire area.

Such plan formulation must resolve several major questions to which answers are not now available. One of these involves the best use and disposition of sewage effluent from urban areas which simultaneously poses difficult problems and involves major potential benefits. An apparently irreconcilable conflict that nevertheless must be resolved is the effect of storage and use of currently unregulated streamflow on fishery values in the San Antonio estuary which apparently are subject to substantial losses if such development occurs. A third major question involves the most effective utilization of our groundwater resources, including the Edwards Underground Reservoir and the Carrizo-Wilcox aquifer, which appear to afford a major potential source of additional groundwater supply.

It is our joint conviction that we will need substantial assistance from appropriate State and Federal agencies if we are to solve these and other questions and to formulate an area-wide plan that will command general acceptance and have a good chance of being put into effect. We look to the Texas Water Development Board to assist us with its staff and to obtain for us the services of other State agencies. All of the actions we are proposing herein represent implementation of the overall Texas Water Plan as advanced by the Texas Water Development Board in November 1968. At the Federal level we believe the Bureau of Reclamation to be well qualified to assume leadership in the necessary investigations, to secure participation by other Federal agencies in those investigations as required, and to prepare a report thereon recommending appropriate Federal actions for submission by the Secretary of the Interior to the Congress.

We understand that the Bureau has adequate authority to undertake the necessary studies as part of its Texas Basins Project investigations if funds for those studies are appropriated by the Congress. Accordingly, we jointly ask that each of you transmit this letter to the Commissioner of Reclamation with a request that he include in his budget for the Texas Basins Project investigation for Fiscal Year 1972 and subsequent years the funds the Bureau will require to provide us the Federal assistance we need to achieve the objectives previously outlined including a report to the Congress.

Very truly yours,

Gerald C. Henckel
City Manager
City of San Antonio

Robert P. Van Dyke
General Manager
City Water Board

McDonald D. Weinert
General Manager
Edwards Underground Water District

Robert H. Vahrenkamp
General Manager
Guadalupe-Blanco River Authority

Fred N. Pfeiffer
General Manager
San Antonio River Authority

cc: Mr. Harry Burleigh
Mr. Trigg Twichell
Mr. Howard Boswell

Plate 1

Figure 1

EDWARDS UNDERGROUND RESERVOIR

Austin, Texas
April 13, 1972

Memorandum

To: Files

From: Chief, Hydrology Division

Subject: Uvalde Pool of Edwards Underground Aquifer

The Uvalde Pool. The Uvalde Pool is a portion of the Edwards Underground Aquifer in the general vicinity of Uvalde which has a relatively flat piezometric water surface and a considerably higher piezometric water surface than the aquifer to the east. It is postulated that the higher water surface elevation of the Uvalde Pool is caused by a zone which has considerable resistance to flow located between the Uvalde Pool and the Central Pool to the east. Plate 1 shows the location of the Uvalde Pool. Its approximate outlines were determined by examination of water level contour maps for the Edwards Underground for various dates (January 1952, August 1954, August 1956, March 1958, and January 1961) that were presented in Texas Board of Water Engineers Bulletins 5608 and 6201 and Texas Water Development Board Report 34.

Historic Water Levels. Water-level observations are available for many wells in the Uvalde Pool Elevations for two of these wells, H-4-6 and H-5-1 are available from 1930 to date. The locations of these two wells is shown on Plate 1. Throughout the period of record, the water level in well H-5-1 was about 10 to 20 feet lower than in well H-4-6. Counting the two wells, frequent observations are available for 1930, and 1938 to date, and less frequent observations during 1931-1937. Plate II shows the observed water-surface elevations for the two wells, and also for wells in other portions of the Edwards Underground.

Historic Recharge. Inspection of water-level isolines indicates that the West Nueces and Nueces Rivers contribute recharge to the Uvalde Pool. The Dry Frio may also contribute recharge to the Uvalde Pool, and possibly the headwaters of Leona River and Pinto, Los Moros, and Turkey Creeks. It appears that the Frio River does not contribute very much if any recharge to the Uvalde Pool.

The U. S. Geological Survey has estimated the net recharge from the Nueces River Basin for 1934-1969. These estimates are based primarily upon flow records for the upstream stations Nueces River at Laguna, drainage area 764 square miles and West Nueces near Bracketville, drainage area 700 square miles, and the downstream station Nueces River below Uvalde, drainage area 1947 square miles. Records for all three stations are available for October 1939 through September 1950, and April 1956 to date. During these two periods, only the runoff from the 483 square miles between the two upstream gages and the downstream gage, which is about 25 percent of the total drainage area, had to be estimated. Thus the recharge estimates for these periods are reasonably accurate. During 1934 through September 1939 and during October 1950 through March 1956, the flow of the West Nueces River was not measured. During these two periods the runoff from 1,183 square miles, which is 61 percent of the total area, had to be estimated. Thus the estimated recharge for these two periods is considerably less reliable. Most of the area in question is sparsely populated and few rainfall records are available. The area is subject to occasional severe flood-producing storms, but the rainfall from such storms often varies substantially over relatively short distances. It was assumed in the Bureau analysis that the outflow from the Uvalde Pool is relatively constant. Under this assumption, substantial recharge must increase storage in the Uvalde Pool area and produce an appropriate increase in water levels in the Uvalde Pool. Conversely, of course, a substantial rise in water levels in the Uvalde Pool is evidence that substantial recharge has occurred. These concepts were applied to the estimated recharge from the Nueces Basin and the recorded water-surface elevations in wells H-4-6 and H-5-1 to see if any of the recharge estimates looked "wild". This test indicated that data for a few years appeared abnormal. The estimated recharge for these years was modified to bring it into better agreement with well observations. The years so adjusted, the USGS recharge estimate, and the modified estimate are listed in Table 1. USGS Water Supply Paper 796-G "Major Texas Floods of 1935" indicates that rainfall during June 9-15, 1935, was greatest in the headwaters of the West Nueces, and least in the "remainder of area" below the two upstream gages.

For purposes of this analysis, it was assumed that about one-half of the recharge from the Dry Frio was to the Uvalde Pool and the remainder to the Central Pool.

Table 2 lists the estimated recharge to the Uvalde Pool from the Nueces Basin and from the Dry Frio River each year, 1934-1969. Table 3 lists the average recharge for various periods. During the 1948-1956 drought period, the estimated average annual recharge is 68 percent of the corresponding figure for the 1940-1969 period. This is a much higher percentage than occurred in the remainder of the Edwards Underground during the 1948-1956 period. During 1960-1969, the estimated recharge is 112 percent of the 1940-1969 average. During 1960-1969, the gaged runoff of the Nueces River at Laguna was 117 percent of the 1940-1969 average, and the gaged runoff of the Nueces River below Uvalde was 115 percent of the 1940-1969 average. Therefore, the above average recharge estimated for the 1960-1969 period appears reasonable.

Correlations between the flow of the Nueces River at Laguna, plus the West Nueces River near Bracketville and the flow of the Nueces River below Uvalde, indicate that for the same upstream flow (provided it is over a threshhold value) the flow below Uvalde has been about 5,000 acre-feet per month larger when the water level in well H-4-6 has been above 883' than when the water level in the well has been below 883'. This indicates that net recharge from the Nueces River may be affected by the water level in the aquifer.

<u>Historic Discharge</u>. Discharge from the Uvalde Pool occurs through Leona Springs and associated Leona River underflow, through wells and through eastward flow in the Edwards Underground Aquifer. Some water may also be discharged back into the Nueces River downstream from the recharge zone, but this has been allowed for in the computation of net recharge from the Nueces River Basin.

The discharge from Leona Springs and associated underflow has been estimated by the USGS for the 1934-1969 period. For purposes of this analysis, the USGS estimate for the 1934 through 1950 was increased by 4,000 acre-feet per year, and the USGS estimate for 1951 was increased by 3,000 acre-feet. The purpose of this adjustment was to make the average relationship between Leona Springs plus underflow and the water level in well H-4-6 the same for the 1934-1951 period as for the 1957-1969 period.

The USGS has estimated the well discharge for eastern Kinney County and for Uvalde County for various uses for each year, 1934-1970. Based upon examination of the irrigation inventory map for Uvalde County for 1969, it was estimated that 60 percent of the Uvalde County area irrigated from the Edwards Underground tapped the Uvalde Pool. In 1970, the city of Uvalde accounted for about 63% of the total population of Uvalde County and a considerably higher percentage of the population in Uvalde County served by municipal water from the Edwards Underground. For purposes of this analysis, it was estimated 80% of the Uvalde County municipal water use from the Edwards Underground occurred from the Uvalde Pool, and that 60% of the irrigation, domestic and stock use tapped the Uvalde Pool. Table 2 lists the estimated well discharge from the Uvalde Pool each year.

The well discharge has increased steadily over the years and at an increased pace during recent years. During recent years, the well discharge has exceeded the flow plus underflow of Leona Springs. However, the highest well discharge for any year (through 1970) is only about one-half of the estimated average annual recharge. Thus a considerable further increase in well discharge from the Uvalde Pool can occur without straining the available water supply. It may be that the amount of suitable land is the physical limitation on irrigation development from the Uvalde Pool, not the water supply. It is very probable that the present level of well discharge, and increases beyond the present level, will cause future water levels in the Uvalde Pool to drop considerably below the historic norm, however.

The discharge from the Uvalde Pool through eastward flow in the Edwards Underground Aquifer can be computed between times of equal Uvalde Pool Aquifer content as the estimated recharge minus the estimated discharge of Leona Springs and underflow, and minus the estimated well discharge. Water levels in observation wells indicate that aquifer content was nearly the same on December 31, 1939, December 31, 1949, and December 31, 1958. December 31, 1959, and December 31, 1969, water levels were also nearly the same. The average aquifer discharge to the east was computed for these time intervals. The results are listed in Table 3 and range from 61,000 acre-feet per year to 69,000 acre-feet per year. Since the discharge to the east was computed as the unknown item in a water budget, its estimated value is subject to a bigger margin of error than any of the components used in the computation. During the 1950-1958 period, water levels in the Uvalde Pool were considerably lower than during the other two periods, yet the computed discharge to the east was about the same. This is not irrational, since the hydraulic gradient between the Uvalde Pool and the Central Pool was roughly the same in the three periods.

Change in Uvalde Pool Content. By using the computed aquifer discharge to the east, plus other items in the Uvalde Pool water balance, it is possible to compute the change in Uvalde Pool content each year. This was done in Table 2. These computed changes in aquifer content can be compared with the change in the water-surface elevation of well H-4-6 each year. Plate 3 is a plot of change of water-surface elevation vs. computed change-in-aquifer content. Based upon this plot, and also accumulated data, for a few years, such as 1950-1952, 1957-1958, and 1962-1963, it was estimated that a change of Uvalde Pool content of 4,500 acre-feet would produce a change of 1 foot in the water surface in well H-4-6. These computations of change in reservoir content are residuals of the water balance and not very accurate.

Operation Study for 1969 Level of Well Discharge. An operation study (same as mathematical model or aquifer simulation) was made for the Uvalde Pool for the 1934-1969 period with the 1969 level of well discharge, to see what effect this well discharge would have had upon water levels in the Uvalde Pool and on the aquifer water balance. The 1969 level of well discharge was estimated to average 38,000 acre-feet per year. The well discharge was varied from year to year according to weather conditions. The discharge from Leona Springs plus underflow was estimated from the estimated water level in well H-4-6 and a correlation.

The discharge in the aquifer from the Uvalde Pool to the Central Pool was estimated to equal 66,000 acre-feet per year (the historic average), multiplied by the drop in elevation from well H-4-6 to well I-4-12 in this study, and divided by the historic drop in elevation from well H-4-6 to well I-4-12. The elevation in well I-4-12 used in the "this study" computation was the historic elevation plus the difference between the historic elevation in well 26 and the elevation computed for well 26 with the 1969 level of well discharge, in an earlier study that lumped the whole Edwards Underground together.

During those months when the historic water level in well H-4-6 was above 883', but the water level in this study was below 883', it was assumed that the net recharge from the Nueces River would increase by an amount equal to the historic flow of the Nueces River below Uvalde in excess of 1,000 acre-feet but not over an increase in recharge of 3,000 acre-feet per month. Correlations described earlier indicate that the increase in recharge could go up to about 5,000 acre-feet per month, but an upper limit to 3,000 acre-feet was used in this study because of the host of unknown factors. Except for this adjustment, historic recharge was used. It was assumed that a 4,500-acre-foot change in the Uvalde Pool content from the historic would cause a 1-foot change in piezometric water level in well H-4-6.

The results of this operation study are summarized in Table 4. The water level in well H-4-6 varies from 3 to 61 feet lower than historic, and Leona Springs plus underflow is almost wiped out. The average discharge to the Central Pool is 59,000 acre-feet per year. The lower water level in the Uvalde Pool is estimated to increase the average net recharge from the Nueces River by 8,000 acre-feet per year compared to historic.

This operation study is crude, with many questionable or very approximate assumptions. Still, if the concepts it is based upon are reasonable correct, it indicates that the 1969 level of well discharge from the Uvalde Pool can be sustained without any serious adverse consequences, except to those who may be dependent upon Leona Springs plus underflow.

Effect of Future Increases in Well Discharge Over the 1969 Level. The 1969 condition study indicates that a considerable expansion in well discharge above the 1969 level can occur without any serious effect except a lowering of aquifer water levels. Thus, if the well discharge were to increase by 30,000 acre-feet per year (one-half of the operation study discharge to the Central Pool) the water level in well H-4-6 would be reduced by an additional 64 feet plus whatever decline in water level would occur at well I-4-12 as a result of a further increase in well discharge from the Central Pool. An increase of well discharge of 30,000 acre-feet per year is equal to about 79 percent of the 1969 level of well discharge from the Uvalde Pool. There may not now be enough unirrigated land suitable for irrigation to cause this large an increase in well discharge from the Uvalde Pool.

George Schwab
M. George Schwab

Enclosures

Table 1. Adjustments to estimated recharge from Nueces Basin
(1,000 acre-feet)

	USGS data or estimates						Modified estimate of recharge	
	Runoff							
Year	Nueces at Laguna	West Nueces nr. Brackettville	Remainder of area above Uvalde gage	Total runoff above Uvalde gage	Outflow at or below Uvalde gage	Est. Recharge	Value	Change from USGS estimate
1935	G 465	228	399	1092	G 681	411	178	-233
1936	G 233	32	161	426	G 250	176	124	- 52
1937	G 62	10	13	85	G 56	29	49	+ 20
1939	G 164	25	126	315	G 88	227	115	-112
1953	G 22	4	6	32	G 10	22	40	+ 18
1957	G 62	G 18	48	128	G 19	109	144	+ 35
1958	G 273	G 182	196	651	G 384	267	232	- 35
1966	G 143	G 19	80	242	G 73	169	134	- 35
Total	1424	518	1029	2971	1561	1410	1016	-394

G = gaged runoff.

Table 2. Uvalde Pool, Estimated Historic Water Balance

Year	Est. recharge: Nueces and West Nueces	Est. recharge: Dry Frio	Est. recharge: Total	Est. discharge: Leona Springs + underflow	Est. discharge: Well discharge	Est. discharge: Underflow to Central Pool	Est. discharge: Total	Recharge minus discharge	WS Elev. Ft Well H-4-6: End of Year 886	WS Elev. Ft Well H-4-6: Change during year
	←				1000 AF			→		
1934	9	3	12	14	2	66	82	-70	877	-9
1935	* 178	26	204	14	1	66	81	123	890	+13
36	* 124	21	145	28	2	66	96	49	890	0
37	* 49	11	60	29	2	66	97	-37	887	-3
38	64	9	73	26	2	66	94	-21	886	-1
39	* 115	5	120	19	2	66	87	33	886	0
1940	50	7	57	17	2	66	85	-28	880	-6
41	90	21	111	19	2	66	87	24	888	+8
42	104	13	117	23	2	66	91	26	887	-1
43	36	5	41	19	3	66	88	-47	880	-7
44	64	10	74	10	2	66	78	-4	881	+1
1945	47	9	56	12	3	66	81	-25	874	-7
46	81	7	88	6	3	66	75	13	878	+4
47	73	10	83	13	3	66	82	1	878	0
48	41	3	44	7	4	66	77	-33	871	-7
49	166	11	177	9	5	66	80	97	885	+14
1950	41	4	45	11	7	66	84	-39	873	-12
51	18	3	21	3	11	66	80	-59	859	-14
52	28	1	29	0	14	66	80	-51	845	-14
53	* 40	2	42	0	17	66	83	-41	844	-1
54	61	2	63	0	17	66	83	-20	846	+2
1955	128	4	132	0	18	66	84	48	850	+4
56	16	0	16	0	37	66	103	-87	827	-23
57	* 144	12	156	1	18	66	85	71	858	+31
58	* 232	28	260	4	13	66	83	177	884	+26
59	110	14	124	17	16	66	99	25	891	+7
1960	89	11	100	30	15	66	111	-11	891	0
61	85	16	101	31	16	66	113	-12	892	+1
62	47	2	49	24	25	66	115	-66	882	-10
63	40	2	42	10	26	66	102	-60	872	-10
64	126	4	130	6	27	66	99	31	877	+5
1965	98	7	105	7	25	66	98	7	880	+3
66	* 134	12	146	8	25	66	99	47	882	+2
67	82	12	94	7	45	66	118	-24	882	0
68	131	17	148	17	26	66	109	39	885	+3
69	120	9	129	18	43	66	127	2	889	+4
Total 1934-69	3061	333	3394	459	481	2376	3316	78		

* Different from USGS, on basis of enveloping lines on ~~attached figure~~. *Correlation similar to Plate 3.*

Table 3. Uvalde Pool, Historic Period Averages

	Average annual value - 1,000 acre-feet				
	1948-56	1940-49	1950-58	1960-69	1940-69
Recharge					
From W. Nueces and Nueces Basins	60	75	79	95	84
From Dry Frio Basin	3	10	6	9	9
Total	63	85	85	104	93
Discharge					
Leona Springs plus underflow	3	13	2	16	11
Well discharge	14	3	17	27	16
Eastward in Edwards Underground to Central Pool		69	66	61	

Table 4. Uvalde Pool, Summary of operation study for the 1969 level of well discharge

Year	Historic WS elev. Well H-4-6, end of year (ft.)	This study: WS Well H-4-6, end of year (ft.)	Change in WS elev. from Historic (ft.)	Increase in net recharge from Nueces (1000 acre-feet)	Leona Springs plus under flow (1000 acre-feet)	Well discharge (1000 acre-feet)	Outflow to Central Pool (1000 acre-feet)	WS Well H-4-6 minus WS Well I-4-12, end of year (ft.)
1933	886	864	-22	-	-	-	-	146
34	877	847	-30	0	0	50	66	136
1935	890	863	-27	21	0	26	63	120
36	890	868	-22	26	0	35	65	123
37	887	866	-21	21	1	46	67	129
38	886	864	-22	21	5	46	67	134
39	886	862	-24	11	0	42	66	148
1940	880	855	-25	2	0	28	65	149
41	888	864	-24	13	7	25	65	124
42	887	861	-26	13	0	44	65	122
43	880	851	-29	2	0	40	64	131
44	881	849	-32	0	0	29	63	125
1945	874	839	-35	0	0	36	61	112
46	878	839	-39	0	0	34	59	115
47	878	836	-42	0	0	38	57	120
48	871	824	-47	0	0	41	56	126
49	885	840	-45	10	0	27	54	127
1950	873	827	-46	1	0	35	55	120
51	859	809	-50	0	0	44	55	126
52	845	792	-53	0	0	40	53	116
53	844	797	-57	0	0	51	51	119
54	846	787	-59	0	0	40	50	125
1955	850	790	-60	0	0	41	50	140
56	827	766	-61	0	0	58	51	126
57	858	798	-60	0	0	27	50	119
58	884	827	-57	3	0	2[illegible]	49	88
59	891	847	-44	34	0	28	46	103
1960	891	858	-33	31	0	40	51	104
61	892	872	-20	34	0	35	55	121
62	882	866	-16	7	0	44	61	141
63	872	854	-18	0	1	43	63	147
64	877	858	-19	0	0	45	62	154
1965	880	861	-19	0	0	36	62	144
66	882	864	-18	0	0	31	61	140
67	882	865	-17	0	0	53	61	134
68	885	878	-8	25	7	28	61	135
69	889	886	-3	9	5	43	65	143
Total 1934-69	31,527	30,330	-1208	284	26	1375	2115	4594
Ave.	876	842	-34	8	1	38	59	128


Annual change in WS Elev. in ft.
Well H-4-6
+30
+20
+10
0
-10
-20
-100
-50
0
50
100
150
200
250
300
350
UVALDE POOL
Est. annual excess of recharge over discharge to Uvalde Pool - 1000 acre-feet

Plate 3

Austin, Texas
May 31, 1972

Memorandum

To: Files

From: Chief, Hydrology Division

Subject: Central Pool of Edwards Underground Aquifer

The Central Pool

The Central Pool is a portion of the Edwards Underground Aquifer extending from eastern Uvalde County to New Braunfels which has a relatively flat piezometric water surface. This water surface is substantially lower than the water surface in the vicinity of Uvalde and moderately higher than the water surface in the vicinity of San Marcos. It is postulated that these differences in water surface elevations are caused by zones which have considerable resistance to flow located between the Uvalde pool and the Central pool and between the Central pool and the San Marcos pool. Plate 1 shows the location of the Central pool. Its approximate outlines were determined by examination of water level contour maps for the Edwards Underground for various dates (January 1952, August 1954, August 1956, March 1958, and January 1961) that were presented in Texas Board of Water Engineers Bulletins 5608 and 6201 and Texas Water Development Board Report 34.

Historic Water Levels

Water level observations are available for many wells in the Central Pool. Water surface elevations for five of these wells are plotted on Plate II. Plate I shows the location of these five wells. The time pattern of their water level fluctuations is very similar, but the amplitude decreases down aquifer. The decreased amplitude of water level fluctuations can be attributed to the influence of San Antonio and Comal Springs, which act as pressure regulating valves. Thus the water surface level of well H-39, which is located between San Antonio Springs and Comal Springs, has always been somewhere between the elevation of the San Antonio Springs outlet and the Comal Springs outlet, except in the summer of 1956. In the summer of 1956, Comal Springs went dry and ceased to be a control. During some recent years the water levels in the five Central pool wells have displayed severe summer drawdowns. This is a striking characteristic of their hydrographs. The drawdowns were particularly severe in 1967 and 1971. Summer drawdowns are evident at well 26 starting about 1953, and at well I-4-12 starting about 1959. These summer drawdowns are caused by large seasonal well discharges from the Central pool and are aggravated by below normal recharge. The summer drawdowns are much larger than would be expected from the volume of pumping and the end-of-year aquifer content vs. elevation relationship of Figure 3. This suggests that whatever maintains the artesian pressure in the Central pool - presumably the gravity portion of the aquifer plus flow through the artesian area - does not transmit water at a fast enough rate during the summer to offset the summer well discharge and also maintain an undiminished flow of Comal Springs. This results in a decreased artesian pressure in the summer followed by a pressure recovery in the winter when the well discharge is smaller. The severe summer drawdowns also suggest that much of the experienced change in aquifer content has occurred in the gravity portion of the aquifer. The flow of Comal Springs is closely correlated with the water level in well CY-26. In recent dry years, Comal Springs has displayed a seasonal pattern of flow with summer flow considerably smaller than winter flow. This was pronounced in 1967. The 1950-56 drought caused severe declines in Central pool water levels. The lowest water levels on record occurred during the summer of 1956, and the water levels at the end of 1956 were much lower than the water levels at the end of any subsequent year.

Historic Inflow

Table 1 lists the estimated direct recharge to the Central pool for each year. Table 2 lists averages for various periods. The values for the Frio and Dry Frio Basins equal the USGS estimate minus the portion of the recharge from the Dry Frio (about one-half) credited to the Uvalde Pool. All other values are USGS estimates. The estimated recharge from the various subbasins vary considerably in the extent to which they are supported by streamflow measurements in the basins. In general, the figures for the Frio and Dry Frio Basins and the Sabinal Basin are well supported from September 1952 on. The estimates for the area between the Sabinal and Medina Basins has partial support from September 1952 on. The estimated recharge from the Medina Basin is based to a large extent upon historic content data for Medina Lake and on the estimated relationship between Medina Lake content and recharge. This relationship is not defined very accurately by available data. The estimates for the area between Medina Basin and Cibolo Creek Basin and for the Cibolo and Dry Comal Creek Basins have very little support from gaging stations within these two subbasins.

The total direct recharge estimates for the period beginning in September 1952 are better supported by local streamflow measurements than the estimates for earlier periods. The total direct recharge estimate for each year was correlated with the gaged flow of the Guadalupe near Spring Branch and the Frio near Concan to test for time trends. No convincing trends were detected by this rather coarse test.

Estimated direct recharge is by far the most variable item and one of the least accurate items in the water budget for the Central pool. Since the other items of inflow and outflow are relatively constant, or in the case of discharge of Comal and San Antonio Springs, accurately measured it was reasoned that a plot of change in water surface elevation in the Central pool each year vs. the computed change in Central pool content would be a test of the estimated direct recharge, and might reveal "wild" estimates. Plate 3 is such a plot; it uses the average of well I-4-12 and well 26 as the index to Central pool water surface elevation. The correlation is fair and most of the outliers, such as 1949 and 1961, plot reasonably well in the correlations of direct recharge vs. flow of Guadalupe near Spring Branch and Frio near Concan. The geological survey estimates of direct recharge to the Central pool were used without change in this study.

The historic inflow to the Central pool through eastward flow in the Edwards Underground from the Uvalde pool is estimated to average 66,000 acre-feet per year. This estimate is based upon water budget studies for the Uvalde pool that are presented in my memo to the files, subject: "Uvalde Pool of Edwards Underground Aquifer," dated April 13, 1972.

Historic Outflow

Discharge from the Central pool occurs through San Antonio Springs, Comal Springs, wells, and eastward flow in the Edwards Underground Aquifer.

Streamflow data adequate to define the flow of San Antonio Springs are available during October 1916-October 1929 and October 1939 to date. Reliable estimates for November 1929 through September 1939 can be made by use of good correlations with other measured items and from miscellaneous measurements. Streamflow data adequate to define the flow of Comal Springs are available from 1927 to date. Reliable estimates for October 1916 through 1926 can be made by use of good correlations with other measured items and from miscellaneous measurements. The discharge from San Antonio Springs and from Comal Springs has been estimated by the USGS for the 1934-1969 period, and these estimates are used in this analysis. The discharge estimates for the two springs are the most accurate items in the water balance for the Central pool.

The USGS has estimated the well discharge for each county for various uses for each year 1934-1970. The categories are municipal and military, agriculture, industry, and domestic, stock, and miscellaneous. A portion of the well discharge from Uvalde County and all of the well discharge from Medina, Bexar, and Comal Counties was estimated to be from the Central pool in this analysis. The Uvalde County well discharge east of the Frio River was assumed to be from the Central pool. This was about 39% of the total Uvalde County well discharge in 1969. The estimated municipal and military and the estimated industry well discharge is believed to be fairly accurate. The estimated use by irrigation and for domestic, stock, and miscellaneous is less accurate. Table 1 lists the estimated well discharge from the Central pool for irrigation each year and also the estimated well discharge for all other uses combined.

The well discharge from the Central pool has shown a gradual increase with time. During 1969, the well discharge was 59% of the estimated average historic inflow to the Central pool.

The discharge from the Central pool through eastward flow in the Edwards Underground aquifer to the San Marcos pool was estimated by use of an annual plot of outflow from the Edwards Aquifer in Hayes County vs. average beginning and end-of-year elevation in well #26. 1939 and 1956 were the key years in this comparison. During these two dry years, almost all of the discharge in Hayes County in excess of local recharge was assumed to be supplied by underflow from the Central pool. A straight line connecting these two points was drawn on the graph. The discharge to the San Marcos pool was estimated by use of this line and the average water surface elevation at well #26 each year. Table 1 lists the estimated underflow to the San Marcos pool each year. It averages 53,000 acre-feet per year during 1934-1969.

Change in Central Pool Content

By subtracting the estimated Central pool outflow from the estimated inflow, it is possible to compute the change in the Central pool content each year. This item is listed in Table 1. As discussed earlier, much of the change in content may occur in the gravity portion of the aquifer. Plate 3 is a plot of computed change in content vs. the average change in water surface elevation in well I-4-12 and well #26 each year. Plate 4 is a plot of accumulated change in content from the end of 1956 vs. water surface elevation in well #26 at the end of each year. The computed change in content for each year is a residual of the water balance and therefore not very accurate. Since estimated outflow is more accurate than estimated inflow, the computed change in content of the Central pool is probably more accurate during years of low inflow than during years of high inflow.

Historic Water Balance

The water level sequences on Plate 2 and inflow data on Tables 1 and 2 indicate that recharge during the 1948-1956 drought period is by far the lowest during the 1934-1969 period. Other studies summarized in the runoff annexes for the Nueces and San Antonio and Guadalupe Basins indicate that recharge during the 1948-1956 drought was much smaller than during any other drought since at least 1900. The 1948-1956 situation is so severe and prolonged that it could be considered an abnormal event of unknown recurrence frequency that belongs to a different population than the remainder of the 1900-1969 period. The following comparison of minimum average annual direct recharge to the Central pool during the 1948-1956 period and during the remainder of the 1934-1969 period shows how severe the 1948-1956 period was.

Consecutive years	Minimum average direct recharge (1,000 acre-feet per year)	
	1948-1956 period	Remainder of 1934-1969 period
1	20	112
2	35	142
3	52	181
4	69	248
5	100	279
6	101	291
7	106	337
8	132	350
9	130	378

Average annual direct recharge during 1934-1969 was 379,000 acre-feet. Excluding 1948-1956, the average annual direct recharge was 461,000 acre-feet. The streams supplying direct recharge are springfed and drain limestone. These springs can provide appreciable base flow during short droughts but not during long droughts such as 1948-1956. Table 2 lists average inflow to the Central pool for various periods.

Comal Springs stopped flowing for the first time of record on June 13, 1956, and started to flow again on November 3, 1956. It has flowed continuously since (through 1971). San Antonio Springs flowed most of the time prior to 1948, but had zero flow during 1949-1957 inclusive. From 1958 through 1971, San Antonio Springs has had intermittent flow.

Well discharge has increased steadily. The highest well discharge for irrigation occurred in 1956, There has been an uptrend in recent years, however. The highest well discharge for purposes other than irrigation and the highest total well discharge occurred in 1967.

Operation Study for the 1969 Level of Well Discharge

Table 3 is an operation study for the Central pool for the 1969 level of well discharge. In this study the change in inflow from the Uvalde pool was obtained from an operation study for 1969 condition well discharge for the Uvalde pool. The 1969 condition well discharge was estimated in two components: irrigation and other. Both of these components were varied from year to year in accordance with precipitation. The variation in irrigation well discharge was based upon computed irrigation requirements for recent cropping patterns for Uvalde, Sabinal, Hondo, Rio Medina, and San Antonio airport. Separate computations were made for Bexar County and for the remainder of the Central pool. During the 1949-1957 period, irrigation well discharge was increased by 6,000 or 12,000 acre-feet per year in this study because of Medina Project shortages and the existence of a considerable number of irrigation wells in the Medina Project service area. These wells were assumed to be idle during the remainder of the period of study. The variation in other well discharge was based upon the irrigation requirement for San Antonio airport and a correlation between historic "other" well discharge and this irrigation requirement. The underflow from the Central pool to the San Marcos pool was estimated from the average water surface elevation of well #26 computed in this study and the estimated historic relationship between underflow and elevation of well #26 described earlier. For the study, the relationship was assumed to be displaced upward 4 feet because of the summer drawdown of well #26 that has occurred during recent years. The discharge of Comal Springs and San Antonio Springs was estimated from correlations for the 1956-1969 period between the flow of these springs and the water surface elevation in well #26 and from the water surface elevation in well #26 computed in this study. A refinement to these estimates consisted of assuming that the historic deviation of spring flow from the correlation each year would persist with 1969 condition well discharge. This deviation was expressed in terms of water surface elevation in well #26. For the 1956-1969 period, the deviation was obtained from the correlations described earlier. For the 1934-1955 period, the deviations were obtained from similar correlations for the earlier period. The correlation curves for the 1934-1955 period were 4 feet lower than the curves for the 1956-1969 period. This is attributed to the larger summer drawdowns that have occurred during recent years. In this study, it was assumed that a change in water surface elevation of 1 foot in well #26 would result from a change in Central pool aquifer content of 36,000 acre-feet. The water surface elevation in well #26 at the end of 1933 was estimated to be 650 feet, which is 22 feet lower than the historic level. The water level in well #26 at the end of each succeeding year was computed by trial and error. The correct value produces an outflow from the Central pool such that the difference in well #26 water surface elevation at the end of the year from the historic value is compatible with the cumulative difference in Central pool (inflow minus outflow) from the historic value and the assumed change in aquifer content of 36,000 acre-feet per foot change in well #26 water surface elevation.

The 1969 condition well discharge study indicates practically no flow from San Antonio Springs and considerably reduced flow from Comal Springs, compared to historic. The study indicates zero flow for Comal Springs in 1955 and 1956, and no flow during part (summers) of 1951, 1952, 1953, 1954, 1957, 1963, and 1967. At the end of 1969, the study shows a water surface elevation in well #26 that is 11 feet lower than historic. This is because of the higher than historic well discharge during years prior to 1969.

Operation Study for a 35 Percent Larger Well Discharge than Occurred in 1969

This operation study is similar to the 1969 condition operation study and is presented in Table 4. The inflow from the Uvalde pool was assumed to be 12,000 acre-feet per year smaller than in the 1969 condition study. This is an allowance for 35 percent higher well discharge in the Uvalde pool. Central pool well discharge for irrigation, exclusive of the Medina Project area, was assumed to increase over 1969 condition values by the ratio $\frac{119}{69}$. Medina Project area well discharge for irrigation during 1949-1957 was assumed to be the same as for the 1969 condition study. Central pool "other" well discharge was assumed to increase over 1969 condition values by the ratio of $\frac{265}{215}$. These ratios reflect trends during recent years. The correlations used to estimate the underflow to the San Marcos pool, and the discharge of San Antonio and Comal Springs were moved up 2 feet. This is an allowance for the more severe summer drawdowns that are assumed to result from the higher well discharge. The water surface elevation in well #26 was assumed to be 630 at the end of 1933. This is 42 feet lower than historic. Otherwise, this study is the same as the 1969 condition study.

This study indicates no flow at all from San Antonio Springs and no flow from Comal Springs during 1950-1959, inclusive, and also during 1962 through 1965 and during 1967. Comal Springs would have zero flow during part of 1934, 1939, 1940, 1943, 1948, 1949, 1960, 1961, 1966, 1968, and 1969. Thus Comal Springs would have no flow during drought periods, intermittent flow during normal periods, and year-around flow during wet years. If historic trends continue, this level of well discharge will be reached by about

1990. However, as pointed out by the 1969 condition study, there will be a lag of a few years between well discharge and effect on water levels, etc., during periods of increasing well discharge.

Year-end water levels in well #26 are 39 to 60 feet lower than historic. This does not appear to be severe enough to make irrigation from the Central pool uneconomic.

Effect of Even Higher Well Discharge Rates

The only discharge from the Central pool other than well discharge shown in Table 4 is an average underflow of 30,000 acre-feet to the San Marcos pool and an average discharge of 20,000 acre-feet from Comal Springs. Thus if well discharge from the Central pool were to increase by another 50,000 acre-feet per year, the Central pool would be on the verge of a mining situation. If historic trends in well discharge continue, this situation will be reached about year 2000. The Central pool might be able to draw some water from the San Marcos pool, but the amount is uncertain, and probably small without very low water levels in the Central pool. Within a few years after this level of well discharge is equalled or exceeded, the water levels in the piezometric portion of the Central pool will be reduced so severely as to affect the economics of irrigation from the Edwards. High levels of well discharge may result in a very rapid decline in piezometric water levels in the Central pool during dry years. During recent dry years, severe summer drawdowns have occurred in the water level in well #26 and other Central pool wells. During the following fall and winter, when well discharge was reduced, the water levels recovered to a level compatible with inflow, outflow, etc. However, with considerably higher well discharges, the summer drawdown would be much more severe. Higher well discharges during the fall and winter might prevent a complete or even partial recovery to normal levels. A computation for 1963 indicated that if the outflow from the Central pool had been 523,000 acre-feet instead of the historic 450,000 acre-feet, the water level in well #26 would have been 58 feet lower at the end of 1963 than at the end of 1962. Historically, the water level was 13.4 feet lower at the end of 1963 than at the end of 1962. In the study of Table 4, the Central pool outflow was 497,000 acre-feet in 1956. During this very dry year this may have exceeded the normal flow capability of the Central pool, and the end-of-year water level in well #26 might have been considerably lower than the 567 feet shown in the study. During favorable years, larger volumes of water can flow through the Central pool without abnormal effects on piezometric water levels. Thus in 1961 the historic outflow from the Central pool was 553,000 acre-feet. Therefore, any abnormal drawdown during dry years would be quickly overcome during subsequent wet years.

M. George Schwab

Table 1. Central pool - historic water balance

1000 AF except as noted

Year	Estimated inflow: Underflow from Uvalde pool	Estimated inflow: Direct recharge	Estimated inflow: Total	Estimated outflow: San Antonio Springs	Estimated outflow: Comal Springs	Estimated outflow: Well discharge: Irrigation	Estimated outflow: Well discharge: Other	Estimated outflow: Underflow to San Marcos pool	Estimated outflow: Total	Inflow minus outflow	Well #26: W.S. elev. end of year (feet)	Well #26: Change from last year (feet)
1934	66	148	214	13	228	21	78	55	395	-181	669	- 3
35	66	781	847	74	236	19	83	56	468	379	680	+11
36	66	670	736	107	260	19	93	58	537	199	682	+ 2
37	66	339	405	88	252	20	97	58	515	-110	678	- 4
38	66	324	390	75	248	20	98	57	498	-108	674	- 4
39	66	155	221	11	218	20	96	55	400	-179	668	- 6
1940	66	233	299	3	202	22	97	55	379	- 80	671	+ 3
41	66	682	748	68	248	24	110	56	506	242	677	+ 6
42	66	413	479	67	253	25	117	57	519	- 40	680	+ 3
43	66	212	278	32	247	26	119	56	480	-202	669	-11
44	66	439	505	26	251	28	118	56	479	26	676	+ 7
1945	66	437	503	56	261	28	121	56	522	- 19	673	- 3
46	66	426	492	35	260	31	119	57	502	- 10	679	+ 6
47	66	310	376	36	255	32	131	56	510	-134	668	-11
48	66	121	187	2	201	33	131	52	419	-232	657	-11
49	66	308	374	0	207	33	140	52	432	- 58	664	+ 7
1950	66	138	204	0	189	33	152	52	426	-222	655	- 9
51	66	106	172	0	140	35	162	49	395	-223	646	- 9
52	66	225	291	0	132	37	163	48	380	- 89	651	+ 5
53	66	118	184	0	139	52	159	48	398	-214	646	- 5
54	66	87	153	0	99	61	167	46	373	-220	637	- 9
1955	66	50	116	0	65	71	169	44	350	-234	631	- 6
56	66	20	86	0	23	94	187	42	346	-260	627	- 4
57	66	947	1,013	0	105	53	166	46	370	643	654	+27
58	66	1,346	1,412	14	227	37	167	53	498	914	678	+24
59	66	534	600	24	227	46	171	57	525	75	675	- 3
1960	66	663	729	26	230	42	169	57	524	205	679	+ 4
61	66	565	631	42	241	39	174	57	553	78	676	- 3
62	66	172	238	9	193	51	188	55	496	-258	666	-10
63	66	112	178	1	150	52	195	52	450	-272	653	-13
64	66	258	324	0	137	48	183	50	418	- 94	653	0
1965	66	452	518	4	189	45	183	52	473	45	669	+16
66	66	399	465	2	193	46	181	53	475	- 10	657	-12
67	66	353	419	0	131	77	214	51	473	- 54	660	+ 3
68	66	688	754	17	231	37	184	53	522	232	670	+10
1969	66	402	468	5	211	55	206	55	532	- 64	670	0
1934-69	2,376	13,633	16,009	837	7,089	1,412	5,288	1,912	16,538	-529		- 2
ave.	66	379	445	23	197	39	147	53	459	- 14		

Table 2. Estimated historic inflow and outflow, Central Pool various periods (1,000 acre-feet per year)

Item	1948-1956	1960-1969	1934-1947 & 1957-1969	1934-1969
Inflow				
Direct recharge				
Frio and Dry Frio Basins	26	96	94	77
Sabinal Basin	11	33	39	32
Area between Sabinal and Medina Basins	22	86	90	73
Medina River Basin	22	60	60	51
Area between Medina and Cibolo	19	48	68	56
Cibolo and Dry Comal Creek Basins	30	83	110	90
Subtotal	130	406	461	379
Underflow from Uvalde pool	66	66	66	66
Total inflow	196	472	527	445
Outflow				
Wells				
Irrigation	50	49	36	39
Other	159	188	142	147
Subtotal	209	237	178	186
San Antonio Springs	0	11	31	23
Comal Springs	134	191	218	197
Underflow to San Marcos pool	48	53	55	53
Total outflow	391	492	482	459

Table 3
Central Pool Operation
1969 Condition

1000 AF except as noted

Year	Historic W.S. Elev Well 26, end of Yr Ft.	Historic Outflow	Increase in inflow from Uvalde Pool, Compared to Historic	Well Discharge	Discharge to San Marcos Pool	Hist. Dischr. San Marcos Springs 1/	Hist. Δ from Curve, San Antonio Springs Ft	San Antonio Springs Elev W.S. Ft	Est. Discharge, San Antonio Springs	Hist Δ from Curve, Comal Springs - Eff Ave Elev Well 26 Ft.	Comal Springs Elev WS Ft	Est. Discharge, Comal Springs	Total Outflow	Cum. Inflow - Outflow, Δ from Historic	Well 26, Δ from Historic, end of Yr. Ft	Well 26 End of Yr Ft	Well 26, average, end of preced. + current year Ft	Year
	672													-792	-22	650		
1934	669	395	0	310	47		0	647	0	0	644	106	463	-860	-24	645	647	1934
1935	680	468	-3	238	48		+3	654	0	-2	649	120	406	-801	-22	658	651	1935
36	682	537	-1	264	51		+1	661	3	-3	657	153	471	-736	-20	662	660	36
37	678	515	+1	296	51		0	660	2	-4	656	148	497	-717	-20	658	660	37
38	674	498	+1	287	50		+2	658	1	-1	655	145	483	-701	-19	655	656	38
39	668	400	0	323	48		-1	650	0	-3	648	116	457	-788	-22	646	651	39
1940	671	379	-1	277	47		-8	639	0	-6	641	85	409	-819	-23	648	647	1940
41	677	506	-1	265	49		+3	655	0	+1	653	136	450	-764	-21	656	652	41
42	680	519	-1	281	50		-1	657	0	-2	656	148	479	-725	-20	660	658	42
43	669	480	-2	286	49		-1	654	0	+1	656	148	483	-730	-20	649	655	43
44	676	479	-3	266	49		0	653	0	+4	657	153	468	-722	-20	656	653	44
1945	673	522	-5	280	49		+1	656	0	+4	659	162	491	-696	-19	654	655	1945
46	679	502	-7	260	50		-3	654	0	+2	659	162	472	-673	-19	660	657	46
47	668	510	-9	306	49		-1	653	0	+3	657	153	508	-680	-19	649	654	47
48	656	419	-10	299	45		-2	640	0	+2	644	98	442	-713	-20	636	642	48
49	664	432	-12	263	45		-2	638	0	+6	646	107	415	-708	-20	644	640	49
1950	656	426	-11	287	45		-2	638	0	+1	641	86	418	-711	-20	636	640	1950
51	646	395	-11	309	41		0	631	0	+1	632	46	396	-723	-20	626	631	51
52	650	380	-13	313	38		0	627	0	0	627	32	383	-739	-20	628	627	52
53	646	398	-15	319	38		0	627	0	+1	628	34	391	-747	-21	625	627	53
54	637	373	-16	335	32		0	620	0	-1	619	3	370	-760	-21	616	620	54
1955	631	350	-16	320	27		0	613	0	-1	612	0	347	-773	-21	610	613	1955
56	627	346	-15	364	22		0	607	0	-4	603	0	386	-828	-23	604	607	56
57	654	370	-16	260	31		0	618	0	+6	624	22	313	-787	-22	632	618	57
58	678	498	-17	264	47		+7	652	0	+8	653	136	447	-753	-21	657	645	58
59	675	525	-20	279	50		0	656	0	-2	654	140	469	-717	-20	655	656	59
1960	679	524	-15	285	50		-1	656	0	-2	655	144	479	-687	-19	660	657	1960
61	676	553	-11	282	50		+1	660	2	0	659	162	496	-641	-18	658	659	61
62	666	496	-5	301	49		-2	652	0	-5	649	120	470	-620	-17	649	654	62
63	653	450	-3	303	46		-1	642	0	-3	640	82	431	-604	-17	636	643	63
64	653	418	-4	275	43		+4	640	0	0	636	64	382	-572	-16	637	636	64
1965	669	473	-4	261	47		+2	649	0	+5	652	132	440	-543	-15	654	647	1965
66	657	475	-5	254	47		-3	645	0	+4	652	132	433	-506	-14	643	648	66
67	660	473	-5	318	46		+1	646	0	-6	639	78	442	-480	-13	647	645	67
68	670	522	-5	242	48		+10	662	3	+11	663	178	471	-434	-12	658	652	68
1969	670	532	-1	261	50		-6	653	0	+1	660	166	477	-380	-11	659	659	1969
Σ1934-69		16538	-261	10333	1624				11 1/			3897	15865					Σ
Avr		459	-7	287	45				0			109	441					Ave

1/ Excess of inflow from Central Pool and increase in San Marcos Pool pumpage over historic. Applies only if well 26 elev., this study, for preced & current year average is below 580'.

Tabl

TABLE 4

Central Pool Operation Study

1969 Condition x 1.35

1000 AF except as noted.

Year	Historic: W.S. Elev Well 26, end of Yr Ft.	Historic: Outflow	Increase in inflow from Uvalde Pool, Compared to Historic	Well Discharge	Discharge to San Marcos Pool	Hist. Dischr. San Marcos Springs 1/	Hist. Δ from Curve, San Antonio Springs Ft	San Antonio Springs Elev W.S. Ft	Est. Discharge, San Antonio Springs	Hist Δ from Curve, Comal Springs - Eff Ave Elev Well 26 Ft.	Comal Springs Elev WS Ft	Est. Discharge, Comal Springs	Total Outflow	Cum. Inflow - Outflow, Δ from Historic	Well 26, Δ from Historic, end of Yr Ft	Well 26 End of Yr Ft	Well 26, average, end of preceed. + current year Ft	Year
	672													-1512	-42	630		
1934	669	395	-12	423	37		0	627	0	0	627	25	485	-1614	-45	624	627	1934
1935	680	468	-15	313	40		+3	634	0	-2	629	32	385	-1546	-43	637	631	1935
36	682	537	-13	354	46		+1	640	0	-3	636	57	457	-1479	-41	641	639	36
37	678	515	-11	402	47		0	639	0	-4	635	52	501	-1476	-41	637	639	37
38	674	498	-11	389	45		+2	637	0	-1	634	48	482	-1471	-41	633	635	38
39	668	400	-12	442	38		-1	628	0	-3	626	22	502	-1585	-44	624	629	39
1940	671	379	-13	370	36		-8	618	0	-6	620	3	409	-1628	-45	626	626	1940
41	677	506	-13	352	39		+3	633	0	+1	631	40	431	-1566	-44	633	630	41
42	680	519	-13	381	42		-1	634	0	-2	633	44	467	-1527	-42	638	635	42
43	669	480	-14	385	41		-1	631	0	+1	633	44	470	-1531	-43	626	632	43
44	676	479	-15	356	39		0	630	0	+4	634	48	443	-1510	-42	634	630	44
1945	673	522	-17	379	42		+1	634	0	+4	637	60	481	-1486	-41	632	633	1945
46	679	502	-19	349	43		-3	633	0	+2	638	65	457	-1460	-40	639	636	46
47	668	510	-21	417	43		-1	632	0	+3	636	57	517	-1488	-41	627	633	47
48	656	419	-22	404	31		-2	618	0	+2	622	9	444	-1535	-43	613	620	48
49	664	432	-24	349	28		-2	615	0	+6	623	12	389	-1516	-42	622	617	49
1950	656	426	-23	383	29		-2	616	0	+1	619	0	412	-1523	-42	614	618	1950
51	646	395	-23	415	21		0	608	0	+1	609	0	436	-1589	-44	602	608	51
52	650	380	-25	420	18		0	603	0	0	603	0	438	-1672	-46	604	603	52
53	646	398	-27	435	15		0	601	0	+1	602	0	450	-1751	-49	597	601	53
54	637	373	-28	456	7		0	591	0	-1	590	0	463	-1869	-52	585	591	54
1955	631	350	-28	432	-1	15	0	580	0	-1	579	0	431	-1978	-55	576	580	1955
56	627	346	-27	500	-3	3	0	571	0	-4	567	0	497	-2156	-60	567	571	56
57	654	370	-28	344	0		0	580	0	+6	586	0	344	-2158	-60	594	580	57
58	678	498	-29	352	20		+7	614	0	+8	615	0	372	-2061	-57	621	607	58
59	675	525	-32	375	31		0	620	0	-2	618	0	406	-1974	-55	620	620	59
1960	679	524	-27	384	33		-1	622	0	-2	621	3	420	-1897	-53	626	623	1960
61	676	553	-23	380	36		+1	627	0	0	626	22	438	-1805	-50	626	626	61
62	666	496	-17	409	32		-2	619	0	-5	616	0	441	-1767	-49	617	621	62
63	653	450	-15	412	23		-1	609	0	-3	607	0	435	-1767	-49	604	610	63
64	653	418	-16	371	17		+4	608	0	0	604	0	388	-1753	-49	604	604	64
1965	669	473	-16	351	25		+2	615	0	+5	618	0	376	-1672	-46	623	613	1965
66	657	475	-17	341	28		-3	615	0	+4	622	9	378	-1592	-44	613	618	66
67	660	473	-17	435	25		+1	615	0	-6	608	0	460	-1596	-44	616	614	67
68	670	522	-17	321	33		+10	632	0	+1	633	44	398	-1489	-41	629	622	68
1969	670	532	-13	348	39		-6	624	0	+1	631	37	424	-1394	-39	631	630	1969
1934-69		16,538	-693	13,929	1065				0			733	15,727					Σ
Ave		459	-19	387	30				0			20	437					Ave

1/ Excess of inflow from Central Pool and increase in San Marcos Pool Pumpage over historic. Applies only if well 26 elev., this study, for preceed & current year average is below 580'.

Table 4

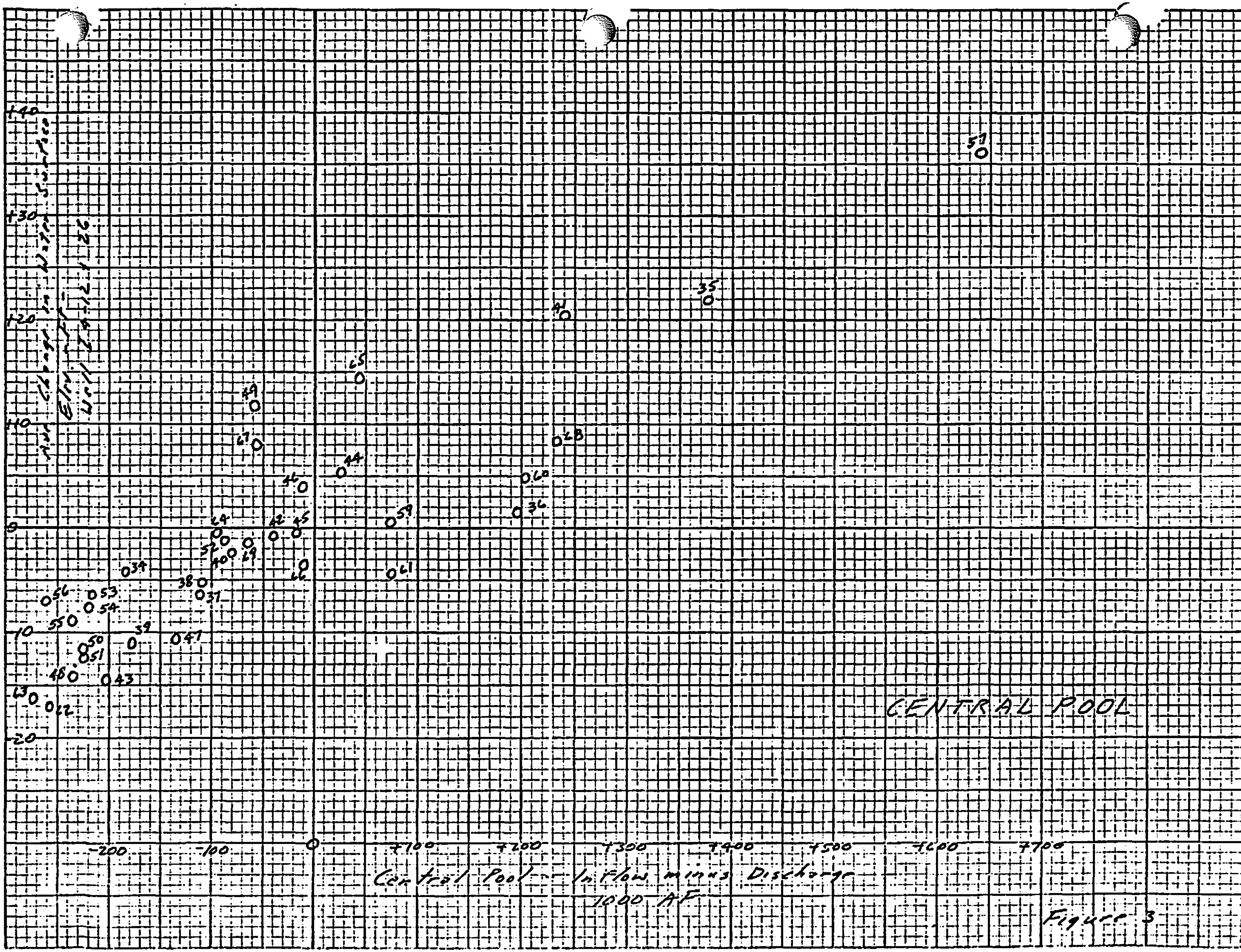
+40
+30
+20
+10
0
-10
-20
-200
-100
0
+100
+200
+300
+400
+500
+600
+700
Central Pool - Inflow minus Discharge
1000 AF
CENTRAL POOL

Figure 3

KEUFFEL & ESSER CO. MADE IN U.S.A.

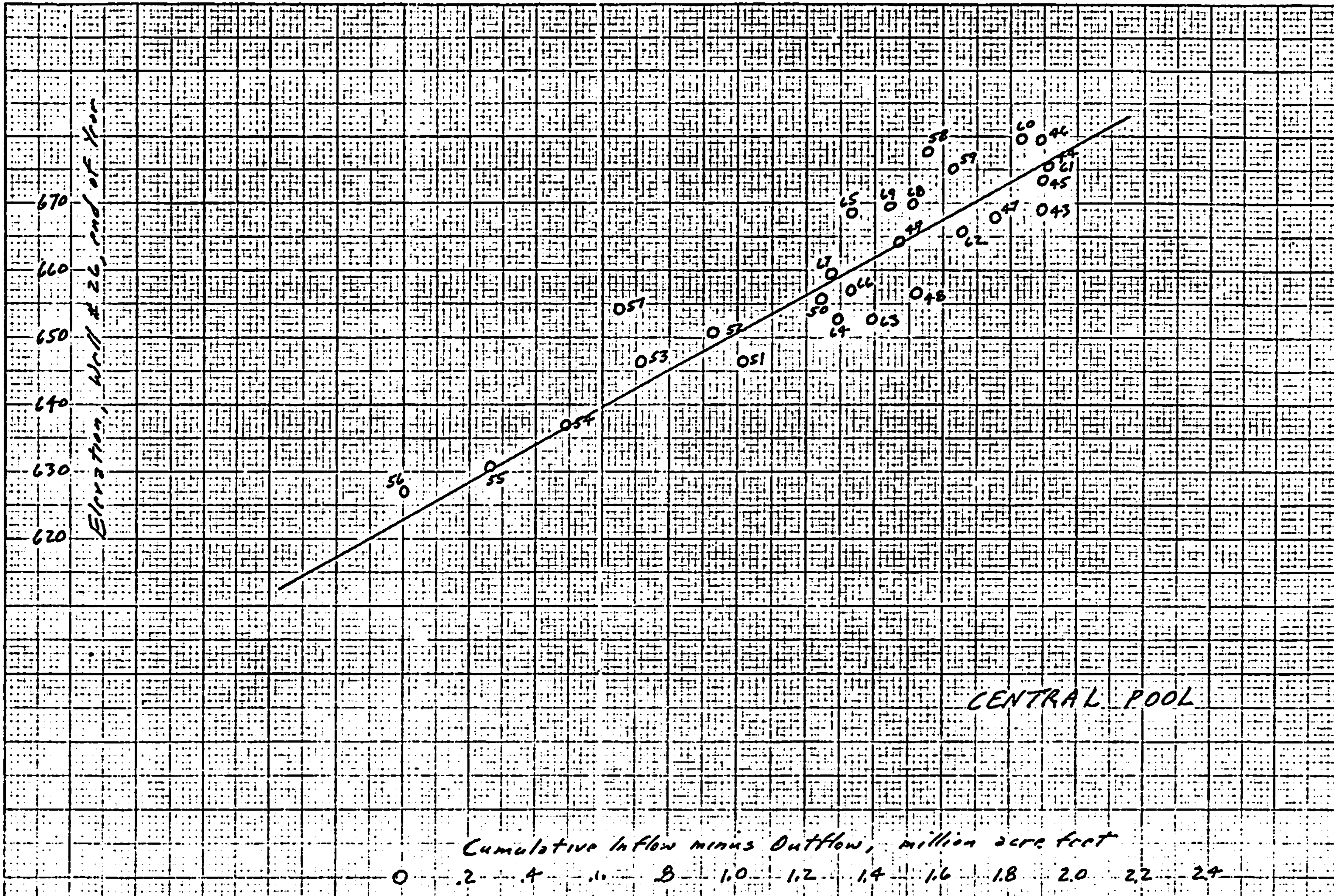

Figure 4

Austin, Texas
June 6, 1972

Memorandum

To: Files

From: Chief, Hydrology Division

Subject: San Marcos Pool of Edwards Underground Aquifer

The San Marcos Pool

The San Marcos Pool is a portion of the Edwards Underground Aquifer in the general vicinity of San Marcos which has a relatively flat piezometric water surface and a lower piezometric water surface than the aquifer to the west. It is postulated that the lower water surface is caused by a zone which has considerable resistance to flow located between the Central Pool and the San Marcos Pool and by fact that San Marcos Springs provides an outlet at a considerably lower elevation than any natural outlet in the Central Pool. Figure 1 shows the location of the San Marcos Pool. Its approximate outlines were determined by examination of water level contour maps for the Edwards Underground for various dates (January 1952, August 1954, August 1956, March 1958, January 1961) that were presented in Texas Board of Water Engineers Bulletins 5608 and 6201 and Texas Water Development Board Report 34.

Historic Water Levels

Water level observations are available for several wells in the San Marcos Pool. Water surface elevations for well G-25 is plotted on Figure 2. Figure 1 shows the location of this well. The historic fluctuations in water levels in well G-25 have been very small compared to wells in the Central Pool. The influence of Comal and San Marcos Springs is responsible for the small fluctuation. So long as these two springs are flowing, water levels in well G-25 will always be somewhere between the outlet elevations of these two springs. Well G-25 does not display the severe summer drawdowns that have occurred in Central Pool wells during some recent years. The lowest water level on record occurred in the summer of 1956.

Historic Inflow

Inflow to the San Marcos Pool consists of underflow in the aquifer from the Central Pool, plus direct recharge to the San Marcos Pool. The inflow to the San Marcos Pool from the Central Pool was estimated from an annual plot of outflow from the aquifer in Hayes County vs. average beginning and end-of-year elevation in well #26. Figure 3 presents this plot. 1939 and 1956 were the key years. During these two dry years, almost all of the discharge in Hayes County in excess of the USGS estimate of local recharge was assumed to be supplied by underflow from the Central Pool. The underflow from the Central Pool was estimated by entering the line of Figure 3 with the average water surface elevation at well #26 each year. Table 1 lists the estimated average annual underflow from the Central Pool each year. It averages 53, 000 acre-feet per year during 1934-1969. This procedure assumes that very little of the 1939 and 1956 outflow in Hayes County was derived from a decrease in aquifer content in the San Marcos Pool. If a considerable amount of the outflow was from storage, then the underflow from the Central Pool is overestimated. The progression on Figure 3 from 1953 through 1956 raises the question of what would have happened in 1957 if it had been a dry year. The 1938-1939-1940 situation is similar.

The USGS has estimated the recharge from the Blanco River Basin and adjacent area for each year 1934-1969. Blanco River recharge estimates are supported by a gaging station above the fault through this period and a gaging station below the fault that began operation in 1956. Recharge estimates for adjacent areas are not supported by gages in those areas. The 1934-1969 average recharge estimate is 32, 000 acre-feet per year. However, the historic outflow in Hayes County is estimated to average 102, 000 acre-feet per year, and the underflow from the Central Pool was estimated to average 53, 000 acre-feet per year. If these values are correct, the average direct recharge to the San Marcos Pool must have been about 49, 000 acre-feet per year since the average annual change in content of the San Marcos Pool during the 1934-1969 period must be quite small. The outflow consists almost entirely of flow from San Marcos Springs and is accurate. As discussed earlier, the estimate of underflow from the Central Pool is more likely to be too high than too low. Consequently, in these studies, the average annual direct recharge to the San Marcos Pool was assumed to average 49, 000 acre-feet per year. A reliable estimate of change in San Marcos Pool content could not be made.

Consequently, direct recharge minus change in San Marcos Pool content were lumped together and are so listed in Table 1. Generally, when outflow increases, content also increases, and direct recharge will be larger than (direct recharge minus change in content). When outflow decreases, the converse will be true, and direct recharge will usually be smaller than (direct recharge minus change in content).

Historic Outflow

Outflow from the San Marcos Pool occurs through San Marcos Springs and through wells. The estimated historic outflow each year is listed in Table 1. The well discharge in Hayes County has increased gradually but is still relatively small. Almost all of the historic outflow has been from San Marcos Springs. Historically, San Marcos Springs has always had a continuous flow. The smallest flow on record is 46 c.f.s. on August 15-16, 1956. Adequate data on the flow of San Marcos Springs is available for the entire 1934-1969 period.

Change in San Marcos Pool Content

Attempts were made to estimate the historic changes in content of the San Marcos Pool. These attempts were unsuccessful.

Effect of the 1969 Level of Well Discharge

Table 2 lists the estimated water balance for the San Marcos Pool for the 1969 level of well discharge from the whole aquifer. The underflow from the Central Pool is from the 1969 condition operation study for the Central Pool. The direct recharge minus change in content for each year is the same as historic. The 1969 condition well discharge was estimated from well discharge data for recent years and from year-to-year variations in 1969 condition well discharge estimated for the Central Pool. The discharge of San Marcos Springs was computed as the unknown item in the water balance.

This tabulation assumes that with 1969 condition well discharge, the change in San Marcos Pool content each year will be the same as historic. This assumption was necessitated by the lack of knowledge of historic changes in Central Pool content. The assumption is not entirely correct of course, but it is not grossly in error.

The estimated average 1969 condition discharge of San Marcos Springs is moderately smaller than the historic discharge. San Marcos Springs continues to have continuous flow throughout the period of study. The 1956 flow of San Marcos Springs is 24,000 acre-feet, compared to the historic 1956 flow of 46,000 acre-feet.

Effect of Aquifer Well Discharge 35% Higher than the 1969 Condition Well Discharge

Table 3 presents the estimated water balance for the San Marcos Pool with the well discharge from the aquifer 35% higher than the 1969 level. The underflow from the Central Pool is from an operation study for this condition for the Central Pool. The direct recharge minus change in content is the same as historic. The well discharge from the San Marcos Pool is 35% higher than the estimated 1969 condition well discharge. The discharge of San Marcos Springs was computed as the unknown item in the water balance.

The estimated discharge of San Marcos Springs is further reduced. Table 3 indicates zero flow for San Marcos Springs in 1956 and a small flow in 1955. The zero flow in 1956 may not be correct. The San Marcos Pool change in storage in 1956 may have been larger than assumed. Table 3 indicates that a small flow would have occurred in 1956 if there had been no well discharge in Hayes County.

If the upward trend in well discharge from the aquifer that has prevailed since 1958 continues, the aquifer well discharge assumed in Table 3 will occur about 1990.

Effect of Even Higher Well Discharge Rates

Even higher well discharge rates would cause a further reduction in the flow of San Marcos Springs. Higher well discharges in Hayes County would have a direct effect on San Marcos Springs. The degree to which San Marcos Springs would be affected by higher well discharges west of Hayes County is uncertain because the reduction in flow of San Marcos Springs that would result from water levels in the Central Pool that are lower than San Marcos Springs is uncertain.

Gerry Schwab
M. George Schwab

Table 1. Historic water balance, San Marcos Pool
(1,000 acre-feet)

Year	Historic: Inflow minus change in content: Underflow from Central Pool	Direct recharge minus change in content	Total	Outflow: San Marcos Springs	Well discharge: Irrigation	Other	Total	Total
1934	55	31	86	85	0	1	1	86
1935	56	41	97	96	0	1	1	97
36	58	35	93	92	0	1	1	93
37	58	29	87	86	0	1	1	87
38	57	36	93	92	0	1	1	93
39	55	16	71	70	0	1	1	71
1940	55	23	78	77	0	1	1	78
41	56	78	134	133	0	1	1	134
42	57	55	112	111	0	1	1	112
43	56	41	97	96	0	1	1	97
44	56	79	135	134	0	1	1	135
1945	56	81	137	136	0	1	1	137
46	57	77	134	133	0	1	1	134
47	56	71	127	126	0	1	1	127
48	52	25	77	75	0	2	2	77
49	52	38	90	88	0	2	2	90
1950	52	27	79	77	0	2	2	79
51	49	20	69	67	0	2	2	69
52	48	31	79	77	0	2	2	79
53	48	53	101	99	0	2	2	101
54	46	34	80	78	0	2	2	80
1955	44	19	63	61	0	2	2	63
56	42	8	50	46	0	4	4	50
57	46	67	113	110	0	3	3	113
58	53	103	156	154	0	2	2	156
59	57	61	118	116	0	2	2	118
1960	57	86	143	141	0	2	2	143
61	57	83	140	138	0	2	2	140
62	55	43	98	96	0	2	2	98
63	52	30	82	79	0	3	3	82
64	50	23	73	70	0	3	3	73
1965	52	74	126	123	0	3	3	126
66	53	63	116	111	1	4	5	116
67	51	31	82	78	1	3	4	82
68	53	93	146	143	0	3	3	146
1969	55	68	123	118	1	4	5	123
1934-69	1,912	1,773	3,685	3,612	3	70	73	3,685
Ave.	53	49	102	100	0	2	2	102

Table 2. San Marcos Pool water balance with 1969 condition aquifer well discharge (1,000 acre-feet)

Year	Inflow minus change in content: Underflow from Central Pool	Inflow minus change in content: Direct recharge minus change in content	Inflow minus change in content: Total	Outflow: San Marcos Springs	Outflow: Well discharge: Irrigation	Outflow: Well discharge: Other	Outflow: Well discharge: Total	Outflow: Total
1934	47	31	78	73	1	4	5	78
1935	48	41	89	86	0	3	3	89
36	51	35	86	82	0	4	4	86
37	51	29	80	76	0	4	4	80
38	50	36	86	82	0	4	4	86
39	48	16	64	59	1	4	5	64
1940	47	23	70	66	0	4	4	70
41	49	78	127	123	0	4	4	127
42	50	55	105	101	0	4	4	105
43	49	41	90	86	0	4	4	90
44	49	79	128	124	0	4	4	128
1945	49	81	130	126	0	4	4	130
46	50	77	127	124	0	3	3	127
47	49	71	120	115	1	4	5	120
48	45	25	70	66	0	4	4	70
49	45	38	83	80	0	3	3	83
1950	45	27	72	68	0	4	4	72
51	41	20	61	57	0	4	4	61
52	38	31	69	64	1	4	5	69
53	38	53	91	86	1	4	5	91
54	32	34	66	61	1	4	5	66
1955	27	19	46	41	1	4	5	46
56	22	8	30	24	1	5	6	30
57	31	67	98	94	0	4	4	98
58	47	103	150	146	0	4	4	150
59	50	61	111	107	0	4	4	111
1960	50	86	136	132	0	4	4	136
61	50	83	133	129	0	4	4	133
62	49	43	92	88	0	4	4	92
63	46	30	76	72	0	4	4	76
64	43	23	66	62	0	4	4	66
1965	47	74	121	118	0	3	3	121
66	47	62	109	105	0	4	4	109
67	46	31	77	72	1	4	5	77
68	48	93	141	138	0	3	3	141
1969	50	67	117	113	0	4	4	117
1934-69	1,624	1,771	3,395	3,246	9	140	149	3,395
Ave.	45	49	94	90	0	4	4	94

Table 3. San Marcos Pool water balance with 1.35 x 1969 condition aquifer well discharge
(1,000 acre-feet)

	Inflow minus change in content			Outflow				
	Under-flow from Central Pool	Direct recharge minus change in content			Well discharge			
Year			Total	San Marcos Springs	Irriga-tion	Other	Total	Total
1934	37	31	68	62	1	5	6	68
1935	40	41	81	77	0	4	4	81
36	46	35	81	76	0	5	5	81
37	47	29	76	70	1	5	6	76
38	45	36	81	75	1	5	6	81
39	38	16	54	48	1	5	6	54
1940	36	23	59	53	1	5	6	59
41	39	78	117	111	1	5	6	117
42	42	55	97	91	1	5	6	97
43	41	41	82	76	1	5	6	82
44	39	79	118	112	1	5	6	118
1945	42	81	123	117	1	5	6	123
46	43	77	120	116	0	4	4	120
47	43	71	114	108	1	5	6	114
48	31	25	56	50	1	5	6	56
49	28	38	66	62	0	4	4	66
1950	29	27	56	50	1	5	6	56
51	21	20	41	35	1	5	6	41
52	18	31	49	43	1	5	6	49
53	15	53	68	62	1	5	6	68
54	7	34	41	35	1	5	6	41
1955	-1	19	18	12	1	5	6	18
56	-3	8	5	1/ 0	1	7	8	1/ 8
57	0	67	67	1/59	0	5	5	1/64
58	20	103	123	118	0	5	5	123
59	31	61	92	86	1	5	6	92
1960	33	86	119	113	1	5	6	119
61	36	83	119	113	1	5	6	119
62	32	43	75	69	1	5	6	75
63	23	30	53	47	1	5	6	53
64	17	23	40	34	1	5	6	40
1965	25	74	99	94	1	4	5	99
66	28	62	90	84	1	5	6	90
67	25	31	56	50	1	5	6	56
68	33	93	126	122	0	4	4	126
1969	39	67	106	100	1	5	6	106
1934-69	1,065	1,771	2,836	2,630	29	177	206	2,836
Ave.	30	49	79	73	1	5	6	79

1/ Overdraft of 3 in 1956 was carried into 1957.

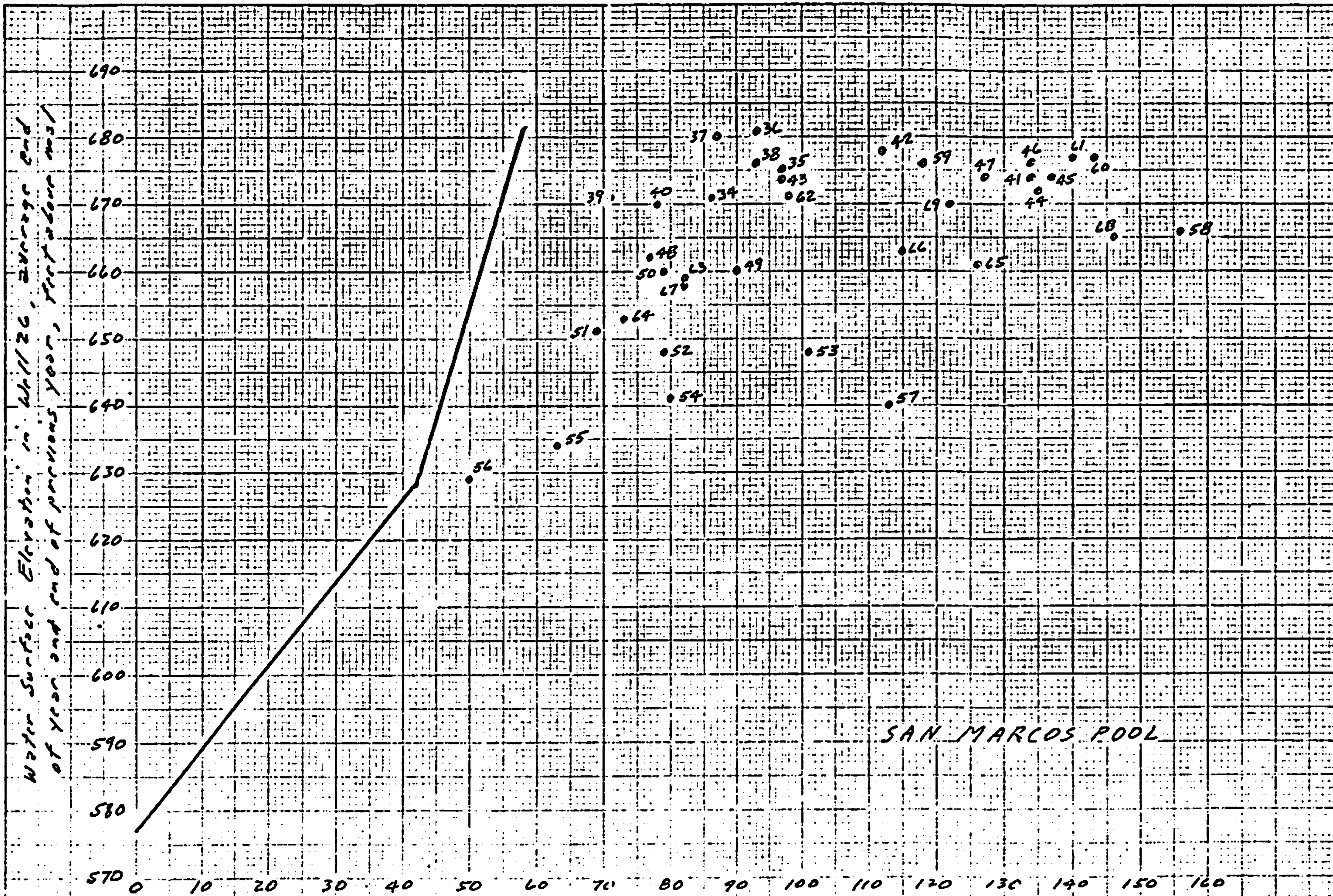
Water Surface Elevation in Well 26, average end of year and end of previous year, feet above msl
690
680
670
660
650
640
630
620
610
600
590
580
570
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
San Marcos Pool Outflow, 1000 Acre Feet
SAN MARCOS POOL
36
37
42
38
35
59
47
46
61
60
43
41
45
39
40
34
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Figure 3

Austin, Texas
June 30, 1972

Memorandum to Files

From: Chief, Hydrology Division

Subject: Edwards Underground Aquifer

General

Studies were made of the historic operation of the aquifer, its estimated performance during the 1934-1969 period with the 1969 level of well discharge, and its performance with a well discharge 35% larger than the 1969 level. Some speculations were made about the effect of still higher levels of well discharge.

For these studies the aquifer was considered to consist of three pools separated by short reaches of restricted flow. The approximate outline of these pools is shown on Figure 1. The Uvalde pool is in the vicinity of Uvalde. It has a relatively flat piezometric water surface and a considerably higher piezometric water surface than the Central pool to the east. It is postulated that the higher water surface elevation of the Uvalde pool is caused by a zone located between the Uvalde pool and the Central pool which has considerable resistance to flow and by the existence of natural outlets (San Antonio and Comal Springs) in the Central pool that are at a considerably lower elevation than the natural outlet (Leona Springs) in the Uvalde pool.

The San Marcos pool is located in the vicinity of San Marcos. It has a relatively flat piezometric water surface and a lower piezometric water surface than the Central pool. It is postulated that the lower water surface is caused by a zone located between the San Marcos pool and the Central pool which has considerable resistance to flow, and also by the fact that San Marcos Springs provides an outlet in the San Marcos pool at a considerably lower elevation than any natural outlet in the Central pool.

The Central pool is located between the Uvalde pool and the San Marcos pool and is by far the largest pool. The pool outlines shown on Figure 1 were determined by examination of water level contour maps for the Edwards Underground for various dates (January 1952, August 1954, August 1956, March 1958, January 1961) that were presented in Texas Board of Water Engineers Bulletins 5608 and 6201 and Texas Water Development Board Report 34.

In the various studies, the flow in the Edwards Underground from the Uvalde pool to the Central pool and the flow from the Central pool to the San Marcos pool were considered to be relatively constant and to vary with the hydraulic gradient between the respective pools.

Figure 2 shows historic well hydrographs. Table 1 lists the estimated historic annual water balance for each of the three pools and aquifer totals. Table 2 lists corresponding data with 1969 condition well discharge, as estimated from aquifer operation studies. Table 3 lists similar data for a well discharge 35% higher than the 1969 condition. Table 4 lists average annual values for the 1948-1956 period for the historic condition, the 1969 well discharge condition, and for a 35% higher well discharge than the 1969 condition. Table 5 lists the corresponding averages for the 1934-1947 plus 1957-1969 period, and Table 6 lists 1934-1969 averages. Figure 3 shows end-of-year water levels in well H-4-6, which is west of Uvalde, historically and as computed for the 1969 condition and 135% of 1969 condition well discharge operation studies. Figure 4 shows corresponding data for well #26 which is located in San Antonio. Figure 5 shows the historic annual flow of Leona Springs plus underflow and also the annual flows estimated in the 1969 condition and 135% of 1969 condition operation studies. Figure 5 also shows similar data for San Antonio Springs. Figure 6 shows similar data for Comal and San Marcos Springs.

The 1948-1956 Drought

The water level sequences on Plate 2 and recharge data on Tables 1, 4, and 5 indicate that recharge to the Edwards Underground during the 1948-1956 drought period is by far the lowest during the 1934-1969 period. Other studies summarized in the runoff annexes for the Nueces and San Antonio and Guadalupe River Basins indicate that recharge during the 1948-1956 drought was much smaller than during any other drought since at least 1900. The 1948-1956 situation is so severe and prolonged that it could be considered to be an abnormal event of unknown recurrence frequency that belongs to a different population than the remainder of the 1900-1969 period. The following comparison of minimum average recharge to the Underground Aquifer during the 1948-1956 period and during the remainder of the 1934-1969 period shows how severe the 1948-1956 period was.

	Minimum average recharge (1000 acre-feet per year)	
Consecutive years	1948-1956 period	Remainder of 1934-1969 period
1	44	184
2	122	224
3	143	286
4	160	366
5	185	419
6	179	429
7	183	459
8	226	476
9	221	487

Excluding 1948-1956, the average annual recharge was 622,000 acre-feet. The streams supplying recharge drain limestone and are springfed. These springs can provide appreciable base flow during short droughts but not during a long drought such as 1948-1956.

The Uvalde Pool

The Uvalde pool occupies a headwaters position in the Edwards Underground aquifer.

Historic. Plate 2 shows the historic water levels in two Uvalde pool wells. Plate 1 shows the location of these wells. The water level in well H-4-6 has varied from 58 to 126 feet below ground surface, and the water level in well H-5-1 has varied between 27 and 105 feet below ground level. Except for the 1948-1956 drought and the recovery in 1957 and 1958, water depths have been in the shallow half of this range and have varied modestly. This favorable depth to water situation, coupled with suitable land, has resulted in a steady increase in irrigated acreage and well withdrawals for irrigation. Through 1969, the increased well withdrawals had not had a very noticeable effect on depth to water or upon Leona Springs plus underflow. Leona Springs plus underflow had no flow historically during 1952-1956 inclusive, but has had some flow during all other years. As indicated by the well hydrographs of Figure 2 and the data in Tables 1, 4, and 5, the 1948-1956 drought was not as severe for the Uvalde pool as for the Central pool. Considerable recharge to the Uvalde pool occurred in 1953, 1954, and 1955.

The Nueces River and adjacent minor streams and the Dry Frio were assumed to supply recharge to the Uvalde pool. It was estimated that about half of the Dry Frio recharge went to the Uvalde pool and about half directly to the Central pool. USGS estimates of recharge from these sources were used for most years.

USGS estimates of well discharge for Uvalde County were divided into Uvalde pool and Central pool components. The dividing line for this estimate was approximately along the Frio River.

The discharge from the Uvalde pool through eastward flow in the Edwards Underground aquifer to the Central pool was computed between times of equal water levels in the Uvalde pool as the estimated recharge minus the estimated discharge of Leona Springs and underflow and minus the estimated well discharge. Such computations resulted in an average result of about 66,000 acre-feet per year. This value was used as the estimated historic underflow from the Uvalde pool to the Central pool for all years despite some moderate historic variations in hydraulic gradient between the two pools.

Annual operation studies for the 1969 condition aquifer well discharge and for an aquifer and individual pool well discharge 35% larger than the 1969 level were made for the Uvalde pool. The well discharge was varied from year to year according to precipitation conditions in both operation studies. In these studies, the underflow from the Uvalde pool to the Central pool was assumed to be proportional to the hydraulic gradient between well H-4-6 and well I-4-12. Since the Uvalde pool and Central pool operation studies were run separately, there is a little inconsistency between the studies for these pools in this gradient or the underflow. These discrepancies are within the margin of error of other items in the computation. The flow of Leona Springs plus underflow was estimated from the computed water level in well H-4-6 and a fairly good correlation between historic water level in well H-4-6 and historic flow of Leona Springs plus underflow. A 4,500 acre-foot change in Uvalde pool content from the historic value was estimated to cause a 1-foot change in water level in well H-4-6. This is based upon analysis of historic data. The operation study procedure was to compute the accumulated change in Uvalde pool content from the historic value at the end of each year, divide this by 4,500 acre-feet to obtain the change in water level in well H-4-6 from the historic value at the end of the year and add this change in level to the historic water level to obtain the study water level at the end of the year. During those months when the historic water level in well H-4-6 was above 883 feet, but the water level in this study was below 883 feet, it was assumed that the net recharge from the Nueces River would increase by an amount equal to the historic flow of the Nueces River below Uvalde in excess of 1,000 acre-feet but not over an increase in recharge of 3,000 acre-feet per month. Correlations using historic flow data for the Nueces River indicate that the net recharge increases by up to about 5,000 acre-feet per month under this situation but an upper limit of 3,000 acre-feet per month was used in this study because of limited knowledge about the effect of pumping induced drawdowns on water levels at the Nueces River.

Figure 3 shows water levels in well H-4-6 at the end of each year historically and as computed in the two operation studies. Figure 5 shows corresponding data on the annual flow of Leona Springs plus underflow. The contrast between the water levels in recent years and those indicated by the 1969 condition study and the contrast between the flow of Leona Springs in recent years and the flow indicated by the 1969 condition study indicates that the 1969 condition study may be a little out of whack and overly pessimistic as regards water levels and the flow of Leona Springs. The decline in water levels in the Uvalde pool indicated by the 1969 condition of well discharge study are significant but not catastrophic. Even with the 35% higher than 1969 well discharge, depth to water in the Uvalde pool would be less than the historic depth to water in much of eastern Uvalde and western and central Medina Counties. The most serious consequence that the operation studies indicate is the virtual elimination of Leona Springs plus underflow.

Even higher well discharges would cause even lower water levels in the Uvalde pool. However, it is almost certain that the depth to water in the Uvalde pool will continue to be considerably less than the depth to water in eastern Uvalde County and western and central Medina County. Therefore any decrease in irrigation use caused by excessive depth to water will occur in eastern Uvalde County and western and central Medina County first and tend to buffer the Uvalde pool for a while.

The Central Pool

The Central pool is far larger than the other two pools. It has a much larger local recharge and much larger discharge.

Historic. Historically, the Central pool has received a relatively constant inflow of about 66,000 acre-feet per year from the Uvalde pool and has discharged a fairly constant outflow of about 53,000 acre-feet per year to the San Marcos pool. Historic water level fluctuations in the Central pool have been almost entirely caused by variations in direct recharge to the Central pool and by the steadily increasing well discharge from the Central pool. Plate 2 shows the historic water levels in five Central pool wells. Plate 1 shows the location of these wells. The depth to water in well I-4-4 has varied from 172 to 289 feet, in well I-4-12 from 180 to 291 feet, in well J-1-82 from 47 to 135 feet, and in well 26 from 43 to 107 feet. The time pattern of the water level fluctuations in the Central pool wells is very similar, but the amplitude decreases down aquifer. The decreased amplitude of water level fluctuations can be attributed to the influence of San Antonio and Comal Springs which act as pressure regulating valves. During some recent years, the water levels in the five Central pool wells have displayed severe summer drawdowns. This is a striking characteristic of their hydrographs. The drawdowns were particularly severe in 1967 and 1971. Summer drawdowns are evident in well 26 starting about 1953 and in well I-4-12 starting about 1959. These summer drawdowns are caused by large seasonal well discharges from the Central pool and are aggravated by below normal recharge. The summer drawdowns are much larger than would be expected from the volume of pumping and comparisons of change in well elevations from beginning to end of a year with computed change in aquifer content during the year. This suggests that whatever maintains the artesian pressure in the Central pool - presumably the gravity portion of the aquifer plus flow through the artesian area - does not transmit water at a fast enough rate during the summer to fully maintain the artesian pressure. This results in a decreased artesian pressure in the summer followed by a pressure recovery in the winter when the well discharge is smaller. The severe summer drawdowns in the artesian portion of the aquifer also suggest that much of the experienced change in aquifer content has occurred in the gravity portion of the aquifer. The flow of Comal Springs is closely correlated with the water level in well 26. During some recent dry years, Comal Springs has displayed a seasonal pattern of flow with summer flow considerably smaller than winter flow. The 1948-1956 drought was very severe in the area that recharges the Central pool and caused severe declines in Central pool water levels. The lowest water levels on record occurred during the summer of 1956, and the water levels at the end of 1956 were much lower than the water levels at the end of any subsequent year. Historically, Comal Springs has flowed continuously except during June 13, 1956, through November 2, 1956, when there was no flow. San Antonio Springs did not have any flow during 1949 through 1957, 1964, and 1967. Since 1947, there have been periods of no flow during most years. Figure 5 shows the historic discharge of San Antonio Springs each year and Figure 6 shows the historic discharge of Comal Springs each year.

USGS estimates of recharge from the various basins were used in compiling the total direct recharge to the Central pool each year.

Well discharge from the Central pool has increased steadily. The largest well discharge for irrigation occurred in 1956. There has been an uptrend in recent years, however. Well discharge for other purposes has increased throughout the 1934-1969 period. The discharge from the Central pool through eastward flow in the Edwards Underground aquifer to the San Marcos pool was estimated by use of an annual plot of outflow from the Edwards Aquifer in Hays County vs. average beginning and end-of-year water elevation in well 26. 1939 and 1956 were the key years in this comparison. During these two dry years almost all of the dischargein Hays County in excess of the USGS estimate of local recharge was assumed to be supplied by underflow from the Central pool. A straight line connecting these two points was drawn on the graph and used to estimate the flow from the Central pool to the San Marcos pool.

Annual operation studies for the 1969 condition aquifer well discharge and for an aquifer and individual pool well discharge 35% larger than the 1969 level were made for the Central pool. The well discharge for both studies was estimated in two components: irrigation and other. Both of these components were varied from year to year according to precipitation. During the 1949-1957 period, irrigation well discharge was increased by 6,000 or 12,000 acre-feet per year in this study because of Medina Project shortages and the existence of a considerable number of irrigation wells in the Medina Project area. These wells were assumed to be idle during the remainder of the period of study. The underflow from the Uvalde pool to the Central pool was obtained from the 1969 condition operation study for the Uvalde pool for the 1969 condition study and was estimated to be 12,000 acre-feet per year smaller than this for the study with a 35% larger well discharge. Direct recharge to the Central pool was assumed to be the same as historic.

The 1969 condition study discharge of San Antonio Springs and of Comal Springs were estimated from correlations for the 1956-1969 period between their flow and the water surface elevation in well 26, and from the water surface elevation in well 26 computed in the study. The same procedure was used in the study with 35% higher well discharge, except that the correlation curves with year-end water level were raised 2 feet to allow for the more severe summer drawdowns assumed to accompany the larger well discharge. The underflow from the Central pool to the San Marcos pool was estimated from the water surface elevation in well 26 computed in the studies and the estimated historic relationship between these two items described earlier. It was also assumed that as the water surface elevation in well 26 approached 577 feet, the underflow to the San Marcos pool would approach zero. In the 1969 condition study, the correlation was raised 4 feet and in the 35% higher discharge study the correlation was raised 6 feet. These adjustments were to allow for the summer drawdowns in well 26 that have occurred in recent years and the greater summer drawdowns that it was assumed would accompany even higher well discharge rates.

In these studies, the water level in well 26 at the end of each succeeding year was computed by trial and error. The correct value produces an outflow from the Central pool such that the difference in well 26 water surface elevation at the end of the year from the historic value is compatible with the cumulative difference in Central pool (inflow minus outflow) from the historic value and the assumed change in aquifer content of 36,000 acre-feet per foot change in well 26 water surface elevation.

Figure 4 shows the end-of-year water levels in well H-4-6 at the end of each year historically and as computed in the two operation studies. The declines in water level in well 26 indicated by the 1969 condition study and by the 35% larger than 1969 condition well discharge study are significant but not extreme.

The depth to water in the well J-1-82 would be 100 to 195 feet and in well 26, 91 to 167 feet, in the high well discharge study, and would be 39 to 60 feet lower than historic.

The 1969 condition operation study shows flow from San Antonio Springs during only a few years, and the operation study for a well discharge 35% higher than the 1969 condition shows no flow at all from San Antonio Springs.

The operation study for 1969 condition well discharge indicates zero flow from Comal Springs in 1955 and 1956 and no flow during part of the year in 1951, 1952, 1953, 1954, 1957, 1963, and 1967. The operation study for a well discharge 35% higher than the 1969 level indicates no flow from Comal Springs during 1950-1959 inclusive, and 1962-1965 inclusive, and no flow during part of the year during many other years. Continuous flow would occur during about one-third of the years. Figure 5 shows the historic and operation study flow each year for San Antonio Springs and Figure 6 shows similar data for Comal Springs.

Even higher well discharges would cause lower water levels in the Central pool. The only discharge from the Central pool other than well discharge shown in Table 4 is an average underflow of 30,000 acre-feet to the San Marcos pool and an average discharge of 20,000 acre-feet from Comal Springs. Thus if well discharge from the Uvalde plus Central pool were to increase by another 50,000 acre-feet per year, the Central pool would be on the verge of a mining situation. If historic trends in well discharge continue, this situation will be reached by about year 2000. The Central pool might be able to draw some water from the San Marcos pool, but the amount is uncertain and probably small without very low water levels in the Central pool. During the first modest drought after this level of well discharge is equalled or exceeded, the water levels in the piezometric portion of the Central pool will be reduced so severely as to seriously affect the economics of irrigation from the Edwards. The decline in piezometric water levels in the Central pool might be very rapid during dry years. The summer drawdown would be even more severe than during recent dry years, and the higher well discharges during the fall and winter might prevent a complete or even partial recovery to normal levels. Piezometric water levels could drop 60 feet a year under such circumstances. Any abnormal drawdown during dry years might be quickly overcome during subsequent wet years. Regardless, well discharges from the Uvalde plus Central pools that exceed average recharge to the two pools would eventually result in water levels much lower than historic and make irrigation uneconomic.

The San Marcos Pool

The San Marcos Pool is the lowermost pool.

Historic. The discharge from the San Marcos Pool has averaged 102,000 acre-feet. Almost all of the discharge from the San Marcos Pool has been from San Marcos Springs. Well discharge has increased gradually but is still relatively small. The smallest flow of record for San Marcos Springs is 46 c.f.s.on August 15-16, 1956.

Inflow to the San Marcos Pool consists of underflow from the Central Pool plus direct recharge to the San Marcos Pool from the Blanco River and adjacent streams. The inflow to the Central Pool has been relatively constant and is estimated to have averaged 53,000 acre-feet per year. If the recharge from the Central Pool has been relatively constant, almost all of the variation in the flow of San Marcos Springs has been caused by variations in local recharge to the San Marcos Pool. The local recharge to the San Marcos Pool is estimated to have averaged about 49,000 acre-feet per year.

Tables 1, 4, and 5 indicate that the 1948-1956 drought was not as severe for the San Marcos Pool as for the Central Pool. The data indicates above average recharge during 1953.

Water level observations are available for several wells in the San Marcos Pool. Water surface elevations for well G-25 are plotted on figure 2. The historic fluctuations in water levels in well G-25 have been very small compared to wells in the Central Pool. The influence of Comal and San Marcos Springs is responsible for the small fluctuation. So long as these two springs are flowing, water levels in well G-25 will always be somewhere between the outlet elevations of these two springs. Well G-25 does not display the severe summer drawdowns that have occurred in Central Pool wells during some recent years. The lowest water level on record occurred in the summer of 1956.

Effect of the 1969 level of well discharge. Table 2 lists the estimated water balance for the San Marcos Pool for the 1969 level of well discharge from the whole aquifer. The underflow from the Central Pool is from the 1969 condition operation study for the Central Pool. The direct recharge minus change in content for each year is the same as historic. The 1969 condition well discharge was estimated from well discharge data for recent years and from year-to-year variations in the 1969 condition well discharge estimated for the Central Pool. The discharge of San Marcos Springs was computed as the unknown item in the water balance. This tabulation assumes that with 1969 condition well discharge, the change in San Marcos Pool content each year will be the same as historic. This assumption was necessitated by the lack of knowledge of historic changes in San Marcos Pool content.

The estimated 1969 condition discharge of San Marcos Springs is moderately smaller than the historic discharge. The estimated 1956 flow of San Marcos Springs is 24,000 acre-feet, compared to the historic 1956 flow of 46,000 acre-feet.

Effect of well discharge 35% higher than the 1969 condition. Table 3 presents the estimated water balance for the San Marcos Pool with the well discharge from the whole aquifer 35% higher than the 1969 level. The method of computation is similar to that for the 1969 condition study. The study indicates that San Marcos Springs would have a small flow in 1955 and no flow in 1956. If more adequate knowledge were available on change in storage in the San Marcos Pool, this result might be modified.

Effect of even higher well discharge rates. Even higher well discharge rates would cause a further reduction in the flow of San Marcos Springs. Higher well discharges in Hays County would have a direct effect on San Marcos Springs. The degree to which San Marcos Springs would be affected by higher well discharges west of Hays County is uncertain because the reduction in flow of San Marcos Springs that would result from water levels in the Central Pool that are lower than San Marcos Springs is uncertain.

George Schwab
M. George Schwab

Table 1
Edwards Underground Aquifer
Annual Summary of Historic Conditions

Unit - 1000AF

'of r., Elev '26 MSL	13	Central Pool Outflow: Total 14	San Antonio Springs 15	Comal Springs 16	Irrigation Wells 17	Other Wells 18	San Marcos Pool Inflow: Underflow, Central Pool to San Marcos Pool 19	Direct Recharge minus increase in content 20	Total 21	Outflow: Total 22	San Marcos Springs 23	Irrigation Wells 24	Other Wells 25	Aquifer Totals: Recharge 26	Outflow: Springs 27	Irrigation Wells 28	Other Wells 29	Total 30	31	Year
672																				
669		395	13	228	21	78	55	31	86	86	85	0	1	191	340	21	81	442		1934
690		468	74	236	19	83	56	41	97	97	96	0	1	1026	420	19	85	524		1935
682		537	107	260	19	93	58	35	93	93	92	0	1	850	437	20	95	602		36
678		515	88	252	20	97	58	29	87	87	86	0	1	428	455	21	99	575		37
674		498	75	248	20	98	57	36	93	93	92	0	1	433	441	21	100	562		38
668		400	11	218	20	76	55	16	71	71	70	0	1	291	318	20	99	437		39
671		379	3	202	22	97	55	23	78	78	77	0	1	313	299	23	99	421		1940
677		506	68	248	24	110	56	78	134	134	133	0	1	871	468	24	113	605		41
680		519	67	253	25	117	57	55	112	112	111	0	1	585	454	26	119	599		42
669		480	32	247	26	119	56	41	97	97	96	0	1	294	394	27	122	543		43
676		479	26	251	28	118	56	79	135	135	134	0	1	592	421	29	120	570		44
67-		522	56	261	28	121	56	81	137	137	136	0	1	574	465	29	124	618		1945
6.		502	35	260	31	119	57	77	134	134	133	0	1	591	434	32	122	588		46
668		510	36	255	32	131	56	71	127	127	126	0	1	464	430	33	134	597		47
658		419	2	201	33	131	52	25	77	77	75	0	2	190	285	35	135	455		48
664		432	0	207	33	140	52	38	90	90	88	0	2	523	304	36	144	484		49
656		426	0	189	33	152	52	27	79	79	77	0	2	210	277	38	156	471		1950
646		395	0	149	35	162	49	20	69	69	67	0	2	147	219	43	167	429		51
650		380	0	132	37	163	48	31	79	79	77	0	2	285	209	48	168	425		52
646		398	0	139	52	159	48	53	101	101	99	0	2	213	238	66	164	468		53
637		373	0	99	60	168	46	34	80	80	78	0	2	184	177	73	174	424		54
631		350	0	66	71	169	44	19	63	63	61	0	2	201	127	85	175	387		1955
627		346	0	23	94	187	42	8	50	50	46	0	4	44	69	126	196	391		56
654		370	0	105	54	165	46	67	113	113	110	0	3	1170	216	68	172	456		57
678		498	14	227	37	167	53	103	156	156	154	0	2	1709	399	46	173	618		58
675		525	24	227	46	171	57	61	118	118	116	0	2	719	384	59	176	619		59
679		524	26	230	42	169	57	86	143	143	141	0	2	849	427	54	174	655		1960
676		553	42	241	39	174	57	83	140	140	138	0	2	749	452	51	180	683		61
666		496	9	193	51	188	55	43	98	98	96	0	2	264	322	71	195	588		62
653		450	1	150	52	195	52	30	82	82	79	0	3	184	240	73	203	516		63
653		418	0	137	49	182	50	23	73	73	70	0	3	411	213	71	190	474		64
669		473	4	189	46	182	52	74	126	126	123	0	3	631	323	66	190	579		1965
657		475	2	193	46	181	53	62	115	115	111	1	4	607	314	68	189	571		66
660		473	0	131	77	214	51	31	82	82	78	1	3	478	216	119	221	556		67
670		522	17	231	38	183	53	93	146	146	143	0	3	929	408	59	191	658		68
670		532	5	211	55	206	55	67	122	122	118	1	4	598	352	95	214	661		1969
		16538	837	7089	1415	5285	1912	1771	3683	3683	3612	3	70	18,798	11997	1795	5459	19,251		
		459	23	197	39	147	53	49	102	102	100	0	2	522	333	50	152	535		

Table 1

Table 1
Edwards Underground Aquifer
Annual Summary of Historic Conditions

			Uvalde Pool						Central Pool									
				Outflow					Inflow				Outflow					
Year	End of Year - WS Elev Well H-4-6 Ft MSL		Recharge	Total	Leona Springs plus Under flow	Irrig Wells	Other Wells	Under-flow, Uvalde Pool to Central Pool	Direct Recharge	Total	End of Year, WS Elev Well 26 Ft MSL		Total	San Antonio Springs	Comal Springs	Irrigation Wells	Other Wells	Under-flow, Central Pool to San Marcos Pool
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
											672							
1934	877		12	82	14	0	2	66	148	214	669		395	13	228	21	78	55
1935	890		204	81	14	0	1	66	781	847	690		468	74	236	19	83	56
36	890		145	96	28	1	1	66	670	736	682		537	107	260	19	93	58
37	887		60	97	29	1	1	66	339	405	678		515	88	252	20	97	58
38	886		73	94	26	1	1	66	324	390	674		498	75	248	20	98	57
39	886		120	87	19	0	2	66	155	221	668		400	11	218	20	96	55
1940	880		57	85	17	1	1	66	233	299	671		379	3	202	22	97	55
41	888		111	87	19	0	2	66	682	748	677		506	68	248	24	110	56
42	887		117	91	23	1	1	66	413	479	680		519	67	253	25	117	57
43	880		41	88	19	1	2	66	212	278	669		480	32	247	26	119	56
44	881		74	78	10	1	1	66	439	505	676		479	26	251	28	118	56
1945	874		56	81	12	1	2	66	437	503	673		522	56	261	28	121	56
46	878		88	75	6	1	2	66	426	492	679		502	35	260	31	119	57
47	878		83	82	13	1	2	66	310	376	668		510	36	255	32	131	56
48	871		44	77	7	2	2	66	121	187	658		419	2	201	33	131	52
49	885		177	80	9	3	2	66	308	374	664		432	0	207	33	140	52
1950	873		45	84	11	5	2	66	138	204	656		426	0	189	33	152	52
51	859		21	80	3	8	3	66	106	172	646		395	0	149	35	162	49
52	845		29	80	0	11	3	66	225	291	650		380	0	132	37	163	48
53	844		42	83	0	14	3	66	118	184	646		398	0	139	52	159	48
54	846		63	83	0	13	4	66	87	153	637		373	0	99	60	168	46
1955	850		132	84	0	14	4	66	50	116	631		350	0	66	71	169	44
56	827		16	103	0	32	5	66	20	86	627		346	0	23	94	187	42
57	858		156	85	1	14	4	66	947	1013	654		370	0	105	54	165	46
58	884		260	83	4	9	4	66	1346	1412	678		498	14	227	37	167	53
59	891		124	99	17	13	3	66	534	600	675		525	24	227	46	171	57
1960	891		100	111	30	12	3	66	663	729	679		524	26	230	42	169	57
61	892		101	113	31	12	4	66	565	631	676		553	42	241	39	174	57
62	882		49	115	24	20	5	66	172	238	666		496	9	193	51	188	55
63	872		42	102	10	21	5	66	112	198	653		450	1	150	52	195	52
64	877		130	99	6	22	5	66	258	324	653		418	0	137	49	182	50
1965	880		105	98	7	20	5	66	452	519	669		473	4	189	46	182	52
66	882		146	99	8	21	4	66	399	465	657		475	2	193	46	181	53
67	882		94	118	7	41	4	66	353	419	660		473	0	131	77	214	51
68	885		148	109	17	21	5	66	688	754	670		522	17	231	38	183	53
1969	885		129	127	18	39	4	66	402	468	670		532	5	211	55	206	55
Σ1934-69	31,527		3394	3316	459	377	104	2376	13,633	16,009			16538	837	7089	1415	5285	1912
Ave.	876		94	92	13	10	3	66	379	445			459	23	197	39	147	53

Table 2

Edwards Underground Aquifer

f 1969 Condition Operation Study

Unit - 1000AF

ntral Pool							San Marcos Pool						Aquifer Totals					Year
well 26	Out flow						Inflow		Out flow					Out flow				
Δ well elev. from Historic Ft.	Total	San Antonio Springs	Comal Springs	Irrigation Wells	Other wells	Underflow, Central Pool to San Marcos Pool	Direct Recharge minus increase in content	Total	Total	San Marcos Springs	Irrigation Wells	Other wells	Recharge	Springs	Irrigation wells	Other wells	Total	
			16	17	18	19	20		22	23	24	25						
-22																		
-24	463	0	106	86	224	47	31	78	78	73	1	4	191	179	132	233	544	1934
-22	406	0	120	41	197	48	41	89	89	86	0	3	1047	206	63	204	473	1935
-20	471	3	153	58	206	51	35	86	86	82	0	4	876	238	89	214	541	36
-20	497	2	148	76	220	51	29	80	80	76	0	4	449	227	117	229	573	37
-19	483	1	145	72	215	50	36	86	86	82	0	4	454	233	113	224	570	38
-22	487	0	116	92	231	48	16	64	64	59	1	4	302	175	131	239	545	39
-23	409	0	85	58	219	47	23	70	70	66	0	4	315	151	82	227	460	1940
-21	450	0	136	53	212	49	78	127	127	123	0	4	884	266	74	220	560	41
-20	479	0	148	70	211	50	55	105	105	101	0	4	598	249	110	219	578	42
-20	483	0	148	67	219	49	41	90	90	86	0	4	296	234	103	227	564	43
-20	468	0	153	58	208	49	79	128	128	124	0	4	592	277	83	216	576	44
-19	491	0	162	68	212	49	81	130	130	126	0	4	574	288	100	220	608	1945
-19	472	0	162	59	201	50	77	127	127	124	0	3	591	286	89	208	583	46
-19	508	0	153	82	224	49	71	120	120	115	1	4	464	268	117	232	617	47
-20	442	0	98	73	226	45	25	70	70	66	0	4	190	164	110	234	508	48
-20	415	0	107	59	204	45	38	83	83	80	0	3	533	187	82	211	480	49
-20	418	0	86	70	217	45	27	72	72	68	0	4	211	154	101	225	480	1950
-20	396	0	46	89	220	41	20	61	61	57	0	4	147	103	129	228	460	51
-20	383	0	32	87	226	38	31	69	69	64	1	4	285	96	124	234	454	52
-21	391	0	34	94	225	38	53	91	91	86	1	4	213	120	141	234	495	53
-21	370	0	3	97	238	32	34	66	66	61	1	4	184	64	134	246	444	54
-21	347	0	0	95	225	27	19	46	46	41	1	4	201	41	133	233	407	1955
-23	386	0	0	124	240	22	8	30	30	24	1	5	44	24	177	251	452	56
-22	313	0	22	58	202	31	67	98	98	94	0	4	1170	116	81	210	407	57
-21	447	0	136	56	208	47	103	150	150	146	0	4	1712	282	78	216	576	58
-20	469	0	140	62	217	50	61	111	111	107	0	4	753	247	86	225	558	59
-19	479	0	144	69	216	50	86	136	136	132	0	4	880	276	105	224	605	1960
-18	496	2	162	66	216	50	83	133	143	129	0	4	783	293	97	224	614	61
-17	470	0	120	79	222	49	43	92	82	88	0	4	271	208	118	231	557	62
-17	431	0	82	79	224	46	30	76	76	72	0	4	184	155	117	233	505	63
-16	382	0	64	67	208	43	23	66	66	62	0	4	411	126	107	217	450	64
-15	440	0	132	59	202	47	74	121	121	118	0	3	631	250	90	210	550	1965
-14	433	0	132	57	197	47	62	109	109	105	0	4	607	237	84	205	526	66
-13	442	0	78	89	229	46	31	77	77	72	1	4	478	150	138	238	526	67
-12	471	3	178	49	193	48	93	141	141	138	0	3	954	326	72	201	599	68
-11	477	0	166	55	206	50	67	117	117	113	0	4	607	284	94	214	592	1969
	15,865	11	3897	2573	7760	1624	1771	3395	3395	3246	9	140	19,082	7180	3801	8056	19,037	
	441	0	109	71	216	45	49	94	94	90	0	4	530	200	105	224	529	

Table 2

Table 2

Edwards Underground Aquifer

of 1969 Condition Operation Study

Unit - 1000AF

...ntral Pool							San Marcos Pool						Aquifer Totals					
		Outflow					Inflow			Outflow				Outflow				
well 26 Δ well elev. from Historic Ft.	Total	San Antonio Springs	Comal Springs	Irrigation Wells	Other wells	Underflow, Central Pool to San Marcos Pool	Direct Recharge minus increase in content	Total	Total	San Marcos Springs	Irrigation Wells	Other Wells	Recharge	Springs	Irrigation Wells	Other wells	Total	Year
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
-22																		
-24	463	0	106	86	224	47	31	78	78	73	1	4	191	179	132	233	544	1934
-22	406	0	120	41	197	48	41	89	89	86	0	3	1047	206	63	204	473	1935
-20	471	3	153	58	206	51	35	86	86	82	0	4	876	238	89	214	541	36
-20	497	2	148	76	220	51	29	80	80	76	0	4	449	227	117	229	673	37
-19	483	1	145	72	215	50	36	86	86	82	0	4	454	233	113	224	570	38
-22	487	0	116	92	231	48	16	64	64	59	1	4	302	175	131	239	545	39
-23	409	0	85	58	219	47	23	70	70	66	0	4	315	151	82	227	460	1940
-21	450	0	136	53	212	49	78	127	127	123	0	4	884	266	74	220	560	41
-20	479	0	148	70	211	50	55	105	105	101	0	4	598	249	110	219	578	42
-20	483	0	148	67	219	49	41	90	90	86	0	4	296	234	103	227	564	43
-20	468	0	153	58	208	49	79	128	128	124	0	4	592	277	83	216	576	44
-19	491	0	162	68	212	49	81	130	130	126	0	4	574	288	100	220	608	1945
-19	472	0	162	59	201	50	77	127	127	124	0	3	591	286	89	208	583	46
-19	508	0	153	82	224	49	71	120	120	115	1	4	464	268	117	232	617	47
-20	442	0	98	73	226	45	25	70	70	66	0	4	190	164	110	234	508	48
-20	415	0	107	59	204	45	38	83	83	80	0	3	533	187	82	211	480	49
-20	418	0	86	70	217	45	27	72	72	68	0	4	211	154	101	225	480	1950
-20	396	0	46	89	220	41	20	61	61	57	0	4	147	103	129	228	460	51
-20	383	0	32	87	226	38	31	69	69	64	1	4	285	96	124	234	454	52
-21	391	0	34	94	225	38	53	91	91	86	1	4	213	120	141	234	496	53
-21	370	0	3	97	238	32	34	66	66	61	1	4	184	64	134	246	444	54
-21	347	0	0	95	225	27	19	46	46	41	1	4	201	41	133	233	407	1955
-23	386	0	0	124	240	22	8	30	30	24	1	5	44	24	177	251	452	56
-22	313	0	22	58	202	31	67	98	98	94	0	4	1170	116	81	210	407	57
-21	447	0	136	56	208	47	103	150	150	146	0	4	1712	282	98	216	576	58
-20	469	0	140	62	217	50	61	111	111	107	0	4	753	247	86	225	558	59
-19	479	0	144	69	216	50	86	136	136	132	0	4	880	276	105	224	605	1960
-18	496	2	162	66	216	50	83	133	143	127	0	4	783	293	97	224	614	61
-17	470	0	120	79	222	49	43	92	82	88	0	4	271	208	118	231	557	62
-17	431	0	82	79	224	46	30	76	76	72	0	4	184	155	117	233	505	63
-16	382	0	64	67	208	43	23	66	66	62	0	4	411	126	107	217	450	64
-15	440	0	132	59	202	47	74	121	121	118	0	3	631	250	90	210	550	1965
-14	433	0	132	57	197	47	62	109	109	105	0	4	607	237	84	205	526	66
-13	442	0	78	89	229	46	31	77	77	72	1	4	478	150	138	238	526	67
-12	471	3	178	49	193	48	93	141	141	138	0	3	954	326	72	201	599	68
-11	477	0	166	55	206	50	67	117	117	113	0	4	607	284	94	214	592	1969
	15,865	11	3897	2573	7760	1624	1771	3395	3395	3246	9	140	19,082	7180	3801	8056	19,037	
	441	0	109	71	216	45	49	94	94	90	0	4	530	200	105	224	529	

Table 2
Edwards Underground Aquifer
Annual Summary of 1969 Condition Operation Study

Year	Uvalde Pool								Central Pool									
				Outflow					Inflow				Outflow					
	End of Year - WS Elev Well H-4-6	Well H-4-6 Δ well elev. from historic	Recharge	Total	Leona Springs plus Underflow	Irrig Wells	Other Wells	Underflow, Uvalde Pool to Central Pool	Direct Recharge	Total	End of Year, WS Elev Well 26	Well 26 Δ well elev. from Historic	Total	San Antonio Springs	Comal Springs	Irrigation Wells	Other Wells	Underflow, Central Pool to San Marcos Pool
	Ft MSL	Ft.									Ft MSL	Ft.						
															16	17	18	19
	864										650	-22						
1934	847	-30	12	116	0	45	5	66	148	214	645	-24	463	0	106	86	224	47
1935	863	-27	225	89	0	22	4	63	781	844	658	-22	406	0	120	41	197	48
36	868	-22	171	100	0	31	4	65	670	735	662	-20	471	3	153	58	206	51
37	866	-21	81	114	1	41	5	67	339	406	658	-20	497	2	148	76	220	51
38	864	-22	94	118	5	41	5	67	324	391	655	-19	483	1	145	72	215	50
39	862	-24	131	108	0	38	4	66	155	221	646	-22	487	0	116	92	231	48
1940	855	-25	59	93	0	24	4	65	233	298	648	-23	409	0	85	58	219	47
41	864	-24	124	97	7	21	4	65	682	747	656	-21	450	0	136	53	212	49
42	861	-26	130	109	0	40	4	65	413	478	660	-20	479	0	148	70	211	50
43	851	-29	43	104	0	36	4	64	212	276	649	-20	483	0	148	67	219	49
44	849	-32	74	92	0	25	4	63	439	502	656	-20	468	0	153	58	208	49
1945	839	-35	56	97	0	32	4	61	437	498	654	-19	491	0	162	68	212	49
46	839	-39	88	93	0	30	4	59	426	485	660	-19	472	0	162	59	201	50
47	836	-42	83	95	0	34	4	57	310	367	649	-19	508	0	153	82	224	49
48	824	-47	44	97	0	37	4	56	121	177	636	-20	442	0	98	73	226	45
49	840	-45	187	81	0	23	4	54	308	362	644	-20	415	0	107	59	204	45
1950	827	-46	46	90	0	31	4	55	138	193	636	-20	418	0	86	70	217	45
51	809	-50	21	99	0	40	4	55	106	161	626	-20	396	0	46	89	220	41
52	792	-53	29	93	0	36	4	53	225	278	628	-20	383	0	32	87	226	38
53	797	-57	42	102	0	46	5	51	118	169	625	-21	391	0	34	94	225	38
54	787	-59	63	90	0	36	4	50	87	137	616	-21	370	0	3	97	238	32
1955	790	-60	132	91	0	37	4	50	50	100	610	-21	347	0	0	95	225	27
56	766	-61	16	109	0	52	6	51	20	71	604	-23	386	0	0	124	240	22
57	798	-60	156	77	0	23	4	50	947	997	632	-22	313	0	22	58	202	31
58	827	-57	263	75	0	22	4	49	1346	1395	657	-21	447	0	136	56	208	47
59	847	-44	158	74	0	24	4	46	534	580	655	-20	469	0	140	62	217	50
1960	858	-33	131	91	0	36	4	51	663	714	660	-19	479	0	144	69	216	50
61	872	-20	135	90	0	31	4	55	565	620	658	-18	496	2	162	66	216	50
62	862	-16	56	105	0	39	5	61	172	233	649	-17	470	0	120	79	222	49
63	854	-18	42	107	1	38	5	63	112	175	636	-17	431	0	82	79	224	46
64	858	-19	130	107	0	40	5	62	258	320	637	-16	382	0	64	67	208	43
1965	861	-19	105	98	0	31	5	62	452	514	654	-15	440	0	132	59	202	47
66	864	-18	146	92	0	27	4	61	399	460	643	-14	433	0	132	57	197	47
67	865	-17	94	114	0	48	5	61	353	414	647	-13	442	0	78	89	229	46
68	878	-8	173	96	7	23	5	61	688	749	658	-12	471	3	178	49	193	48
1969	886	-3	138	113	5	39	4	65	402	467	659	-11	477	0	166	55	206	50
Σ 1934-69	30,330	-1208	3678	3516	26	1219	156	2115	13,633	15,748			15,865	11	3897	2573	7760	1624
Average	842	-34	102	98	1	34	4	59	379	438			441	0	109	71	216	45

Table 5
Edwards Underground Aquifer
Summary of 1969 x 1.35 Condition Operation Study

Unit - 1000 AF

Central Pool							San Marcos Pool						Aquifer Totals					
Jul 26	Out Flow						Inflow		Outflow					Out Flow				Year
Δ Well Elev from Historic (Ft)	Total	San Antonio Springs	Comal Springs	Irrigation Wells	Other Wells	Underflow, Central Pool to San Marcos Pool	Direct Recharge minus increase in content	Total	Total	San Marcos Springs	Irrigation Wells	Other Wells	Recharge	Springs	Irrigation Wells	Other Wells	Total	
13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
-42																		
-45	485	0	25	147	276	37	31	68	68	62	1	5	191	87	209	288	584	1934
-43	385	0	32	71	242	40	41	81	81	77	0	4	1047	109	101	251	461	1935
-41	457	0	57	100	254	46	35	81	81	76	0	5	876	133	142	264	539	36
-41	501	0	52	131	271	47	29	76	76	70	1	5	449	122	187	283	592	37
-41	482	0	48	124	265	45	36	81	81	75	1	5	454	123	180	277	580	38
-44	502	0	22	158	284	38	16	54	54	48	1	5	302	70	210	294	574	39
-45	409	0	3	101	269	36	23	59	59	53	1	5	315	56	134	279	469	1940
-44	431	0	40	90	262	39	78	117	117	111	1	5	884	151	119	272	542	41
-42	467	0	44	120	261	42	55	97	97	91	1	5	598	135	175	271	581	42
-43	470	0	44	116	269	41	41	82	82	76	1	5	296	120	166	279	565	43
-42	443	0	48	100	256	39	79	118	118	112	1	5	592	160	135	266	561	44
-41	481	0	60	118	261	42	81	123	123	117	1	5	574	177	162	271	610	1945
-40	457	0	65	101	248	43	77	120	120	116	0	4	591	181	141	257	579	46
-41	517	0	57	142	275	43	71	114	114	108	1	5	464	165	189	285	639	47
-43	444	0	9	125	279	31	25	56	56	50	1	5	190	59	176	289	524	48
-42	389	0	12	98	251	28	38	66	66	62	0	4	533	74	129	260	463	49
-42	412	0	0	116	267	29	27	56	56	50	1	5	211	50	159	277	486	1950
-44	436	0	0	144	271	21	20	41	41	35	1	5	147	35	199	282	516	51
-46	438	0	0	141	279	18	31	49	49	43	1	5	285	43	191	290	524	52
-49	450	0	0	157	278	15	53	68	68	62	1	5	213	62	220	290	572	53
-52	463	0	0	162	294	7	34	41	41	35	1	5	184	35	212	305	552	54
-55	431	0	0	155	277	-1	19	18	18	12	1	5	201	12	206	288	506	1955
-60	497	0	0	205	295	-3	8	5	5	0	1	7	44	0	276	310	586	56
-60	344	0	0	95	249	0	67	67	67	59	0	5	1170	59	126	260	445	57
-57	372	0	0	97	255	20	103	123	123	118	0	5	1712	118	127	266	511	58
-55	406	0	0	107	268	31	61	92	92	86	1	5	753	86	140	279	505	59
-53	420	0	3	118	266	33	86	119	119	113	1	5	880	116	168	276	560	1960
-50	438	0	22	114	266	36	83	119	129	113	1	5	783	135	157	276	568	61
-49	441	0	0	135	274	32	43	75	65	69	1	5	271	69	189	286	544	62
-49	435	0	0	136	276	23	30	53	53	47	1	5	184	47	188	288	523	63
-49	388	0	0	115	256	17	23	40	40	34	1	5	411	34	170	268	472	64
-46	376	0	0	102	249	25	74	99	99	94	1	4	631	94	145	260	499	1965
-44	378	0	9	98	243	28	62	90	90	84	1	5	607	93	135	254	482	66
-45	460	0	0	153	282	25	31	56	56	50	1	5	478	50	219	294	563	67
-41	318	0	44	83	238	33	93	126	126	122	0	4	954	166	114	249	529	68
-39	424	0	37	95	253	39	67	106	106	100	1	5	607	137	149	263	549	1969
	15,727	0	733	4370	9559	1065	1771	2836	2836	2630	29	177	19,082	3363	6045	9947	19,355	
	437	0	20	121	266	30	49	79	79	73	1	5	530	93	168	277	538	

1/ Total of Cols 6,7,8+9, Varies slightly from Total Discharge on Operatio Study for Uvalde Pool due to difference in Discharge to Central Pool Values used in Uvalde Pool and in Central Pool Operation Studies.

Table 3
Edwards Underground Aquifer
Annual Summary of 1969 x 1.35 Condition Operation Study

Year	Uvalde Pool: End of Year - WS Elev Well H-4-6 (Ft MSL)	Well H-4-6 Δ Well Elev from Historic (Ft)	Recharge	Outflow: Total 1/	Outflow: Leona Springs plus Underflow	Outflow: Irrig Wells	Outflow: Other Wells	Outflow: Underflow, Uvalde Pool to Central Pool	Inflow: Direct Recharge	Inflow: Total	Central Pool: End of Year, WS Elev Well 26 (Ft MSL)	Well 26 Δ Well Elev from Historic (Ft)	Outflow: Total	Outflow: San Antonio Springs	Outflow: Comal Springs	Outflow: Irrigation Wells	Outflow: Other Wells	Outflow: Underflow, Central Pool to San Marcos Pool	Direct Recharge minus increase in content
						7					12	13		15	16	17	18	19	20
											630	-42							
1934	798	-79	12	122	0	61	7	54	148	202	624	-45	485	0	25	147	276	37	31
1935	815	-75	225	86	0	30	5	51	781	832	637	-43	385	0	32	71	242	40	41
36	821	-69	171	100	0	42	5	53	670	723	641	-41	457	0	57	100	254	46	35
37	819	-68	81	117	0	55	7	55	339	394	637	-41	501	0	52	131	271	47	29
38	818	-68	94	117	0	55	7	55	324	379	633	-41	482	0	48	124	265	45	36
39	816	-70	131	110	0	51	5	54	155	209	624	-44	502	0	22	158	284	38	16
1940	809	-72	59	90	0	32	5	53	233	286	626	-45	409	0	3	101	269	36	23
41	819	-69	124	86	0	28	5	53	682	735	633	-44	431	0	40	90	262	39	78
42	817	-70	130	112	0	54	5	53	413	466	638	-42	467	0	44	120	261	42	55
43	806	-74	43	106	0	49	5	52	212	264	626	-43	470	0	44	116	269	41	41
44	805	-76	74	90	0	34	5	51	439	490	634	-42	443	0	48	100	256	39	79
1945	794	-80	56	97	0	43	5	49	437	486	632	-41	481	0	60	118	261	42	81
46	794	-84	88	92	0	40	5	47	426	473	639	-40	457	0	65	101	248	43	77
47	791	-87	83	96	0	46	5	45	310	355	627	-41	517	0	57	142	275	43	71
48	779	-92	44	99	0	50	5	44	121	165	613	-43	444	0	9	125	279	31	25
49	795	-90	187	78	0	31	5	42	308	350	622	-42	389	0	12	98	251	28	38
1950	781	-92	146	90	0	42	5	43	138	181	614	-42	412	0	0	116	267	29	27
51	762	-97	21	103	0	54	6	43	106	149	602	-44	436	0	0	144	271	21	20
52	744	-101	29	96	0	49	6	41	225	266	604	-46	438	0	0	141	279	18	31
53	737	-107	42	108	0	62	7	39	118	157	597	-49	450	0	0	157	278	15	53
54	736	-110	63	93	0	49	6	38	87	125	585	-52	463	0	0	162	294	7	34
1955	736	-114	132	94	0	50	6	38	50	88	576	-55	431	0	0	155	277	-1	19
56	709	-118	116	117	0	70	8	39	20	59	567	-60	497	0	0	205	295	-3	8
57	741	-117	156	75	0	31	6	38	947	985	594	-60	344	0	0	95	249	0	67
58	769	-115	263	73	0	30	6	37	1346	1383	621	-57	372	0	0	97	255	20	103
59	789	-102	158	72	0	32	6	34	534	568	620	-55	406	0	0	107	268	31	61
1960	799	-92	131	93	0	49	5	39	663	702	626	-53	430	0	3	118	266	33	86
61	812	-80	135	90	0	42	5	43	565	608	626	-50	438	0	22	114	266	36	83
62	805	-77	56	109	0	53	7	49	172	221	617	-49	441	0	0	135	274	32	43
63	793	-79	42	109	0	51	7	51	112	163	604	-49	435	0	0	136	276	23	30
64	795	-82	130	111	0	54	7	50	258	308	604	-49	388	0	0	115	256	17	23
1965	797	-83	105	99	0	42	7	50	452	502	623	-46	376	0	0	102	249	25	74
66	800	-82	146	91	0	36	6	49	399	448	613	-44	378	0	9	98	243	28	62
67	800	-82	94	121	0	65	7	49	353	402	616	-45	460	0	0	153	282	25	31
68	813	-72	173	87	0	31	7	49	688	737	629	-41	348	0	44	83	238	33	93
1969	823	-66	138	111	0	53	5	53	402	455	631	-39	424	0	37	95	253	39	67
Σ 1934-69			3678	3540	0	1646	211	1683	13633	15316			15,727	0	733	4370	9559	1065	1771
Avr			102	99	0	46	6	47	379	426			437	0	20	121	266	30	49

Table 4.
Edwards Underground Aquifer
1948-1956 averages
(1000 acre-feet per year)

Item	Historic	1969 condition	1.35 x 1969 condition well discharge
Uvalde Pool:			
Recharge	63	65	65
Outflow:			
Leona Springs plus underflow	3	0	0
Irrigation wells	11	38	51
Other wells	3	4	6
Underflow to Central Pool	66	53	41
Total	83	95	98
Central Pool:			
Inflow:			
Underflow from Uvalde Pool	66	53	41
Direct recharge	130	130	130
Total	196	183	171
Outflow:			
San Antonio Springs	0	0	0
Comal Springs	134	45	2
Irrigation wells	50	88	144
Other wells	159	224	277
Underflow to San Marcos Pool	48	37	16
Total	391	394	439
San Marcos Pool:			
Inflow minus change in content:			
Underflow from Central Pool	48	37	16
Direct recharge minus change in content	28	28	28
Total	76	65	44
Outflow:			
San Marcos Springs	74	61	38
Irrigation wells	0	0	1
Other wells	2	4	5
Total	76	65	44
Aquifer total:			
Recharge	221	223	223
Outflow:			
Springs	211	106	40
Irrigation wells	61	126	196
Other wells	164	232	288
Total	436	464	524

Table 5.
Edwards Underground Aquifer
1934-1947 plus 1957-1969 Averages
(1000 acre-feet per year)

Item	Historic	1969 condition	1.35 x 1969 condition well discharge
Uvalde Pool:			
Recharge	105	115	115
Outflow:			
Leona Springs plus underflow	16	1	0
Irrigation wells	10	33	44
Other wells	3	4	6
Underflow to Central Pool	66	61	49
Total	95	99	99
Central Pool:			
Inflow:			
Underflow from Uvalde Pool	66	61	49
Direct recharge	461	461	461
Total	527	522	510
Outflow:			
San Antonio Springs	31	0	0
Comal Springs	218	129	27
Irrigation wells	36	66	113
Other wells	142	212	261
Underflow to San Marcos Pool	55	48	34
Total	482	455	435
San Marcos Pool:			
Inflow minus change in content:			
Underflow from Central Pool	55	48	34
Direct recharge minus change in content	56	56	56
Total	111	104	90
Outflow:			
San Marcos Springs	109	100	84
Irrigation wells	0	0	1
Other wells	2	4	5
Total	111	104	90
Aquifer total:			
Recharge	622	632	632
Outflow:			
Springs	374	230	111
Irrigation wells	46	99	158
Other wells	147	220	272
Total	567	549	541

Table 6.
Edwards Underground Aquifer
1934-1969 Averages
(1000 acre-feet per year)

Item	Historic	1969 condition	1.35 x 1969 condition well discharge
Uvalde Pool:			
Recharge	94	102	102
Outflow:			
Leona Springs plus underflow	13	1	0
Irrigation wells	10	34	46
Other wells	3	4	6
Underflow to Central Pool	66	59	47
Total	92	98	99
Central Pool:			
Inflow:			
Underflow from Uvalde Pool	66	59	47
Direct recharge	379	379	379
Total	445	438	426
Outflow:			
San Antonio Springs	23	0	0
Comal Springs	197	109	20
Irrigation wells	39	71	121
Other wells	147	216	266
Underflow to San Marcos Pool	53	45	30
Total	459	441	437
San Marcos Pool:			
Inflow minus change in content:			
Underflow from Central Pool	53	45	30
Direct recharge minus change in content	49	49	49
Total	102	94	79
Outflow:			
San Marcos Springs	100	90	73
Irrigation wells	0	0	1
Other wells	2	4	5
Total	102	94	79
Aquifer total:			
Recharge	522	530	530
Outflow:			
Springs	333	200	93
Irrigation wells	50	105	168
Other wells	152	224	277
Total	535	529	538

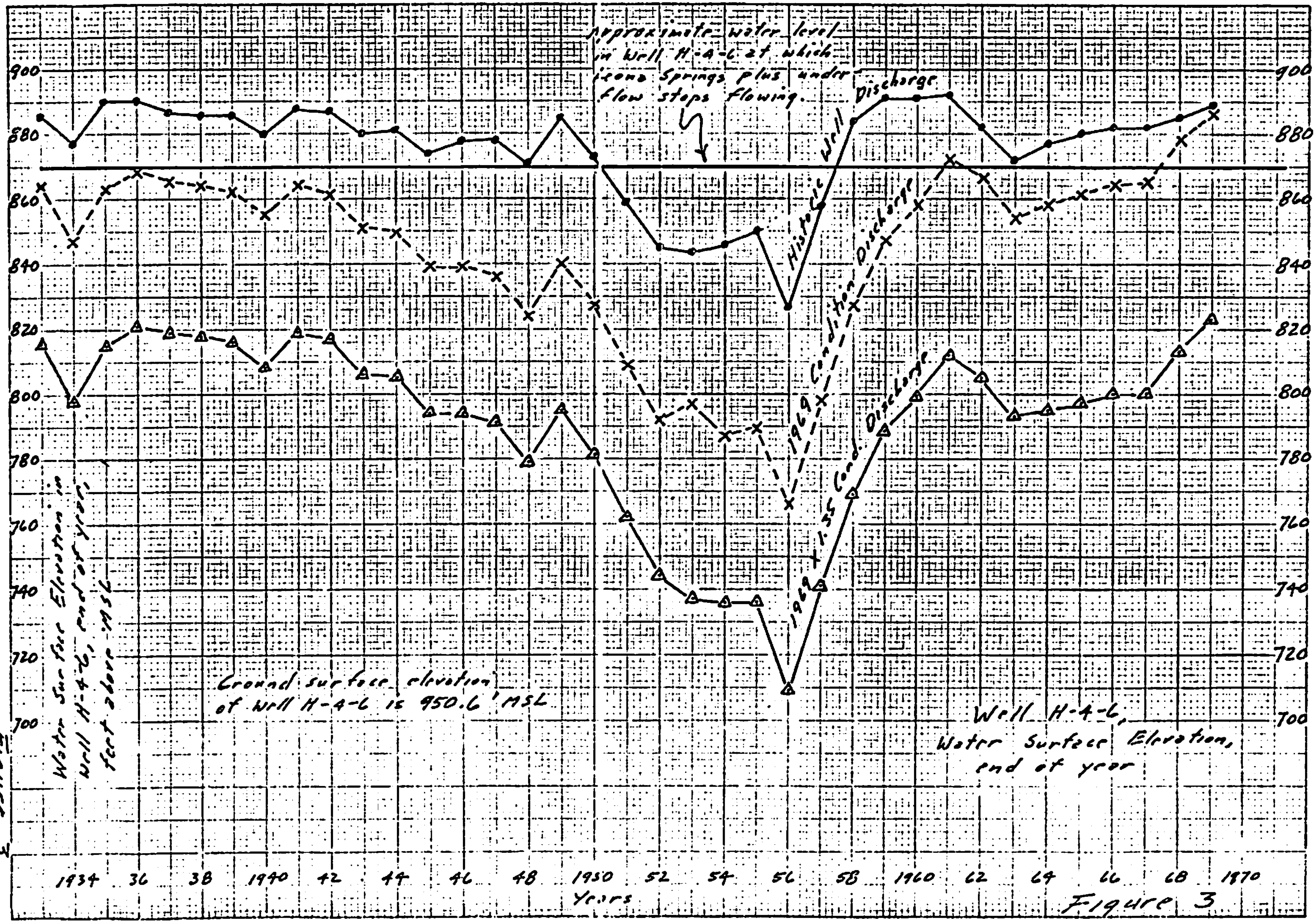
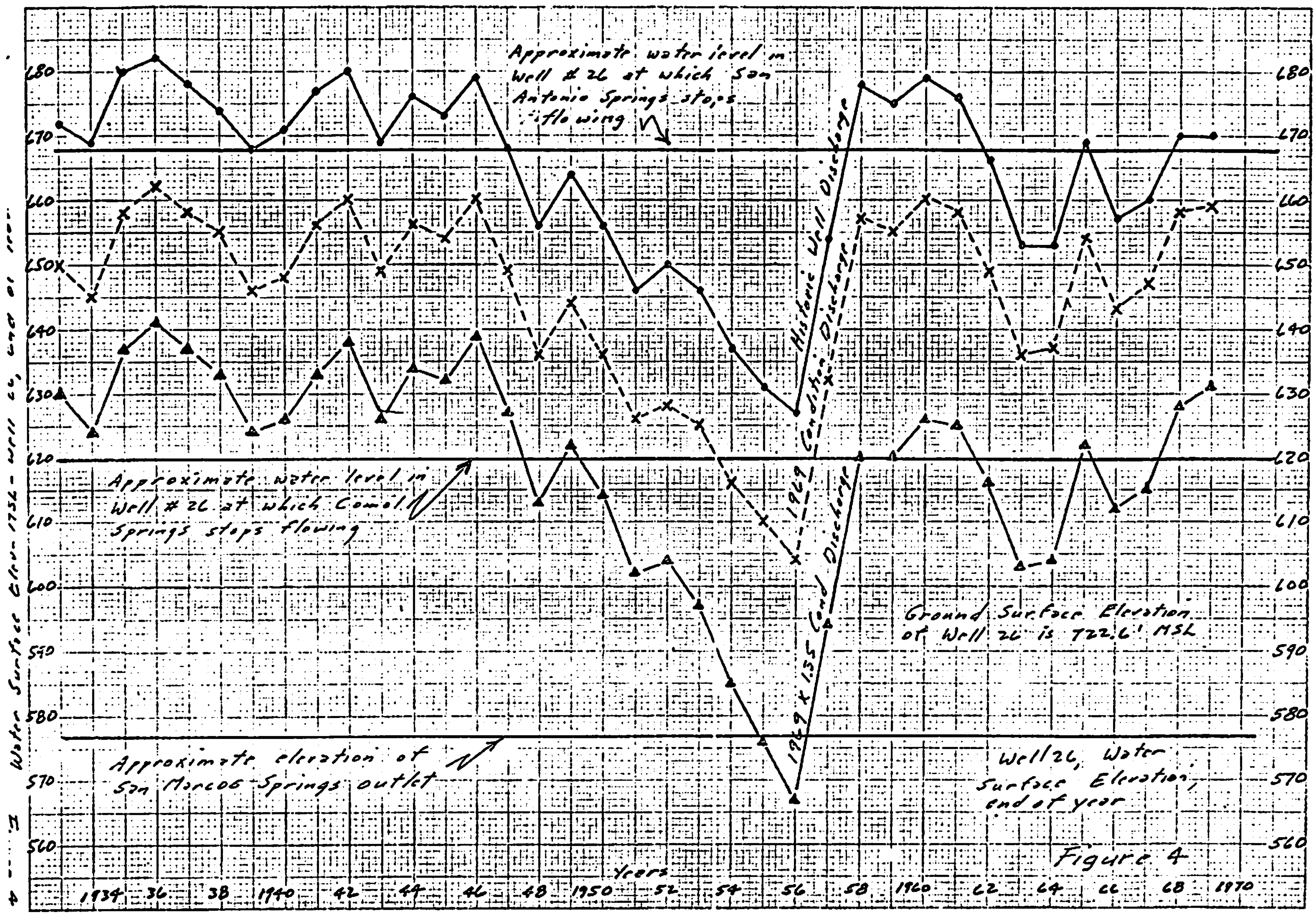

approximate water level in Well H-4-6 at which
Springs plus under-flow stops flowing.
Historic Well Discharge
1969 Condition Discharge
1969 x 1.35 Cond. Discharge
Ground surface elevation of Well H-4-6 is 950.6' MSL
Well H-4-6, Water Surface Elevation, end of year
Water Surface Elevation in Well H-4-6, end of year, feet above MSL
900
880
860
840
820
800
780
760
740
720
700
1934
36
38
1940
42
44
46
48
1950
52
54
56
58
1960
62
64
66
68
1970
Years

Figure 3



Approximate water level in Well # 26 at which San Antonio Springs stops flowing
Approximate water level in Well # 26 at which Comal Springs stops flowing
Approximate elevation of San Marcos Springs outlet
Ground Surface Elevation of Well 26 is 722.6' MSL
Well 26, Water Surface Elevation, end of year
Historic Well Discharge
Condition Discharge
1969
1969 X 1.35 Cond Discharge
Water Surface Elev 1934 - Well 26, end of year
680
670
660
650
640
630
620
610
600
590
580
570
560
1934
36
38
1940
42
44
46
48
1950
52
54
56
58
1960
62
64
66
68
1970
Years

Figure 4

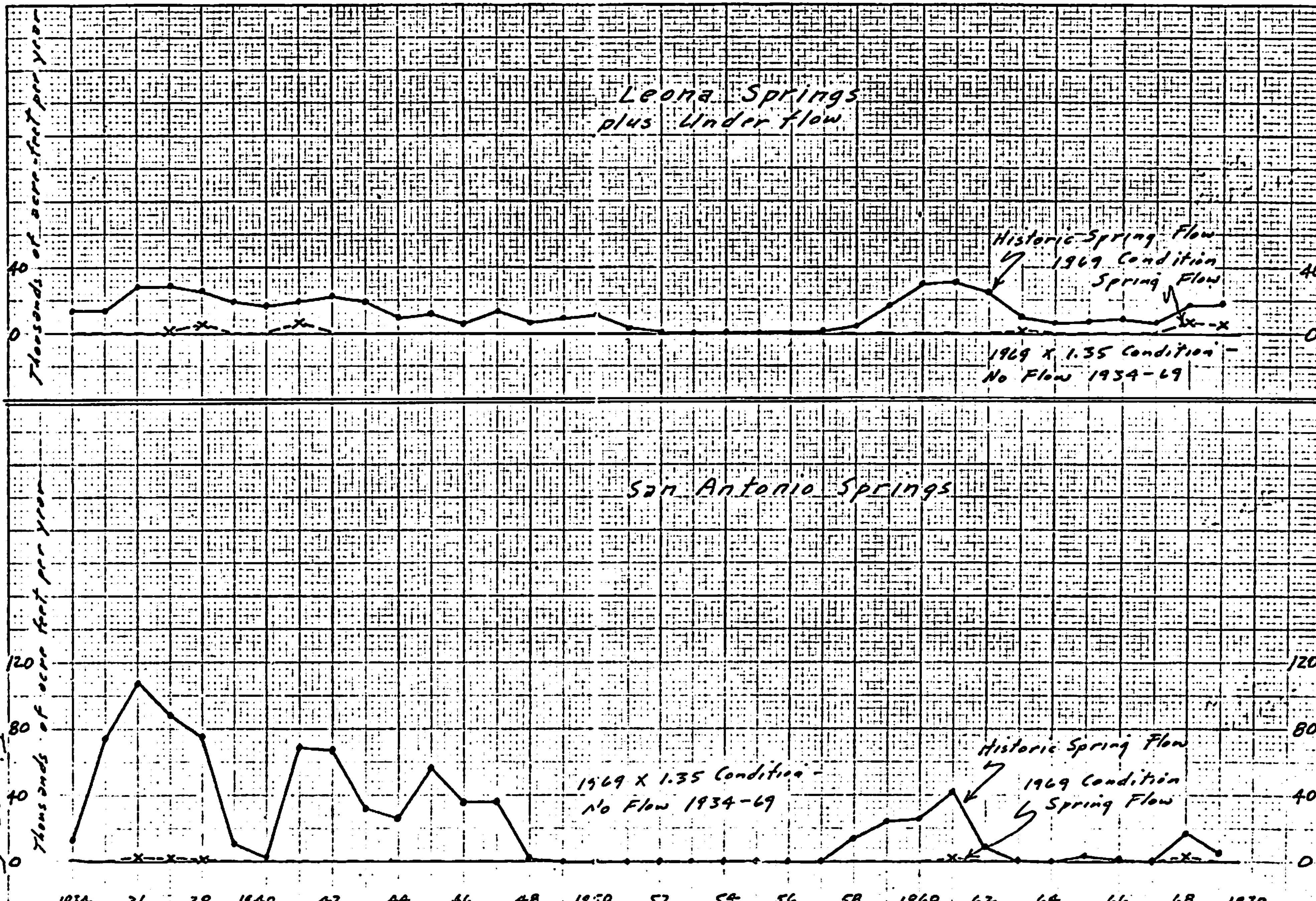

Leona Springs
plus Under flow
Thousands of acre-feet per year
40
0
Historic Spring Flow
1969 Condition
Spring Flow
1969 X 1.35 Condition -
No Flow 1934-69
San Antonio Springs
Thousands of acre feet per year
120
80
40
0
1969 X 1.35 Condition -
No Flow 1934-69
Historic Spring Flow
1969 Condition
Spring Flow
1934
36
38
1940
42
44
46
48
1950
52
54
56
58
1960
62
64
66
68
1970
Years

Figure 5

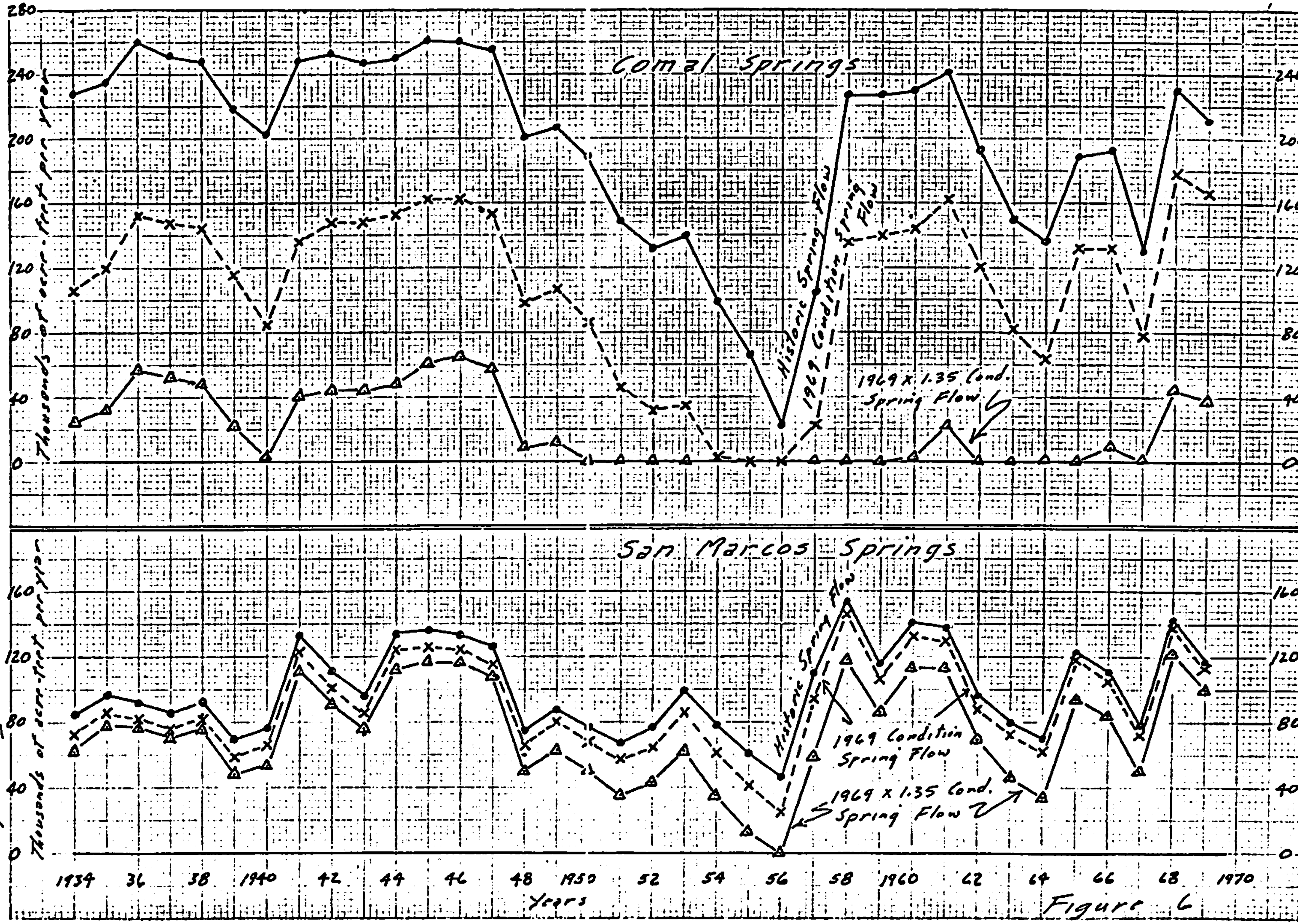

Comal Springs
San Marcos Springs
Thousands of acre-feet per year
Historic Spring Flow
1969 Condition Spring Flow
1969 X 1.35 Cond. Spring Flow
0
40
80
120
160
200
240
280
1934
36
38
1940
42
44
46
48
1950
52
54
56
58
1960
62
64
66
68
1970
Years

Figure 6

United States Department of the Interior
BUREAU OF RECLAMATION

SOUTHWEST REGION
HERRING PLAZA BOX H-4377
AMARILLO, TEXAS 79101

IN REPLY
REFER TO: 750
144.

September 19, 1973

Memorandum

To: Files

From: George Schwab, Hydraulic Engineer

Subject: Performance of Edwards Aquifer When Subjected to Increasing Well Discharge

My memorandum to files dated June 30, 1972, described and summarized the results of studies of the performance of the Edwards aquifer when subjected to steady state levels of well demand, namely, the 1969 level of demand and 1.35 x the 1969 level of demand. Historically, the aquifer has been subjected to increasing well discharges. This is shown on attached figure 1. In the absence of new restrictive laws, this trend toward increasing well discharge can be expected to continue in the future, with perhaps occasional interruptions and drops in well discharge when and if surface waters are developed and substituted for well water. This memorandum describes studies of the performance of the Edwards aquifer if it is subjected to steadily increasing well discharges and variety of climatic conditions in the future. The studies are on an annual basis.

Period of study. The studies begin with well elevations at the end of 1971, and cover the period from 1972 through 2027. Climatic conditions during the 1972-2027 period are assumed to be as follows:

	Climatic sequence of historic years	
Study Years	In Study I	In Study II
1972- 1985	1934-1947	1957-1970
1986-1999	1957-1970	1934-1947
2000-2013	1934-1947	1957-1970
2014-2027	1957-1970	1934-1947

These studies omit the 1948-1956 drought period, and are intended to show the performance of the aquifer if a drought as severe as 1948-1956 does not occur during the 1972-2027 period. Three substudies were run to determine what would happen if the 1948-1956 drought did occur. The study years during which the 1948-1956 climatic sequence was assumed to recur were:

	Study I B	Study I C	Study II B
Study Years	1986-1994	2014-2022	2000-2008

In each case, the 1948-1956 climatic sequence is assumed to follow the 1934-1947 climatic sequence of study I or study II.

Of course droughts less severe than 1948-1956, but more severe than the droughts that occurred during the remainder of the 1934-1970 climatic sequence can occur. Available evidence indicates that such a drought did occur during the 1925-1930 period. Aquifer conditions in this event would be intermediate between those of studies I and II, and those of studies I B, I C, and II B.

Projected well discharge. Figures 1 and 2 show the projected future average well discharge for the 1934-1947 and 1948-1970 climatic conditions. The average well discharges shown on figure 1 exclude Hays County, which is not very pertinent to studies of the Uvalde and Central Pools, and are divided into "irrigation" and "other" subcomponents. In the year-by-year studies, separate computations were made for the Uvalde Pool and the Central Pool. Consequently, the well discharges were subdivided into Uvalde Pool and Central Pool components. For the Uvalde Pool, irrigated acreage was assumed to reach a maximum by 1990 because of limited suitable land and remain constant thereafter. In the Central Pool irrigated acreage and irrigation demands were assumed to increase throughout the 1972-2027 study period. The average "other" well demands for the Uvalde and Central Pools were also assumed to increase throughout the 1972-2027 period approximately in proportion to the population increase estimated for the two areas by the Texas Water Development Board in December 1972.

In the studies, the well discharge for each year for irrigation and "other" was assumed to vary from average in response to the assumed climatic condition that year. This year-to-year variation from average is substantial for the irrigation well discharge and much smaller for the "other" well discharge. The variations from average are the same as those used in the 1969 condition studies described in my June 30, 1972, memorandum. The actual values used in each year of the studies are shown in tables 1, 2, and 3.

Aquifer recharge. The historic recharge for each climatic year was used for the Central Pool. For the Uvalde Pool, the historic recharge was used if the elevation of well H-4-6 at the end of the preceding year in this study was above 883 feet. If the elevation at the end of the preceding year was below 883 feet, the 1969 condition study recharge was used. Nueces River rejected recharge is believed to be smaller when the well H-4-6 water surface elevation is below elevation 883 feet than when it is above that elevation. For 1957 and 1958 climatic conditions a recharge smaller than historic was used in this study, if the end of preceding year, water surface elevation in well H-4-6 exceeded 883 feet. Historically, the water levels prior to these two years were less than 883 feet.

Underflow between pools. The underflow in the aquifer from the Uvalde Pool to the Central Pool was estimated by use of a correlation between the underflow estimated for the 1969 condition study, and the difference in water surface elevation between well H-4-6 and well 26 at the end of the preceding year in the 1969 condition study. This correlation is shown on figure 4. The underflow was estimated by entering figure 4 with the difference in water surface elevation of well H-4-6 and well 26 at the end of the preceding year in this study.

The underflow in the aquifer from the Central Pool to the San Marcos Pool was estimated from a correlation between the underflow and the average of the water surface elevation of well 26 at the end of the preceding and current year. This correlation is shown on figure 5. Its derivation is described in my June 30, 1972, and June 6, 1972, memorandums. The correlation shown in the June 6, 1972, memorandum was displaced upward 6 feet to allow for greater than historic summer draw-downs in well 26. When the water surface elevation of well 26 in these studies was below the San Marcos Springs outlet level, a reverse flow from the San Marcos Pool to the Central Pool was assumed to occur.

Discharge from Springs. The discharge of Leona Springs plus Leona River underflow was estimated from a correlation between this flow and the end of preceding year water surface elevation in well H-4-6. Figure 6 shows this correlation.

The discharge of San Antonio Springs was estimated by use of a correlation between its flow and the average of the water surface elevation of well 26 at the end of the preceding and current year. Figure 7 shows this correlation.

The discharge of Comal Springs was estimated by use of a correlation between its flow and the average of the water surface elevation of well 26 at the end of the preceding and current year. Figure 8 shows this correlation.

For all three springs, the historic climatic year deviation from the correlation expressed in terms of water surface elevation was assumed to recur in that climatic year of the study.

For Comal and San Antonio Springs, the historic relationship (for 1956-1969) between springflow and water surface elevation in well 26 was displaeed upward two feet to allow for the greater than historic summer drawdown of well 26 that is expected to accompany greater than historic well discharges.

Aquifer end of year water surface elevations. The end of the year water surface elevation of well H-4-6 in this study was computed by adding the estimated change of this water surface elevation from the historic value to the historic value. The change was computed by dividing the accumulated value of (inflow this study-outflow this study)-(historic inflow-historic outflow) by 4.5.

The end of the year water surface elevation of well 26 was computed by a similar procedure. The accumulated change in content from historic was divided by 36.0.

A Uvalde Pool change in content of 4.5 thousand acre-feet is assumed to cause a one foot change in year end elevation of well H-4-6. A Central Pool change in content of 36.0 thousand acre-feet was assumed to cause a one foot change in year end elevation of well 26. Derivation of these values is described in my memorandums dated June 30, 1972, April 13, 1972, and May 31, 1972.

An upper limit of 894 feet was placed upon the computed end of year water surface elevation of well H-4-6, and an upper limit of 685 feet was placed upon the well 26 elevation. These are historic maximums for these wells and are believed to reflect physical constraints. No corresponding limit was placed upon the cumulative change in aquifer content from historic. This has a considerable effect on study years 1972-1985 of study II.

Results of studies. The results of the studies are presented graphically on figures 1, 2, and 3, and the annual studies are presented on tables 1, 2, and 3.

Figure 1 shows the historic and projected future conditions in the Central Pool. The top graph shows historic and projected future well discharge from the Uvalde plus Central Pools, and the average recharge to these two pools for the 1934-1947 and 1957-1969 periods. What happens in the "upstream" Uvalde Pool affects the Central Pool. The projected demands are for an average climatic year.

The bottom graph on figure 1 shows the historic end of year water surface elevation in well 26, which is located in San Antonio, and the range of elevations experienced each year. The range in elevations during recent dry years has been very large. This is because of summer drawdowns caused by large summer well discharges. During fall and winter, the water surface elevation in well 26 has returned to "normal" values that would be expected with the annual values of inflow and outflow. The graph also shows the approximate water surface elevation in well 26 at which San Antonio Springs stops flowing, and th. approximate elevation at which Comal Springs stops flowing. The flow of these two springs is very nearly proportioned to the amount by which the water surface elevation in well 26 exceeds these zero flow elevations. The approximate elevation of the San Marcos Springs outlet is also shown. Although the water surface elevation in well 26 influences the flow of San Marcos Springs, local recharge to the San Marcos Pool also has a major effect upon San Marcos Springs. If the water surface elevation in well 26 were to drop below the San Marcos Springs outlet elevation, the hydraulic gradient would be reversed and water would tend to flow from the San Marcos Pool to the Central Pool.

For the projected future well discharge, the lower graph of figure 1 shows the median end of year water surface elevation in well 26 that the studies show could occur with the 1934-1947 and 1957-1970 climatic sequences following each other. Most end of the year water surface elevations would be within ± 12 feet of the median. The end of year water surface elevation that would occur at the end of the 1948-1956 climatic sequence if it should recur is also shown. The estimated future range in water elevations in well 26 is also shown. Two minimums are shown; one for the 1934-1947, 1957-1970 climatic sequence, which would be the expected minimum without a severe prolonged drought such as occurred during 1948-1956; the other is for the summer of 1956 if the 1948-1956 climatic sequence should recur. It is estimated that the minimum annual water surface elevation will equal or be lower than the minimum for the 1934-1947, 1957-1970 climatic sequence about 14 percent of the years. This is about 1 year in 7. 1967 is the climatic year in which this minimum occurs. The projected summer drawdown for recent climatic years is assumed to be proportioned to the well discharge, study value versus historic value. For 1956 the projected summer drawdown is assumed to equal the historic 1967 summer drawdown multiplied by the ratio of the projected future "1956" well discharge to tthe historic 1967 well discharge.

These computations of minimum water surface elevations assume that the severe summer drawdowns of artesian head are overcome during the winter, and that the changes in end of year water levels are consistent with their historic relationship with computed change in aquifer content. If the winter well discharge gets large enough, this recovery may not occur during dry years. If the annual well discharge gets large enough, only a partial recovery of artesian head may occur in the winter during dry years even if winter well discharge is relatively small. Aquifer transmissibility rather than aquifer content could control end of year water surface elevations. Without the complete winter recovery of artesian head, water levels during dry years may be much lower than those shown for well 26 in the studies and on figure 1. Without any winter recovery during dry years the minimum elevation for the 1934-1947, 1957-1970 climatic sequence could be 60 feet lower than the values shown on figure 1, and the minimum water surface elevation for the 1948-1956 climatic sequence could be 250 feet lower than the values shown on plate 1. However, an adequate flow of water might be induced by an increased drawdown of considerably less than 250 feet. During subsequent wet years, the water levels would recover rapidly to the "normal" values indicated by the studies. Thus median water levels would not be substantially changed by this phenomenon. It is estimated that incomplete winter recovery may occur during dry years when well discharge from the Central Pool exceeds 400 to 500 thousand acre-feet per year.

If water levels drop far enough, part of the artesian portion of the aquifer will become unconfined. When this happens, the decline in water levels may slow down because of the water drained out of these portions of the aquifer. This dewatering of part of the present artesian area may begin at about elevation 700 in the Uvalde area and about elevation 450 in the San Antonio area.

The downward curvature of the lines that indicate the estimated future water surface elevations in well 26 is partly caused by the steady decrease in flow of San Antonio and Comal Springs. Increased well discharge is partly offset by decreased spring flow if there is spring flow. When there is no spring flow this offsetting factor is absent. Spring flow also tends to moderate the water level fluctuation in well 26. Without spring flow, the fluctuations in water level will increase. During 1948-1956, the excess of well discharge over aquifer recharge becomes more severe as well discharge increases, and this also causes a downward curvature of the indicated 1956 water levels.

Figure 2 is similar to figure 1 except that it pertains to conditions in the Uvalde Pool. The progression of estimated future water levels in well H-4-6 is affected by the assumption that expansion of irrigation in the Uvalde Pool will not occur after 1990. After 1990, there is very little increase in well discharge from the Uvalde Pool in these studies. The decline in water levels after 1990 is caused almost entirely by increased underflow to the Central Pool.

Figure 3 shows the estimated future probability of flow from Leona Springs, San Antonio Springs, Comal Springs, and San Marcos Springs, from the perspective of a few years before the year in question so that the beginning of the year water level elevations for the year in question are not known. For Comal Springs, San Antonio Springs, and San Marcos Springs, figure 3 shows the estimated percentage chance of continuous flow throughout the year. The percentage chance of flow during at least part of the year is shown for all four springs. During years when there is spring flow during only part of the year, zero flow will usually occur in the summer. In deriving these probability curves, the 1948-1953 period was assumed to have a recurrence interval of 50 years. The 1954-1956 period following the 1948-1953 period was assumed to have a recurrence interval of 100 years.

Figure 3 shows the San Marcos Pool (Hays County) well discharge assumed in computing San Marcos Springs discharge. The chance of continuous flow from San Marcos Springs was computed by subtracting the estimated decrease in summer underflow from the Central Pool compared to historic, and the estimated increase in San Marcos Pool summer well discharge over historic from the minimum historic monthly summer flow of San Marcos Springs for each climatic year.

The values in figure 3 for Comal Springs and San Antonio Springs assume that "normal" end of year water levels will occur regardless of how large the well discharge is during dry years. This is an optimistic assumption and the indicated probability of Comal Springs flow during part of the year and of San Marcos Springs spring flow may be overly optimistic after about 1990.

Reliability of studies. The studies assume that the aquifer characteristics and relationships that have occurred within the historic range of water levels will continue to occur at lower water levels. This assumption cannot be completely true, and the possible errors in the studies from this source increase the farther the study water levels drop below the historic range. As previously discussed, the studies also assume that the severe summer drawdowns of artesian head are overcome during the winter, and that the changes in end of year water levels are consistent with their historic relationship with change in aquifer content. If well discharges get large enough, this recovery may not occur during dry years and water levels during dry years may be much lower than those shown for well 26 in the studies and on figure 1. The historic performance of the aquifer is not completely understood. This no doubt causes error in the studies. Knowledge is believed to be more complete for the Central Pool than for the Uvalde and San Marcos Pools.

Comparison with constant condition studies. A comparison was made of the results of this study with the results of the studies described in my June 30, 1972, memorandum to the files. The aquifer relationships used in the two studies are nearly identical, so differences are caused by variable versus constant state well discharge and by eliminating the 1948-1956 period from the climatic sequences of studies I and II. The three climatic years 1947, 1956, and 1969 were chosen for comparison. The water levels indicated for these climatic years in the "1969 condition" and "1.35 x 1969 condition" studies would not be matched in these studies until several years after the well discharge was matched. This lag was:

	Well H-4-6	Well 26
1969 condition study		
1947	17 years	12 years
1956	12 years	7 years
1969	12 years	16 years
1.35 x 1969 condition study		
1947	25 years	8 years
1956	26 years	9 years
1969	60 years	21 years

Some lag would be expected. The lag times for 1947 and 1956 are affected by possible inexact selection of initial (1933) steady state well elevations in the 1969 and 1.35 x 1969 condition studies, and by the high 1971 water surface elevations at the start of the current studies. The comparison for 1969 is affected by omission of the 1948-1956 sequence in these studies and its inclusion in the earlier studies.

The 1956 water levels would be least affected by these items, and the lags indicated for 1956 are probably nearer the true lags that would be caused by increasing well discharge. The lag indicated for well 26 is about 8 years. The lag indicated for well H-4-6 is about 12 years until about 1990 and about 25 years after 1990. Expansion of irrigation in the Uvalde Pool was assumed to cease in 1990 in studies I and II. It takes the Uvalde Pool longer to adjust to changed water levels in the Central Pool than to adjust to changed well discharge in the Uvalde Pool.

Aquifer performance with other assumptions regarding future well discharge.

Rough answers on aquifer performance with other assumptions regarding future well discharge can be obtained by entering figures 1, 2, and 3 with the assumed well discharges and ignoring the time scale. This will not take into account any differences in aquifer lag that may occur.

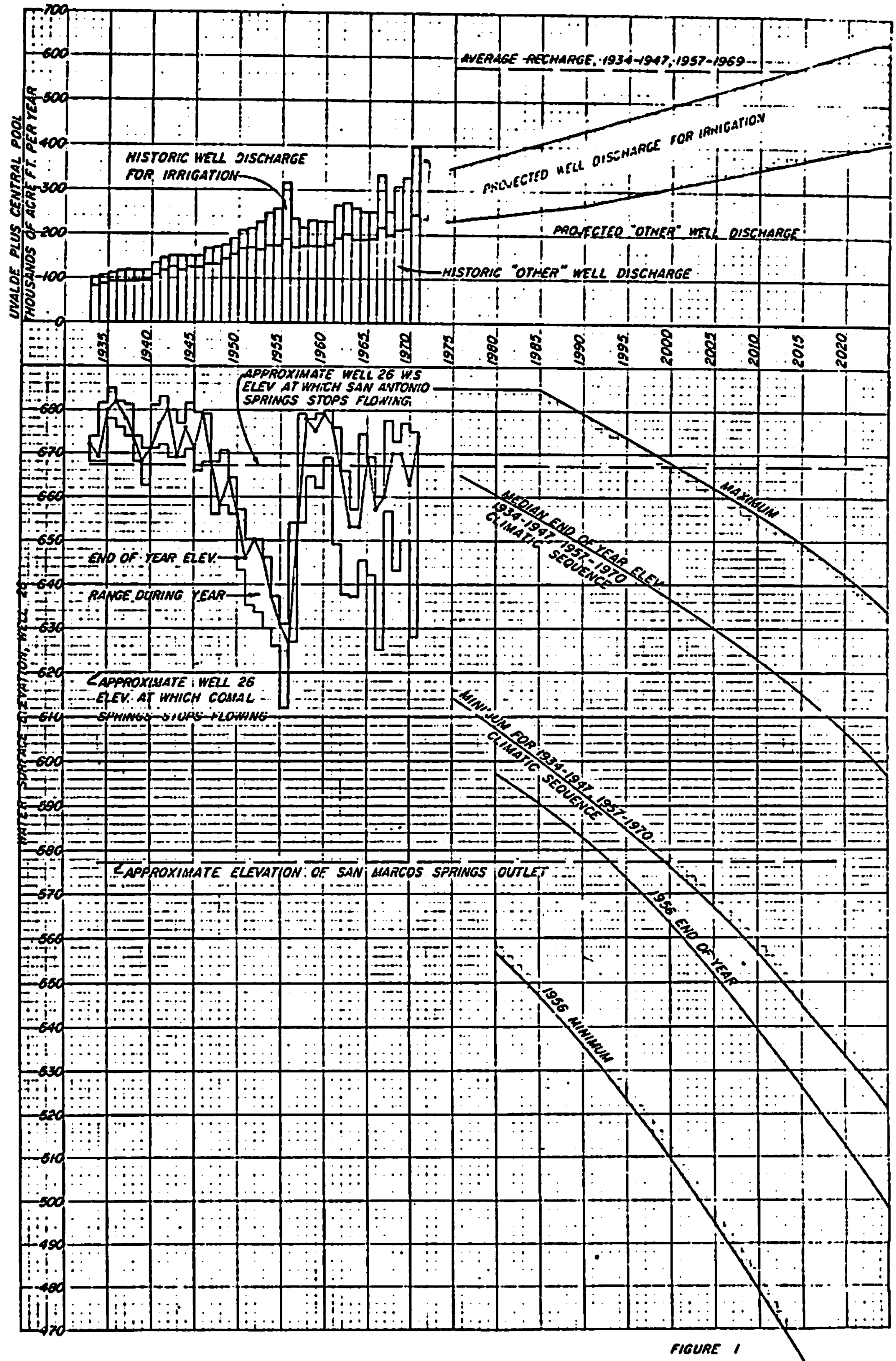
The studies were run on a computer. Rerunning the studies with other well discharge projections would involve modest expenditures of time and money.

Noted:

____

Regional Planning Officer

cc: Norman Flaigg, Austin, Texas
Charles Arndt



UVALDE PLUS CENTRAL POOL
THOUSANDS OF ACRE FT. PER YEAR
AVERAGE RECHARGE, 1934-1947, 1957-1969
PROJECTED WELL DISCHARGE FOR IRRIGATION
HISTORIC WELL DISCHARGE FOR IRRIGATION
PROJECTED "OTHER" WELL DISCHARGE
HISTORIC "OTHER" WELL DISCHARGE
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
APPROXIMATE WELL 26 W.S. ELEV AT WHICH SAN ANTONIO SPRINGS STOPS FLOWING
MAXIMUM
MEDIAN END OF YEAR ELEV. 1934-1947, 1957-1970 CLIMATIC SEQUENCE
END OF YEAR ELEV.
RANGE DURING YEAR
APPROXIMATE WELL 26 ELEV. AT WHICH COMAL SPRINGS STOPS FLOWING
MINIMUM FOR 1934-1947, 1957-1970 CLIMATIC SEQUENCE
APPROXIMATE ELEVATION OF SAN MARCOS SPRINGS OUTLET
1956 END OF YEAR
1956 MINIMUM
WATER SURFACE ELEVATION, WELL 26

FIGURE 1

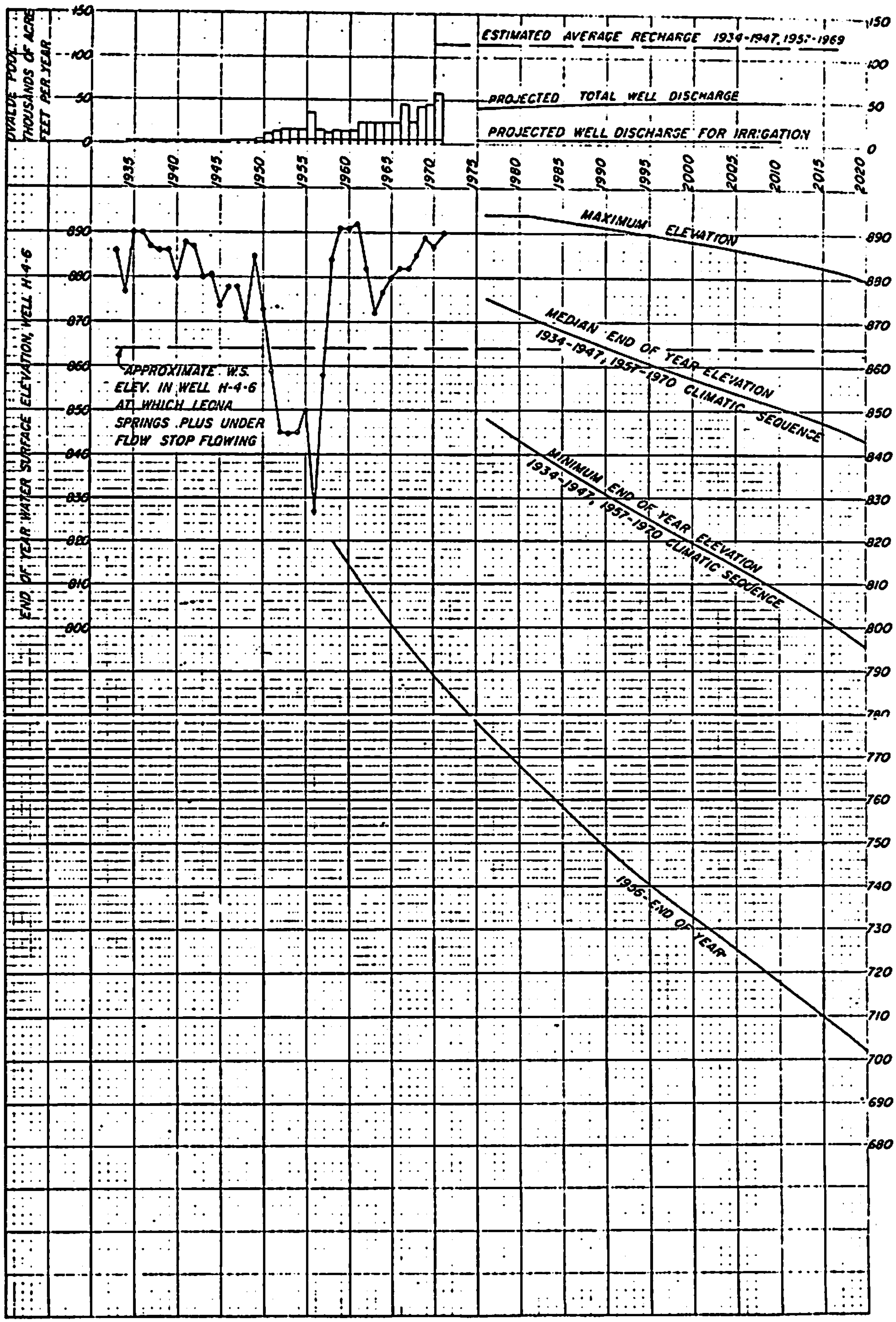
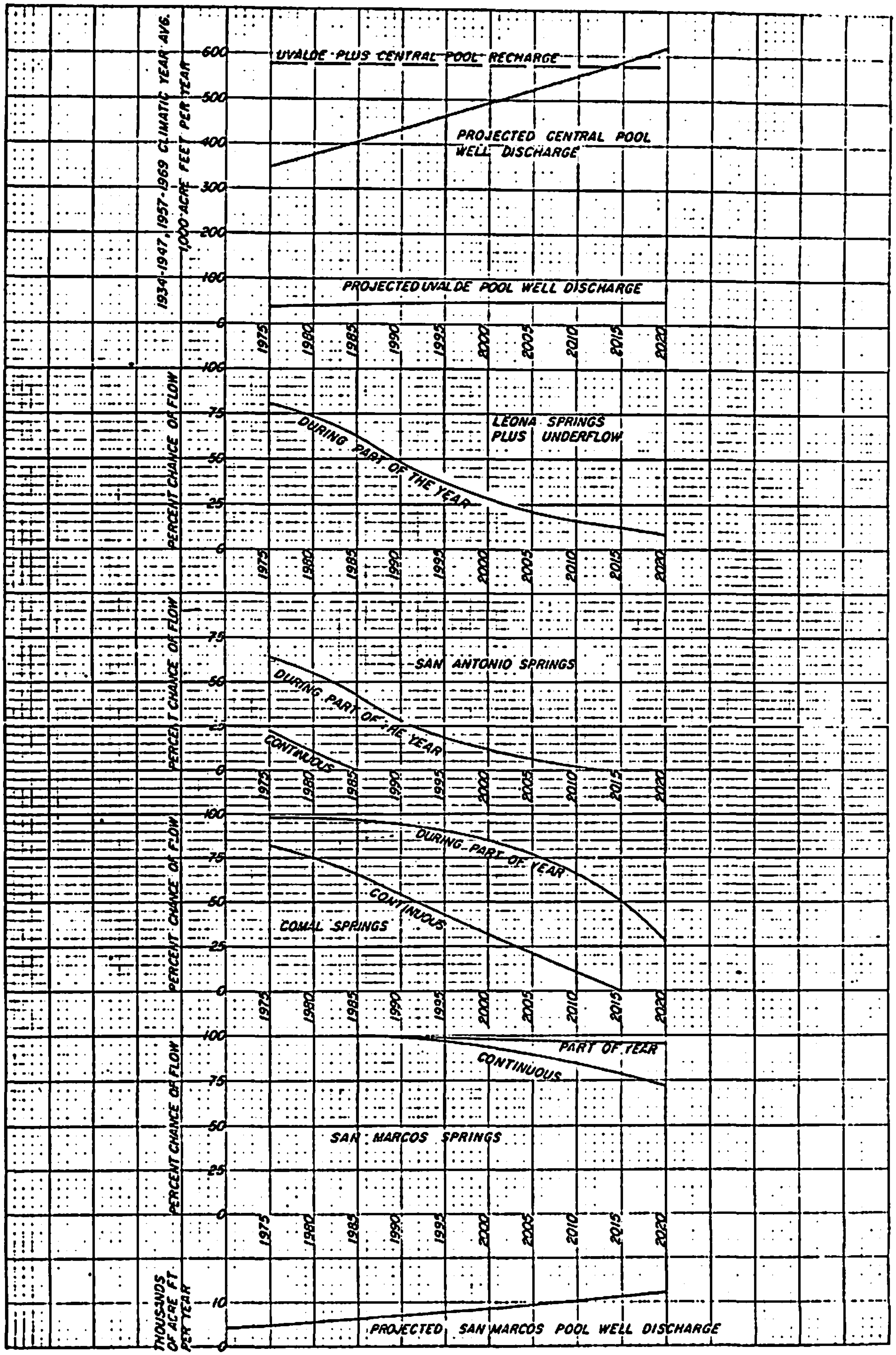

UVALDE POOL THOUSANDS OF ACRE FEET PER YEAR
END OF YEAR WATER SURFACE ELEVATION, WELL H-4-6
ESTIMATED AVERAGE RECHARGE 1934-1947, 1957-1969
PROJECTED TOTAL WELL DISCHARGE
PROJECTED WELL DISCHARGE FOR IRRIGATION
MAXIMUM ELEVATION
MEDIAN END OF YEAR ELEVATION 1934-1947, 1957-1970 CLIMATIC SEQUENCE
MINIMUM END OF YEAR ELEVATION 1934-1947, 1957-1970 CLIMATIC SEQUENCE
1956 END OF YEAR
APPROXIMATE W.S. ELEV. IN WELL H-4-6 AT WHICH LEONA SPRINGS PLUS UNDER FLOW STOP FLOWING
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
150
100
50
0
890
880
870
860
850
840
830
820
810
800
790
780
770
760
750
740
730
720
710
700
690
680

FIGURE 2



1934-1947, 1957-1969 CLIMATIC YEAR AVG. 1,000 ACRE FEET PER YEAR
600
500
400
300
200
100
0
UVALDE PLUS CENTRAL POOL RECHARGE
PROJECTED CENTRAL POOL WELL DISCHARGE
PROJECTED UVALDE POOL WELL DISCHARGE
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
PERCENT CHANCE OF FLOW
100
75
50
25
0
LEONA SPRINGS PLUS UNDERFLOW
DURING PART OF THE YEAR
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
PERCENT CHANCE OF FLOW
75
50
25
0
SAN ANTONIO SPRINGS
DURING PART OF THE YEAR
CONTINUOUS
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
PERCENT CHANCE OF FLOW
100
75
50
25
0
DURING PART OF YEAR
CONTINUOUS
COMAL SPRINGS
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
PERCENT CHANCE OF FLOW
100
75
50
25
0
PART OF YEAR
CONTINUOUS
SAN MARCOS SPRINGS
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
THOUSANDS OF ACRE FT. PER YEAR
10
0
PROJECTED SAN MARCOS POOL WELL DISCHARGE

FIGURE 3

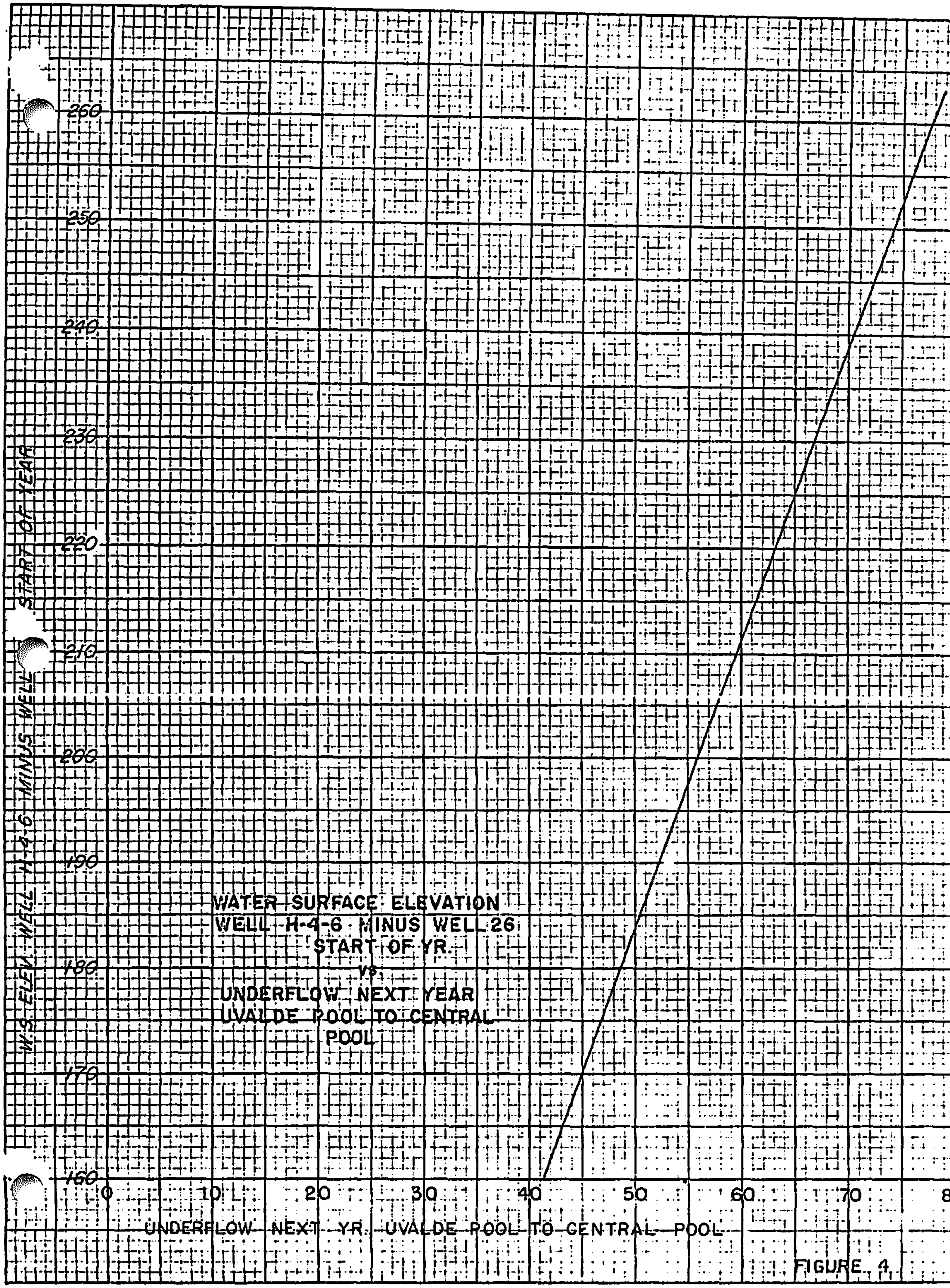
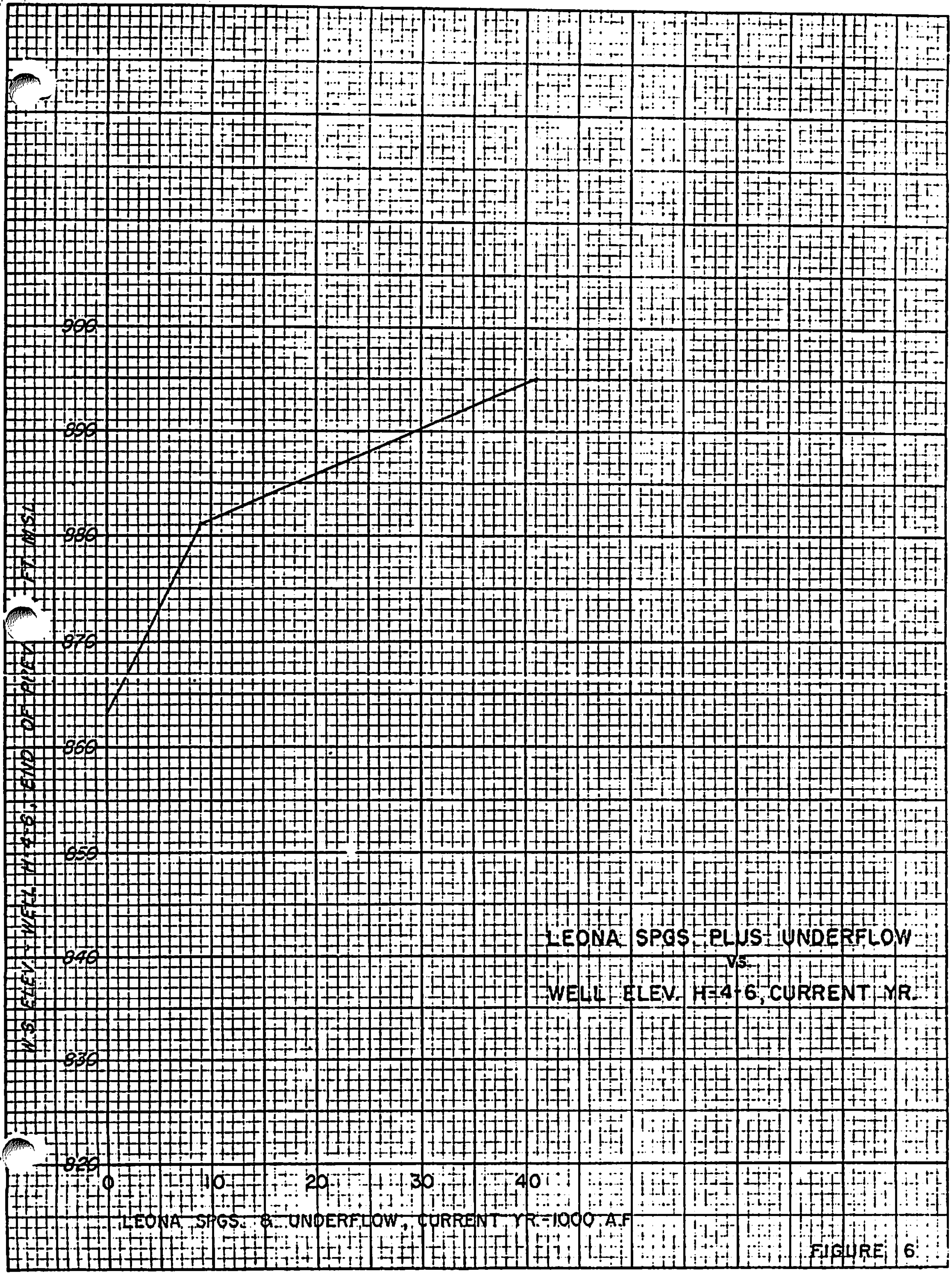
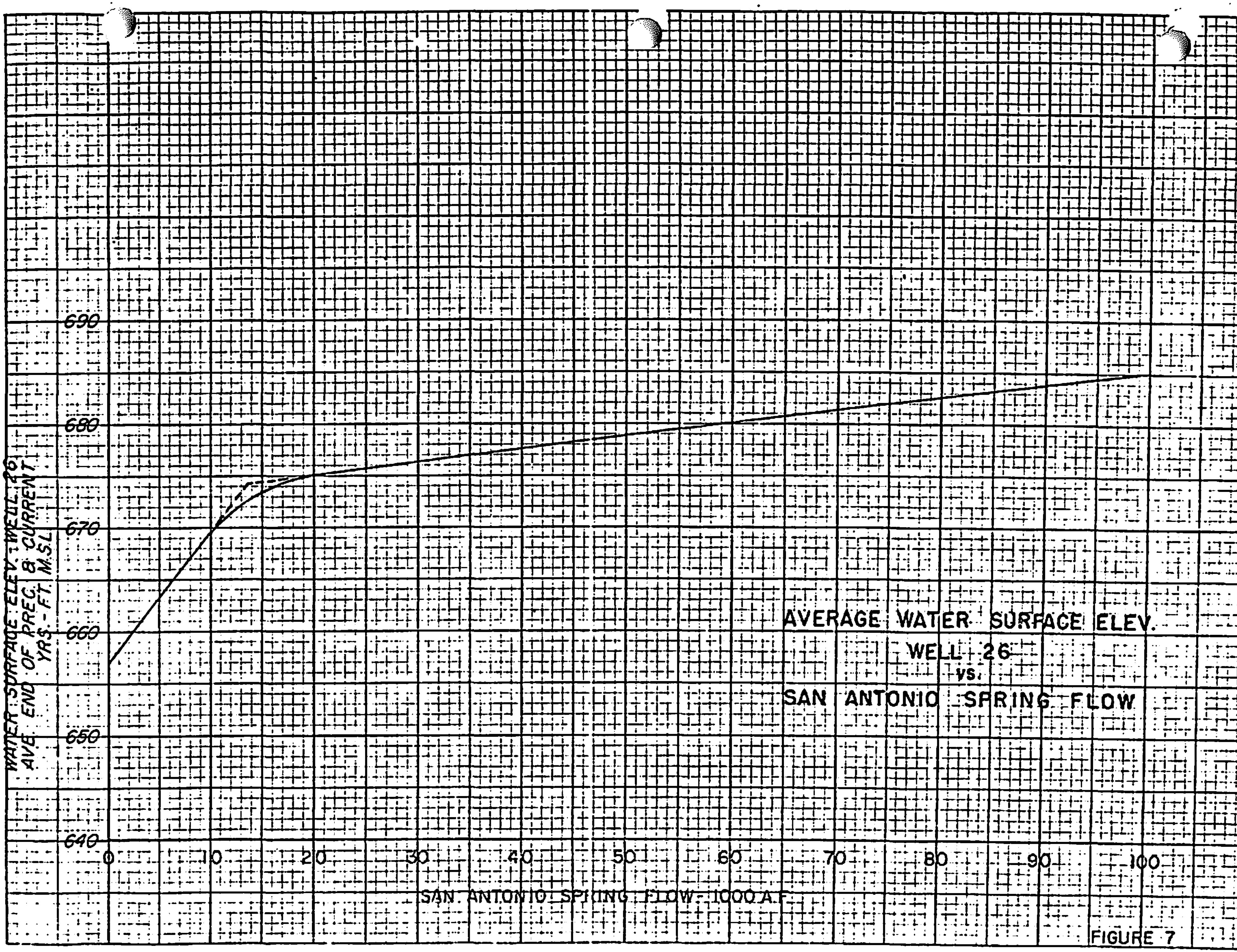

W.S. ELEV. WELL H-4-6 MINUS WELL START OF YEAR
260
250
240
230
220
210
200
190
180
170
160
0
10
20
30
40
50
60
70
80
UNDERFLOW NEXT YR. UVALDE POOL TO CENTRAL POOL
WATER SURFACE ELEVATION
WELL H-4-6 MINUS WELL 26
START OF YR.
VS.
UNDERFLOW NEXT YEAR
UVALDE POOL TO CENTRAL
POOL

FIGURE 4



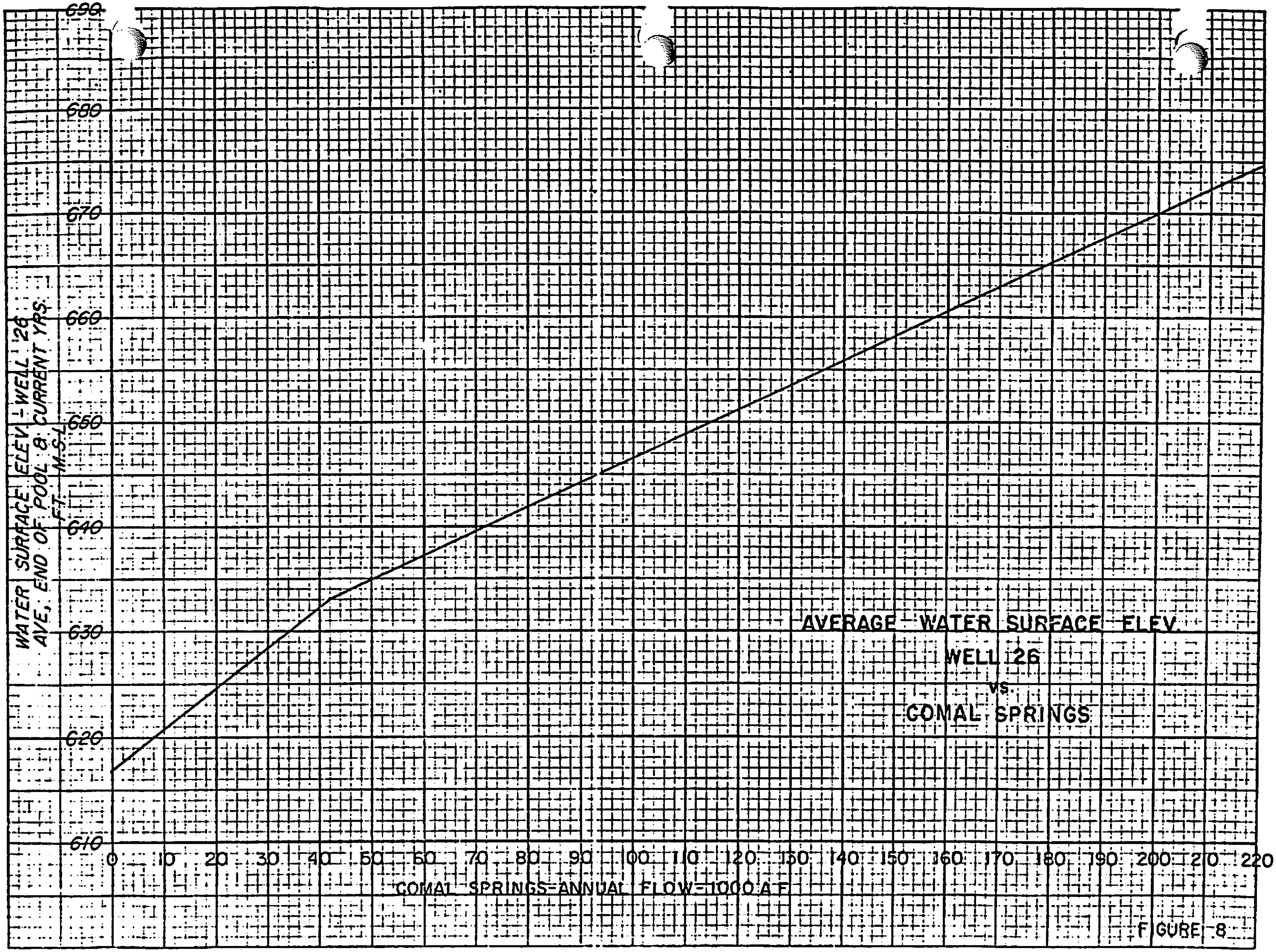
W.S. ELEV. - WELL H-4-6, END OF PREV. - FT. MSL
900
890
880
870
860
850
840
830
820
0
10
20
30
40
LEONA SPGS. & UNDERFLOW, CURRENT YR.-1000 A.F.
LEONA SPGS. PLUS UNDERFLOW
VS.
WELL ELEV. H-4-6, CURRENT YR.

FIGURE 6



WATER SURFACE ELEV.-WELL 26
AVE. END OF PREC. 8 CURRENT YRS.-FT. M.S.L.
690
680
670
660
650
640
0
10
20
30
40
50
60
70
80
90
100
SAN ANTONIO SPRING FLOW-1000 A.F.
AVERAGE WATER SURFACE ELEV.
WELL 26
VS.
SAN ANTONIO SPRING FLOW

FIGURE 7



AVERAGE WATER SURFACE ELEV.
WELL 26
vs.
COMAL SPRINGS
WATER SURFACE ELEV. - WELL 26
AVE., END OF POOL 8; CURRENT YRS.
FT. M.S.L.
690
680
670
660
650
640
630
620
610
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220
COMAL SPRINGS-ANNUAL FLOW-1000 A.F.

FIGURE 8

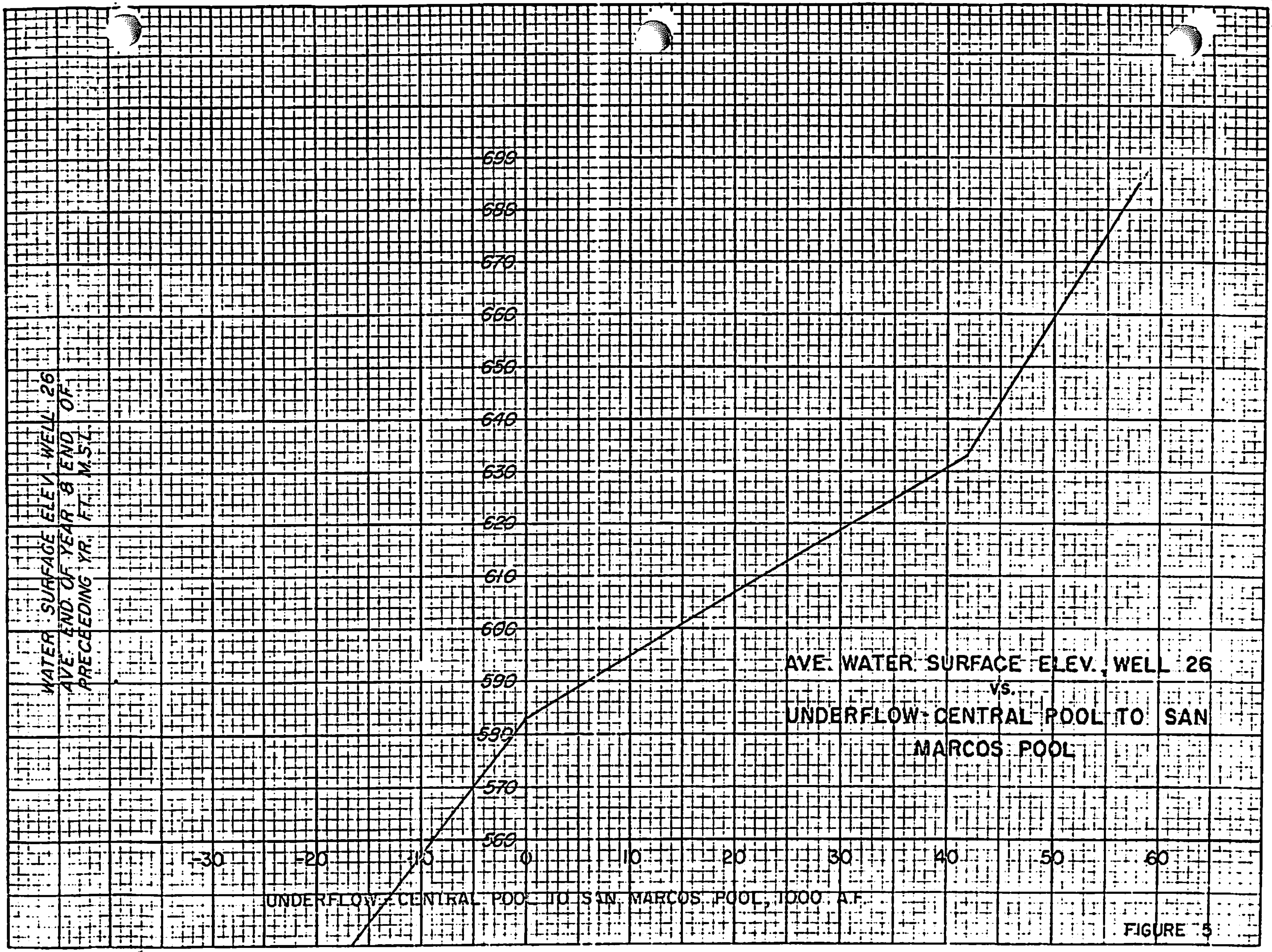

AVE. WATER SURFACE ELEV., WELL 26
vs.
UNDERFLOW-CENTRAL POOL TO SAN
MARCOS POOL
WATER SURFACE ELEV. WELL 26
AVE. END OF YEAR & END OF
PRECEEDING YR. FT. M.S.L.
UNDERFLOW-CENTRAL POOL TO SAN MARCOS POOL, 1000 A.F.
690
680
670
660
650
640
630
620
610
600
590
580
570
560
-30
-20
-10
0
10
20
30
40
50
60

FIGURE 5

Column Descriptions for Studies I and II

UVALDE POOL

							LEONA SPRINGS			INFLOW - OUTFLOW			WELL H-4-6 END OF YEAR WATER SURFACE ELEV.		
Historic Year (1)	Study Year (2)	Recharge (3)	Total Discharge (4)	Δ Water Surface Well H-46– Well 26 Start of Year (5)	Discharge to Central Pool (6)	Well Discharge (7)	Historic Dev. from correl. with Well H-4-6 (8)	Adjusted Water Surface Elev. Well H-4-6 Start of Year (9)	Flow Leona Springs (10)	This Study (11)	Historic (12)	Cumulative Change from Historic (13)	Change from Historic (14)	Historic (15)	This Study (16)

CENTRAL POOL

		INFLOW						SAN ANTONIO SPRINGS			COMAL SPRINGS			INFLOW - OUTFLOW			WELL 26 WATER SURFACE ELEV.			
Historic Year (18)	Study Year (19)	From Uvalde Pool (20)	Direct Recharge (21)	Total (22)	Total Outflow (23)	To San Marcos Pool (24)	Well Discharge (25)	Historic Dev. from correl. with Well 26 (26)	Adjusted Average Water Surface Well 26 (27)	Flow San Antonio Springs (28)	Historic from correl. with Well 26 (29)	Adjusted Average Water Surface Well 26 (30)	Flow Comal Springs (31)	This Study (32)	Historic (33)	Cumulative Change from Historic (34)	Change from Historic (35)	Historic (36)	End of Year This Study (37)	Avg. of Preceeding and this Year (38)

STUDY I CYCLE I

UVALDE POOL

							LEONA SPRINGS			INFLOWS - OUTFLOWS			WELL H-A-6 END OF YEAR		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1933												22.0	5.0	886.0	891.0
1934	1972	12.0	100.2	217.0	62.0	53.0	-3.0	888.0	25.2	-128.2	-70.0	-36.2	-8.0	877.0	869.0
1935	1973	225.0	90.0	203.5	57.1	27.0	6.0	875.0	6.0	135.0	125.0	-26.2	-5.8	890.0	884.2
1936	1974	145.0	111.1	209.0	59.1	38.0	-1.0	883.2	14.1	33.9	51.0	-43.4	-9.6	890.0	880.4
1937	1975	81.0	117.1	204.6	57.5	51.0	.0	880.4	8.7	-36.1	-35.0	-44.5	-9.9	887.0	877.1
1938	1976	94.0	118.1	207.7	58.6	52.0	1.0	878.1	7.6	-24.1	-19.0	-49.7	-11.0	886.0	875.0
1939	1977	131.0	113.0	211.6	60.0	47.0	.0	875.0	6.0	18.0	34.0	-65.6	-14.6	886.0	871.4
1940	1978	59.0	97.8	216.5	62.6	32.0	-2.0	869.4	3.2	-38.8	-29.0	-75.4	-16.8	880.0	863.2
1941	1979	124.0	90.1	210.1	59.5	28.0	5.0	868.2	2.6	33.9	26.0	-67.5	-15.0	888.0	873.0
1942	1980	130.0	117.4	214.0	60.9	52.0	-1.0	872.0	4.5	12.6	27.0	-81.9	-18.2	887.0	868.8
1943	1981	43.0	107.9	207.5	58.5	47.0	-1.0	867.8	2.4	-64.9	-44.0	-102.8	-22.9	880.0	857.1
1944	1982	74.0	93.9	208.6	58.9	35.0	1.0	858.1	.0	-19.9	-3.0	-119.8	-26.6	881.0	854.4
1945	1983	56.0	98.8	200.1	55.8	43.0	1.0	855.4	.0	-42.8	-22.0	-140.6	-31.2	874.0	842.8
1946	1984	88.0	94.0	192.3	53.0	41.0	1.0	843.8	.0	-6.0	18.0	-164.6	-36.6	878.0	841.4
1947	1985	83.0	97.5	185.4	50.5	47.0	5.0	846.4	.0	-14.5	7.0	-186.1	-41.4	878.0	836.6

CENTRAL POOL

		INFLOWS						SAN ANTONIO SPRINGS			COMAL SPRINGS			INFLOWS - OUTFLOWS			WELL 26 WATER SURFACE ELEV.			
(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)
																72.0	2.0	672.0	674.0	
1934	1972	62.0	148.0	210.0	589.6	53.2	326.0	.0	670.0	10.4	.0	670.0	200.0	-379.6	-181.0	-126.6	-3.5	669.0	665.5	669.7
1935	1973	57.1	781.0	838.1	508.2	53.1	252.0	3.0	672.7	12.6	-2.0	667.7	190.5	329.9	377.0	-173.7	-4.8	680.0	675.2	670.3
1936	1974	59.1	670.0	729.1	581.4	54.8	288.0	1.0	676.3	28.8	-3.0	672.3	209.8	107.6	197.0	-223.1	-6.2	682.0	675.8	675.5
1937	1975	57.5	339.0	396.5	593.3	54.3	328.0	.0	673.5	13.2	-4.0	669.5	197.9	-196.9	-112.0	-307.9	-8.6	678.0	669.4	672.6
1938	1976	58.6	324.0	382.6	566.0	52.1	323.0	2.0	668.6	9.3	-1.0	665.6	181.6	-183.4	-110.0	-381.3	-10.6	674.0	663.4	666.4
1939	1977	60.0	155.0	215.0	558.5	49.6	370.0	-1.0	657.4	.3	-3.0	655.4	138.6	-343.5	-180.0	-544.8	-15.1	668.0	652.9	658.1
1940	1978	62.6	233.0	295.6	472.6	47.9	321.0	-8.0	645.1	.0	-6.0	647.1	103.6	-177.0	-79.0	-642.6	-17.9	671.0	653.1	653.0
1941	1979	59.5	682.0	741.5	507.7	48.8	312.0	3.0	659.0	1.6	1.0	657.0	145.2	233.8	240.0	-649.0	-18.0	677.0	659.0	656.1
1942	1980	60.9	413.0	473.9	539.4	50.1	338.0	-1.0	659.1	1.6	-2.0	658.1	149.7	-65.5	-41.0	-673.5	-18.7	680.0	661.3	660.1
1943	1981	58.5	212.0	270.5	539.1	48.5	349.0	-1.0	654.1	.0	1.0	656.1	141.6	-268.6	-205.0	-737.1	-20.5	669.0	648.5	654.9
1944	1982	58.9	439.0	497.9	517.2	47.5	329.0	.0	651.9	.0	4.0	655.9	140.6	-19.2	25.0	-781.3	-21.7	676.0	654.3	651.6
1945	1983	55.8	437.0	492.8	543.4	47.7	353.0	1.0	653.4	.0	4.0	656.4	142.7	-50.6	-22.0	-809.9	-22.5	673.0	650.5	652.4
1946	1984	53.0	426.0	479.0	511.9	47.7	330.0	-3.0	649.6	.0	2.0	654.4	134.3	-33.0	-15.0	-827.9	-23.0	679.0	656.0	653.1
1947	1985	50.5	310.0	360.5	574.4	47.0	398.0	-1.0	649.3	.0	3.0	653.3	129.4	-214.0	-140.0	-901.8	-25.1	668.0	642.9	649.5

Table I
Sheet 1 of 4

STUDY I CYCLE II

U V A L D E P O O L

(1)	(2)	(3)	(4)	(5)	(6)	(7)	LEONA SPRINGS (8)	LEONA SPRINGS (9)	LEONA SPRINGS (10)	INFLOWS - OUTFLOWS (11)	INFLOWS - OUTFLOWS (12)	INFLOWS - OUTFLOWS (13)	WELL H-4-6 END OF YEAR (14)	WELL H-4-6 END OF YEAR (15)	WELL H-4-6 END OF YEAR (16)
1956												40.0	9.0	827.0	836.0
1957	1986	156.0	87.3	193.0	53.3	34.0	8.0	844.0	.0	68.7	76.0	32.7	7.3	858.0	865.3
1958	1987	263.0	93.0	200.3	55.9	34.0	4.0	869.3	3.1	170.0	183.0	19.7	4.4	884.0	888.4
1959	1988	124.0	120.0	205.7	57.9	36.0	.0	888.4	26.1	4.0	33.0	-9.3	-2.1	891.0	888.9
1960	1989	100.0	138.0	214.0	60.9	52.0	-1.0	887.9	25.1	-38.0	-7.0	-40.2	-8.9	891.0	882.1
1961	1990	135.0	115.9	207.2	59.4	46.0	.0	882.1	11.5	19.1	-6.0	-15.2	-3.4	692.0	888.6
1962	1991	49.0	139.5	220.0	63.1	59.0	-4.0	884.6	17.4	-90.5	-62.0	-43.7	-9.7	882.0	872.3
1963	1992	42.0	123.8	217.4	62.1	57.0	.0	872.3	4.6	-81.8	-56.0	-69.4	-15.4	872.0	856.6
1964	1993	130.0	122.4	218.0	62.4	60.0	3.0	859.6	.0	7.6	34.0	-95.8	-21.3	877.0	855.7
1965	1994	105.0	111.0	219.7	63.0	48.0	.0	855.7	.0	-6.0	8.0	-109.8	-24.4	880.0	855.6
1966	1995	146.0	98.7	205.3	57.7	41.0	-1.0	654.6	.0	47.3	53.0	-115.5	-25.7	882.0	856.3
1967	1996	94.0	133.9	219.5	62.9	71.0	-5.0	851.3	.0	-39.9	-23.0	-132.4	-29.4	882.0	852.6
1968	1997	173.0	98.5	215.6	61.5	37.0	3.0	855.6	.0	74.5	41.0	-98.9	-22.0	885.0	863.0
1969	1998	138.0	119.8	216.5	61.8	58.0	.0	863.0	0	18.2	7.0	-87.7	-19.5	889.0	869.5
1970	1999	143.0	123.1	223.5	64.4	56.0	-1.0	868.5	2.8	19.9	-16.0	-51.8	-11.5	887.0	875.5

C E N T R A L P O O L

(18)	(19)	INFLOWS (20)	INFLOWS (21)	INFLOWS (22)	(23)	(24)	(25)	SAN ANTONIO SPRINGS (26)	SAN ANTONIO SPRINGS (27)	SAN ANTONIO SPRINGS (28)	COMAL SPRINGS (29)	COMAL SPRINGS (30)	COMAL SPRINGS (31)
1957	1986	53.3	947.0	1000.3	543.1	48.2	337.0	.0	654.0	.0	6.0	660.0	157.9
1958	1987	55.9	1346.0	1401.9	721.5	54.4	350.0	7.0	681.0	66.5	8.0	682.0	250.6
1959	1988	57.9	534.0	591.9	695.0	55.6	374.0	.0	677.8	40.8	-2.0	675.8	224.5
1960	1989	60.9	663.0	723.9	670.9	54.7	391.0	-1.0	673.8	13.4	-2.0	672.8	211.8
1961	1990	58.4	565.0	623.4	666.4	53.8	392.0	1.0	672.9	12.7	.0	671.9	207.9
1962	1991	63.1	172.0	235.1	630.2	50.9	428.0	-2.0	660.7	3.0	-5.0	657.7	148.3
1963	1992	62.1	112.0	174.1	572.4	45.9	437.0	-1.0	645.8	.0	-3.0	643.8	89.5
1964	1993	62.4	258.0	320.4	508.1	43.1	401.0	4.0	641.7	.0	.0	637.7	64.0
1965	1994	63.0	452.0	515.0	532.8	44.5	384.0	2.0	644.3	.0	5.0	647.3	104.2
1966	1995	57.7	399.0	456.7	525.5	44.8	377.0	-3.0	640.2	.0	4.0	647.2	103.7
1967	1996	62.9	353.0	415.9	574.2	43.1	491.0	1.0	638.[illegible]	.0	-6.0	631.6	40.1
1968	1997	61.5	688.0	749.5	535.8	44.1	368.0	10.0	650.[illegible]	.0	11.0	651.9	123.7
1969	1998	61.8	402.0	463.8	550.6	45.6	403.0	-6.0	639.1	.0	1.0	646.7	101.9
1970	1999	64.4	504.0	568.4	588.9	44.5	436.0	.0	642.[illegible]	.0	6.0	648.3	108.4

C E N T R A L P O O L

(18)	INFLOWS - OUTFLOWS (32)	INFLOWS - OUTFLOWS (33)	INFLOWS - OUTFLOWS (34)	WELL 26 WATER SURFACE ELEV. (35)	WELL 26 WATER SURFACE ELEV. (36)	WELL 26 WATER SURFACE ELEV. (37)	WELL 26 WATER SURFACE ELEV. (38)
			576.0	16.0	627.0	643.0	
1957	457.2	638.0	395.2	11.0	654.0	665.0	654.0
1958	680.4	906.0	167.6	4.7	678.0	682.7	673.8
1959	-103.1	67.0	-2.5	-.1	675.0	674.9	678.8
1960	53.0	201.0	-150.5	-4.2	679.0	674.8	674.9
1961	-42.9	72.0	-265.4	-7.4	676.0	666.6	671.7
1962	-395.1	-262.0	-398.5	-11.1	666.0	654.9	661.8
1963	-398.3	-276.0	-520.8	-14.5	653.0	636.5	646.7
1964	-187.8	-97.0	-611.5	-17.0	653.0	636.0	637.3
1965	-17.8	44.0	-673.3	-18.7	669.0	650.3	643.2
1966	-68.8	-16.0	-726.1	-20.2	657.0	636.8	643.6
1967	-158.3	-55.0	-829.4	-23.0	660.0	637.0	636.9
1968	213.7	230.0	-845.7	-23.5	670.0	646.5	641.7
1969	-86.7	-69.0	-863.5	-24.0	670.0	646.0	646.3
1970	-20.6	8.0	-892.0	-24.8	663.0	638.2	642.1

STUDY I CYCLE III

UVALDE POOL

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) LEONA SPRINGS	(9) LEONA SPRINGS	(10) LEONA SPRINGS	(11) INFLOWS - OUTFLOWS	(12) INFLOWS - OUTFLOWS	(13) INFLOWS - OUTFLOWS	(14) WELL H-4-6 END OF YEAR	(15) WELL H-4-6 END OF YEAR	(16) WELL H-4-6 END OF YEAR
1933												-45.0	-10.0	886.0	876.0
1934	2000	12.0	142.6	238.0	69.6	68.0	-3.0	873.0	5.0	-130.6	-70.0	-105.6	-23.5	877.0	853.5
1935	2001	225.0	99.5	223.9	64.5	35.0	6.0	859.5	.0	125.5	125.0	-105.1	-23.4	890.0	866.6
1936	2002	171.0	113.5	225.8	65.2	47.0	-1.0	865.6	1.3	57.5	51.0	-98.7	-21.9	890.0	868.1
1937	2003	81.0	129.5	225.3	65.0	62.0	.0	868.1	2.5	-48.5	-35.0	-112.2	-24.9	887.0	862.1
1938	2004	94.0	127.1	225.4	65.1	62.0	1.0	863.1	.0	-33.1	-19.0	-126.3	-28.1	886.0	857.9
1939	2005	131.0	121.7	227.3	65.7	56.0	.0	857.9	.0	9.3	34.0	-151.0	-33.6	886.0	852.4
1940	2006	59.0	105.0	233.5	68.0	37.0	-2.0	850.4	.0	-46.0	-29.0	-168.0	-37.3	880.0	842.7
1941	2007	124.0	97.6	224.1	64.6	33.0	5.0	847.7	.0	26.4	26.0	-167.6	-37.2	888.0	850.8
1942	2008	130.0	124.3	226.0	65.3	59.0	-1.0	849.8	.0	5.7	27.0	-188.9	-42.0	887.0	845.0
1943	2009	43.0	116.4	218.2	62.4	54.0	-1.0	844.0	.0	-73.4	-44.0	-218.3	-48.5	880.0	831.5
1944	2010	74.0	101.3	217.8	62.3	39.0	1.0	832.5	.0	-27.3	-3.0	-242.6	-53.9	881.0	827.1
1945	2011	56.0	106.6	207.6	58.6	48.0	1.0	828.1	.0	-50.6	-22.0	-271.1	-60.3	874.0	813.7
1946	2012	88.0	100.2	198.3	55.2	45.0	1.0	814.7	.0	-12.2	18.0	-301.3	-67.0	878.0	811.0
1947	2013	83.0	103.2	190.1	52.2	51.0	5.0	816.0	.0	-20.2	7.0	-328.5	-73.0	878.0	805.0

CENTRAL POOL

(18)	(19)	(20) INFLOWS	(21) INFLOWS	(22) INFLOWS	(23)	(24)	(25)	(26) SAN ANTONIO SPRINGS	(27) SAN ANTONIO SPRINGS	(28) SAN ANTONIO SPRINGS	(29) COMAL SPRINGS	(30) COMAL SPRINGS	(31) COMAL SPRINGS	(32) INFLOWS - OUTFLOWS	(33) INFLOWS - OUTFLOWS	(34) INFLOWS - OUTFLOWS	(35) WELL 26 WATER SURFACE ELEV.	(36) WELL 26 WATER SURFACE ELEV.	(37) WELL 26 WATER SURFACE ELEV.	(38) WELL 26 WATER SURFACE ELEV.
																-1224.0	-34.0	672.0	638.0	
1934	2000	69.6	148.0	217.6	593.3	42.0	503.0	.0	634.0	.0	.0	634.0	48.2	-375.6	-181.0	-1418.6	-39.4	669.0	629.6	633.6
1935	2001	64.5	781.0	845.5	459.7	42.2	374.0	3.0	637.8	.0	-2.0	632.8	43.5	385.8	377.0	-1409.8	-39.2	680.0	640.8	635.2
1936	2002	65.2	670.0	735.2	540.2	44.2	430.0	1.0	642.2	.0	-3.0	638.2	66.0	195.0	197.0	-1411.9	-39.2	682.0	642.8	641.8
1937	2003	65.0	339.0	404.0	592.7	43.8	493.0	.0	639.8	.0	-4.0	635.8	55.9	-188.6	-112.0	-1488.5	-41.3	678.0	636.7	639.7
1938	2004	65.1	324.0	389.1	570.1	41.8	485.0	2.0	635.7	.0	-1.0	632.7	43.3	-181.0	-110.0	-1559.5	-43.3	674.0	630.7	633.7
1939	2005	65.7	155.0	220.7	607.8	35.1	557.0	-1.0	624.7	.0	-3.0	622.7	15.6	-387.1	-180.0	-1766.6	-49.1	668.0	618.9	624.6
1940	2006	68.0	233.0	301.0	501.5	29.5	472.0	-8.0	610.8	.0	-6.0	612.8	.0	-200.5	-79.0	-1888.1	-52.4	671.0	618.6	610.7
1941	2007	64.6	682.0	746.6	500.2	31.1	456.0	3.0	623.7	.0	1.0	621.7	13.1	246.4	240.0	-1881.7	-52.3	677.0	624.7	621.0
1942	2008	65.3	413.0	478.3	551.4	35.1	496.0	-1.0	624.0	.0	-2.0	623.6	18.3	-73.2	-41.0	-1913.8	-53.2	680.0	626.8	625.6
1943	2009	62.4	212.0	274.4	556.3	31.1	512.0	-1.0	619.1	.0	1.0	621.8	13.2	-281.9	-205.0	-1990.8	-55.3	669.0	613.7	620.3
1944	2010	62.3	439.0	501.3	520.0	28.2	480.0	.0	617.[illegible]	.0	4.0	621.3	11.8	-18.7	25.0	-2034.5	-56.5	676.0	619.5	616.6
1945	2011	56.6	437.0	495.6	554.6	27.7	517.0	1.0	617.0	.0	4.0	620.6	9.9	-59.0	-22.0	-2071.5	-57.5	673.0	615.5	617.5
1946	2012	55.2	426.0	481.2	514.2	28.4	479.0	-3.0	614.[illegible]	.0	2.0	619.5	6.8	-33.1	-15.0	-2089.6	-58.0	679.0	621.0	618.2
1947	2013	52.2	310.0	362.2	607.3	25.7	581.0	-1.0	613.[illegible]	.0	3.0	617.2	.6	-245.1	-140.0	-2194.7	-61.0	668.0	607.0	614.0

Table I
Sheet 3 of 4

STUDY I CYCLE IV

UVALDE POOL

(1)	(2)	(3)	(4)	(5)	(6)	(7)	LEONA SPRINGS (8)	(9)	(10)	INFLOWS - OUTFLOWS (11)	(12)	(13)	WELL H-4-6 END OF YEAR (14)	(15)	(16)
956												-99.0	-22.0	827.0	805.0
957	2014	156.0	92.1	198.0	55.1	37.0	8.0	813.0	.0	63.9	76.0	-111.1	-24.7	858.0	833.3
958	2015	263.0	93.2	203.9	57.2	36.0	4.0	837.3	.0	169.8	183.0	-124.3	-27.6	884.0	856.4
959	2016	158.0	96.5	207.3	58.5	38.0	.0	856.4	.0	61.5	33.0	-95.8	-21.3	891.0	869.7
960	2017	131.0	122.7	227.7	65.9	54.0	-1.0	868.7	2.9	8.3	-7.0	-80.5	-17.9	891.0	873.1
961	2018	135.0	119.3	231.4	67.2	47.0	.0	873.1	5.1	15.7	-6.0	-56.8	-13.1	892.0	878.9
962	2019	56.0	137.5	243.3	71.6	60.0	-4.0	874.9	6.0	-81.5	-62.0	-78.3	-17.4	882.0	864.6
963	2020	42.0	130.4	243.4	71.6	58.0	.0	864.6	.8	-88.4	-56.0	-110.7	-24.6	872.0	847.4
964	2021	130.0	133.0	244.4	72.0	61.0	3.0	850.4	.0	-3.0	34.0	-147.7	-32.8	877.0	844.2
965	2022	105.0	122.4	245.6	72.4	50.0	.0	844.2	.0	-17.4	8.0	-173.1	-38.5	880.0	841.5
966	2023	146.0	109.4	229.1	66.4	43.0	-1.0	840.5	.0	36.6	53.0	-189.5	-42.1	882.0	839.9
967	2024	94.0	143.8	241.3	70.8	73.0	-5.0	834.9	.0	-49.8	-23.0	-216.3	-48.1	882.0	833.9
968	2025	173.0	108.8	238.5	69.8	39.0	3.0	836.9	.0	64.2	41.0	-193.2	-42.9	885.0	842.1
969	2026	138.0	128.1	236.6	69.1	59.0	.0	842.1	.0	9.9	7.0	-190.3	-42.3	889.0	846.7
970	2027	143.0	128.2	242.3	71.2	57.0	-1.0	845.7	.0	14.8	-16.0	-159.5	-35.4	887.0	851.6

CENTRAL POOL

(18)	(19)	INFLOWS (20)	(21)	(22)	(23)	(24)	(25)	SAN ANTONIO SPRINGS (26)	(27)	(28)	COMAL SPRINGS (29)	(30)	(31)	INFLOWS - OUTFLOWS (32)	(33)	(34)	WELL 26 WATER SURFACE ELEV. (35)	(36)	(37)	(38)
																-720.0	-20.0	627.0	607.0	
1957	2014	55.1	947.0	1002.1	528.7	29.7	477.0	.0	619.0	.0	6.0	625.0	22.1	473.4	638.0	-884.6	-24.6	656.0	629.4	618.2
1958	2015	57.2	1346.0	1403.2	652.5	43.6	505.0	7.0	646.2	.0	8.0	647.2	104.0	750.7	908.0	-1042.0	-28.9	678.0	649.1	639.2
1959	2016	56.5	534.0	592.5	670.7	45.5	538.0	.0	645.2	.0	-2.0	643.2	87.2	-78.2	67.0	-1107.2	-33.0	675.0	642.0	645.5
1960	2017	65.9	663.0	728.9	682.4	44.6	562.0	-1.0	641.5	.0	-2.0	640.5	75.8	46.4	201.0	-1341.7	-37.3	679.0	641.7	641.9
1961	2018	67.2	565.0	632.2	671.3	43.5	559.0	1.0	639.9	.0	.0	638.9	68.8	-39.1	72.0	-1452.8	-40.4	676.0	635.6	638.7
1962	2019	71.6	172.0	243.6	667.1	37.6	611.0	-2.0	626.7	.0	-5.0	623.7	18.4	-423.5	-262.0	-1614.3	-44.8	666.0	621.2	628.4
1963	2020	71.6	112.0	183.6	647.2	24.2	623.0	-1.0	611.4	.0	-3.0	609.4	.0	-463.6	-276.0	-1801.9	-50.1	653.0	602.9	612.1
1964	2021	72.0	258.0	330.0	584.9	14.9	570.0	4.0	605.1	.0	.0	601.1	.0	-254.9	-97.0	-1959.8	-54.4	653.0	598.6	600.8
1965	2022	72.4	452.0	524.4	557.9	17.9	540.0	2.0	606.8	.0	5.0	609.8	.0	-33.5	44.0	-2037.3	-56.6	669.0	612.4	605.5
1966	2023	66.4	399.0	465.4	546.5	16.5	526.0	-3.0	602.5	.0	4.0	609.5	.0	-81.1	-16.0	-2102.4	-58.4	657.0	596.6	605.5
1967	2024	70.8	353.0	423.8	701.9	11.9	690.0	1.0	598.5	.0	-6.0	591.5	.0	-278.1	-55.0	-2325.6	-64.6	660.0	595.4	597.0
1968	2025	69.8	688.0	757.8	526.0	14.0	512.0	10.0	610.0	.0	11.0	611.0	.0	231.8	230.0	-2323.7	-64.5	670.0	605.5	600.4
1969	2026	69.1	402.0	471.1	577.6	17.6	560.0	-6.0	598.4	.0	1.0	605.4	.0	-106.5	-69.0	-2361.3	-65.6	670.0	604.4	604.9
1970	2027	71.2	504.0	575.2	619.8	14.8	605.0	.0	600.9	.0	6.0	606.9	.0	-44.6	8.0	-2413.8	-67.1	663.0	595.9	600.2

Table I
Sheet 4 of 4

STUDY II CYCLE I

U V A L D E P O O L

(1)	(2)	(3) Recharge	(4) E. out	(5) S. elev.	(6) V. out	(7) Well	(8) LEONA SPRINGS	(9)	(10)	(11) INFLOWS - OUTFLOWS	(12)	(13)	(14) WELL H-4-6 END OF YEAR	(15)	(16)
1956												288.0	64.0	827.0	891.0
1957	1972	[1] 136.0	129.0	217.0	62.0	28.0	8.0	894.0	39.1	7.0	76.0	219.0	48.7	858.0	894.0
1958	1973	[1] 230.0	126.1	209.0	59.1	28.0	4.0	894.0	39.1	103.9	183.0	139.8	31.1	884.0	894.0
1959	1974	124.0	129.1	209.0	59.1	31.0	.0	894.0	39.1	-5.1	33.0	101.7	22.6	891.0	894.0
1960	1975	100.0	139.8	209.0	59.1	44.0	-1.0	893.0	36.7	-39.8	-7.0	68.9	15.3	891.0	894.0
1961	1976	101.0	137.1	204.0	59.1	39.0	.0	894.0	39.1	-36.1	-6.0	30.8	8.6	892.0	894.0
1962	1977	49.0	138.9	209.0	59.1	50.0	-4.0	890.0	29.8	-89.9	-62.0	10.9	2.4	882.0	884.4
1963	1978	42.0	125.0	206.2	58.1	50.0	.0	884.4	16.9	-83.0	-56.0	-16.1	-3.6	872.0	868.4
1964	1979	130.0	115.8	207.5	58.5	53.0	3.0	871.4	4.2	14.2	34.0	-35.9	-8.0	877.0	869.0
1965	1980	105.0	106.0	211.6	60.0	43.0	.0	869.0	3.0	-1.0	8.0	-44.9	-10.0	880.0	870.0
1966	1981	146.0	95.5	199.2	55.5	37.0	-1.0	869.0	3.0	50.5	53.0	-47.5	-10.5	882.0	871.5
1967	1982	94.0	128.0	215.0	61.3	65.0	-5.0	866.5	1.7	-34.0	-23.0	-58.4	-13.0	882.0	869.0
1968	1983	173.0	98.8	212.2	60.2	34.0	3.0	872.0	4.5	74.2	41.0	-25.2	-5.6	885.0	879.4
1969	1984	138.0	122.1	214.0	60.9	53.0	.0	879.4	8.2	15.9	7.0	-16.3	-3.6	889.0	885.4
1970	1985	(138.0) 118	132.2	220.9	63.4	52.0	-1.0	884.4	16.8	5.8	-16.0	5.5	1.2	887.0	888.2

C E N T R A L P O O L

(18)	(19)	(20) INFLOWS	(21)	(22)	(23)	(24)	(25)	(26) SAN ANTONIO SPRINGS	(27)	(28)	(29) COMAL SPRINGS	(30)	(31)
1957	1972	62.0	947.0	1009.0	651.0	56.3	273.0	.0	680.0	58.5	6.0	685.0	263.3
1958	1973	59.1	1346.0	1405.1	702.9	57.7	283.0	7.0	685.0	99.0	8.0	685.0	263.3
1959	1974	59.1	534.0	593.1	715.6	57.8	304.0	.0	685.0	99.0	-2.0	683.0	254.8
1960	1975	59.1	663.0	722.1	718.5	57.8	315.0	-1.0	684.0	90.9	-2.0	683.0	254.8
1961	1976	59.1	565.0	624.1	736.1	57.8	316.0	1.0	685.0	99.0	.0	685.0	263.3
1962	1977	59.1	172.0	231.1	649.9	56.9	305.0	-2.0	680.0	58.5	-5.0	677.0	229.5
1963	1978	58.1	112.0	170.1	600.9	53.0	353.0	-1.0	668.6	9.3	-3.0	666.6	185.6
1964	1979	58.5	258.0	316.5	538.0	49.9	327.0	4.0	663.5	5.2	.0	659.5	155.8
1965	1980	60.0	452.0	512.0	562.7	51.0	313.0	2.0	665.1	6.5	5.0	668.1	192.2
1966	1981	55.5	399.0	454.5	553.6	51.3	307.0	-3.0	661.1	3.3	4.0	668.1	192.0
1967	1982	61.3	353.0	414.3	565.9	49.0	398.0	1.0	657.6	.5	-6.0	650.6	118.4
1968	1983	60.2	688.0	746.2	570.1	50.3	302.0	10.0	670.6	10.9	11.0	671.6	206.9
1969	1984	60.9	402.0	462.9	562.4	51.3	331.0	-6.0	658.1	.9	1.0	665.1	179.2
1970	1985	63.4	504.0	567.4	598.6	50.3	358.0	.0	660.9	3.1	6.0	666.9	187.1

C E N T R A L P O O L

(18)	(32) INFLOWS - OUTFLOWS	(33)	(34)	(35) WELL 26 WATER SURFACE ELEV.	(36)	(37)	(38)
1956			1692.0	47.0	627.0	674.0	
1957	357.9	636.0	1411.9	39.2	654.0	665.0	679.5
1958	702.2	908.0	1206.1	33.5	678.0	685.0	685.0
1959	-122.6	67.0	1016.5	28.2	675.0	685.0	685.0
1960	3.5	201.0	819.1	22.8	679.0	685.0	685.0
1961	-112.0	72.0	635.1	17.6	676.0	685.0	685.0
1962	-458.9	-262.0	438.2	12.2	666.0	670.2	681.[illegible]
1963	-430.9	-276.0	283.4	7.9	653.0	660.9	669.5
1964	-221.4	-97.0	158.9	4.4	653.0	657.4	659.1
1965	-50.7	44.0	64.2	1.8	669.0	670.8	664.[illegible]
1966	-99.1	-16.0	-18.9	-.5	657.0	656.5	663.[illegible]
1967	-151.6	-55.0	-115.5	-3.2	660.0	658.8	656.[illegible]
1968	178.2	230.0	-167.3	-4.6	670.0	665.4	661.[illegible]
1969	-99.5	-69.0	-197.8	-5.5	670.0	664.5	664.[illegible]
1970	-31.2	8.0	-237.0	-6.6	663.0	656.4	660.[illegible]

[1] Elev. of H-4-6 at beginning of 1957 and 1958 above 883

Table II
Sheet I of 4

UVALDE POOL

							LEONA SPRINGS			INFLOWS - OUTFLOWS			WELL M-4-6 END OF YEAR		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1933												9.9	2.2	886.0	888.2
1934	1986	12.0	150.1	231.8	67.4	64.0	-3.0	885.2	18.[illegible]	-138.1	-70.0	-58.2	-12.9	877.0	864.1
1935	1987	225.0	98.1	215.9	61.6	33.0	6.0	870.1	3.5	126.9	125.0	-56.3	-12.5	890.0	877.5
1936	1988	171.0	114.4	218.7	62.6	45.0	-1.0	876.5	6.[illegible]	56.6	51.0	-50.7	-11.3	890.0	878.7
1937	1989	81.0	130.4	218.4	62.5	60.0	.0	878.7	7.[illegible]	-49.4	-35.0	-65.1	-14.5	887.0	872.5
1938	1990	94.0	128.7	218.2	62.4	61.0	1.0	873.5	5.1	-34.7	-19.0	-80.8	-17.9	886.0	868.1
1939	1991	131.0	120.5	219.7	63.0	55.0	.0	868.1	2.5	10.5	34.0	-104.3	-23.2	886.0	862.8
1940	1992	59.0	101.1	225.5	65.1	36.0	-2.0	860.8	.1	-42.1	-29.0	-117.4	-26.1	880.0	853.9
1941	1993	124.0	93.8	216.4	61.8	32.0	5.0	858.9	.1	30.2	26.0	-113.1	-25.1	888.0	862.9
1942	1994	130.0	120.9	219.4	62.9	58.0	-1.0	861.9	.1	9.1	27.0	-131.0	-29.1	887.0	857.9
1943	1995	43.0	113.2	212.2	60.2	53.0	-1.0	856.9	.1	-70.2	-44.0	-157.2	-34.9	880.0	845.1
1944	1996	74.0	90.3	212.3	60.3	38.0	1.0	846.1	.1	-24.3	-3.0	-178.5	-39.7	881.0	841.3
1945	1997	56.0	103.8	202.8	56.8	47.0	1.0	842.3	.1	-47.8	-22.0	-204.3	-45.4	874.0	828.6
1946	1998	88.0	98.6	193.9	55.6	45.0	1.0	829.6	.1	-10.6	18.0	-232.9	-51.8	878.0	826.2
1947	1999	83.0	101.7	186.1	50.7	51.0	5.0	831.2	.1	-18.7	7.0	-258.7	-57.5	878.0	820.5

CENTRAL POOL

		INFLOWS						SAN ANTONIO SPRINGS			COMAL SPRINGS			INFLOWS - OUTFLOWS			WELL 26 WATER SURFACE ELEV.			
(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)
																-561.6	-15.6	672.0	656.4	
1934	1986	67.4	148.0	215.4	586.2	47.9	410.0	.0	653.0	.0	.0	653.0	128.3	-370.9	-181.0	-751.5	-20.9	664.0	646.1	652.3
1935	1987	61.6	781.0	842.6	479.0	46.0	310.0	3.0	656.3	.0	-2.0	651.3	121.0	363.6	377.0	-764.8	-21.2	680.0	658.8	653.4
1936	1988	62.6	670.0	732.6	550.5	49.9	355.0	1.0	660.4	2.8	-3.0	656.4	142.9	182.1	197.0	-779.7	-21.7	682.0	660.3	659.5
1937	1989	62.5	339.0	401.5	586.4	44.3	406.0	.0	657.5	.4	-4.0	653.5	130.7	-184.9	-112.0	-852.6	-23.7	678.0	654.3	657.3
1938	1990	62.4	324.0	386.4	566.4	47.4	402.0	2.0	653.3	.0	-1.0	650.3	117.1	-180.0	-110.0	-922.6	-25.6	674.0	646.4	651.3
1939	1991	63.0	155.0	218.0	540.9	44.9	461.0	-1.0	642.3	.0	-3.0	640.3	75.0	-362.9	-180.0	-1105.5	-30.7	665.0	637.3	642.6
1940	1992	65.1	233.0	298.1	478.0	43.2	394.0	-8.0	629.8	.0	-6.0	631.8	40.8	-179.9	-79.0	-1206.4	-33.5	671.0	637.5	637.4
1941	1993	61.8	682.0	743.8	504.4	44.0	381.0	3.0	643.4	.0	1.0	641.4	79.4	239.4	240.0	-1207.0	-33.5	677.0	643.5	640.5
1942	1994	62.9	413.0	475.9	544.2	45.2	415.0	-1.0	643.5	.0	-2.0	642.5	84.0	-68.4	-41.0	-1234.4	-34.3	680.0	645.7	644.6
1943	1995	60.2	212.0	272.2	547.7	43.7	428.0	-1.0	638.6	.0	1.0	640.6	76.0	-275.5	-205.0	-1304.9	-36.2	669.0	632.8	639.2
1944	1996	60.3	439.0	499.3	519.2	42.7	402.0	.0	636.2	.0	4.0	640.2	74.5	-19.9	25.0	-1349.8	-37.5	676.0	636.5	635.6
1945	1997	56.8	437.0	493.8	546.5	42.5	432.0	1.0	636.6	.0	4.0	639.6	72.0	-52.6	-22.0	-1380.4	-38.3	673.0	634.7	636.6
1946	1998	53.6	426.0	479.6	512.3	42.8	402.0	-3.0	633.6	.0	2.0	638.6	67.6	-32.7	-15.0	-1398.2	-38.8	679.0	640.2	637.4
1947	1999	50.7	310.0	360.7	586.9	41.5	487.0	-1.0	632.4	.0	3.0	636.4	58.4	-226.2	-140.0	-1484.4	-41.2	668.0	626.8	633.5

STUDY II CYCLE III

U V A L D E   P O O L

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) LEONA SPRINGS	(9) LEONA SPRINGS	(10) LEONA SPRINGS	(11) INFLOWS - OUTFLOWS	(12) INFLOWS - OUTFLOWS	(13) INFLOWS - OUTFLOWS	(14) WELL H-4-6 END OF YEAR	(15) WELL H-4-6 END OF YEAR	(16) WELL H-4-6 END OF YEAR
1956												-29.2	-6.5	827.0	820.5
1957	2000	156.0	90.5	193.7	53.5	37.0	8.0	828.5	.0	65.5	76.0	-39.7	-8.8	858.0	849.2
1958	2001	263.0	91.9	200.4	55.9	36.0	4.0	853.2	.0	171.1	183.0	-51.6	-11.5	884.0	872.5
1959	2002	158.0	100.2	204.4	57.4	38.0	.0	872.5	4.8	57.8	33.0	-26.8	-6.0	891.0	885.0
1960	2003	100.0	134.7	224.2	64.6	54.0	-1.0	884.0	16.1	-34.7	-7.0	-54.5	-12.1	891.0	878.9
1961	2004	135.0	117.4	218.3	62.5	47.0	.0	878.9	7.9	17.6	-6.0	-30.9	-6.9	892.0	885.1
1962	2005	49.0	136.4	230.8	67.0	60.0	-4.0	881.1	9.4	-87.4	-62.0	-56.3	-12.5	882.0	869.5
1963	2006	42.0	127.7	229.2	66.4	58.0	.0	869.5	3.2	-85.7	-56.0	-85.9	-19.1	872.0	852.9
1964	2007	130.0	127.6	229.7	66.6	61.0	3.0	855.9	.0	2.4	34.0	-117.5	-26.1	877.0	850.9
1965	2008	105.0	115.9	230.6	66.9	49.0	.0	850.9	.0	-10.9	8.0	-136.4	-30.3	880.0	849.7
1966	2009	146.0	103.3	215.0	61.3	42.0	-1.0	848.7	.0	42.7	53.0	-146.7	-32.6	882.0	849.4
1967	2010	94.0	138.0	228.1	66.0	72.0	-5.0	844.4	.0	-44.0	-23.0	-167.7	-37.3	882.0	834.7
1968	2011	173.0	102.7	224.5	64.7	38.0	3.0	847.7	.0	70.3	41.0	-138.5	-30.8	885.0	854.2
1969	2012	138.0	122.6	224.2	64.6	58.0	.0	854.2	.0	15.4	7.0	-130.1	-28.9	889.0	860.1
1970	2013	143.0	122.9	230.5	66.9	56.0	-1.0	859.1	.0	20.1	-16.0	-94.0	-20.9	887.0	866.1

C E N T R A L   P O O L

(18)	(19)	(20) INFLOWS	(21) INFLOWS	(22) INFLOWS	(23)	(24)	(25)	(26) SAN ANTONIO SPRINGS	(27) SAN ANTONIO SPRINGS	(28) SAN ANTONIO SPRINGS	(29) COMAL SPRINGS	(30) COMAL SPRINGS	(31) COMAL SPRINGS	(32) INFLOWS - OUTFLOWS	(33) INFLOWS - OUTFLOWS	(34) INFLOWS - OUTFLOWS	(35) WELL 26 WATER SURFACE ELEV.	(36) WELL 26 WATER SURFACE ELEV.	(37) WELL 26 WATER SURFACE ELEV.	(38) WELL 26 WATER SURFACE ELEV.
																-7.2	-.2	627.0	626.8	
1957	2000	53.5	947.0	1000.5	541.6	43.2	408.0	.0	638.0	.0	6.0	644.0	90.4	458.9	638.0	-186.3	-5.2	654.0	648.8	637.
1958	2001	55.9	1346.0	1401.9	662.0	49.4	424.0	7.0	664.8	6.2	8.0	665.8	182.4	739.9	908.0	-354.4	-9.8	678.0	668.2	656.
1959	2002	57.4	534.0	591.4	678.8	51.5	453.0	.0	664.5	6.0	-2.0	662.5	168.4	-87.4	67.0	-508.8	-14.1	675.0	660.9	664.
1960	2003	64.6	663.0	727.6	681.1	50.5	472.0	-1.0	660.5	2.8	-2.0	659.5	155.8	46.5	201.0	-663.3	-18.4	679.0	660.6	660.
1961	2004	62.5	565.0	627.5	671.0	49.4	472.0	1.0	658.7	1.4	.0	657.7	148.2	-43.5	72.0	-778.6	-21.6	670.0	654.4	657.
1962	2005	67.0	172.0	239.0	646.1	46.2	516.0	-2.0	645.5	.0	-5.0	642.5	84.0	-407.1	-262.0	-924.0	-25.7	666.0	640.3	647.
1963	2006	66.4	112.0	176.4	601.7	40.7	527.0	-1.0	631.3	.0	-3.0	629.3	34.0	-423.3	-276.0	-1071.2	-29.8	653.0	623.2	631.
1964	2007	66.6	258.0	324.6	527.2	32.0	482.0	4.0	625.8	.0	.0	621.8	13.2	-202.6	-97.0	-1176.8	-32.7	653.0	620.3	621.
1965	2008	66.9	452.0	518.9	534.8	36.1	458.0	2.0	628.8	.0	5.0	631.8	40.7	-15.8	44.0	-1236.6	-34.4	669.0	634.0	627.
1966	2009	61.3	399.0	460.3	525.5	36.6	449.0	-3.0	624.5	.0	4.0	631.5	39.9	-65.2	-16.0	-1285.9	-35.7	657.0	621.3	626.
1967	2010	66.0	353.0	419.0	620.3	31.3	589.0	1.0	622.0	.0	-6.0	615.0	.0	-201.2	-55.0	-1432.1	-39.8	660.0	620.2	620.
1968	2011	64.7	688.0	752.7	528.0	34.4	438.0	10.0	634.8	.0	11.0	635.8	55.6	224.7	230.0	-1437.4	-39.9	670.0	630.1	625.
1969	2012	64.6	402.0	466.6	553.2	38.0	479.0	-6.0	623.1	.0	1.0	630.1	36.2	-86.6	-69.0	-1455.0	-40.4	670.0	624.6	629.
1970	2013	66.9	504.0	570.9	595.1	35.3	519.0	.0	625.8	.0	6.0	631.8	40.8	-24.2	8.0	-1487.2	-41.3	663.0	621.7	625.

Table II
Sheet 3 of 4

STUDY II CYCLE IV

U V A L D E P O O L

(1)	(2)	(3)	(4)	(5)	(6)	(7)	LEONA SPRINGS (8)	LEONA SPRINGS (9)	LEONA SPRINGS (10)	INFLOWS - OUTFLOWS (11)	INFLOWS - OUTFLOWS (12)	INFLOWS - OUTFLOWS (13)	WELL H-4-6 END OF YEAR (14)	WELL H-4-6 END OF YEAR (15)	WELL H-4-6 END OF YEAR (16)
1933												-89.6	-19.9	886.0	866.1
1934	2014	[illegible]	140.0	284.4	72.0	68.0	-3.0	863.1	.0	-128.0	-70.0	-147.6	-32.8	877.0	844.2
1935	2015	225.0	102.4	231.8	67.4	35.0	6.0	850.2	.0	122.6	125.0	-150.0	-33.3	890.0	856.7
1936	2016	171.5	114.9	233.3	67.9	47.0	-1.0	855.7	.0	56.1	51.0	-144.9	-32.2	890.0	857.8
1937	2017	[illegible]	129.8	232.8	67.8	62.0	.0	857.8	.0	-48.8	-35.0	-158.7	-35.3	887.0	851.7
1938	2018	[illegible]	130.0	233.6	68.0	62.0	1.0	852.7	.0	-36.0	-19.0	-175.7	-39.0	886.0	847.0
1939	2019	[illegible]	124.8	235.6	68.8	56.0	.0	847.0	.0	6.2	34.0	-203.5	-45.2	886.0	840.8
1940	2020	[illegible]	108.5	243.1	71.5	37.0	-2.0	838.8	.0	-49.5	-29.0	-224.0	-49.8	880.0	830.2
1941	2021	[illegible]	101.4	234.7	68.4	33.0	5.0	835.2	.0	22.6	26.0	-227.4	-50.5	888.0	837.5
1942	2022	[illegible]	129.3	237.1	69.3	60.0	-1.0	836.5	.0	.7	27.0	-253.7	-56.4	887.0	830.6
1943	2023	[illegible]	121.5	229.4	66.5	55.0	-1.0	829.6	.0	-78.5	-44.0	-288.2	-64.0	880.0	816.0
1944	2024	74.0	106.5	229.3	66.5	40.0	1.0	817.0	.0	-32.5	-3.0	-317.6	-70.6	881.0	810.4
1945	2025	56.0	111.8	219.1	62.8	49.0	1.0	811.4	.0	-55.8	-22.0	-351.4	-78.1	874.0	795.9
1946	2026	[illegible]	105.5	210.1	59.5	46.0	1.0	796.9	.0	-17.5	18.0	-386.9	-86.0	878.0	792.0
1947	2027	[illegible]	108.5	201.9	56.5	52.0	5.0	797.0	.0	-25.5	7.0	-419.4	-93.2	878.0	784.8

C E N T R A L P O O L

(18)	(19)	INFLOWS (20)	INFLOWS (21)	INFLOWS (22)	(23)	(24)	(25)	SAN ANTONIO SPRINGS (26)	SAN ANTONIO SPRINGS (27)	SAN ANTONIO SPRINGS (28)	COMAL SPRINGS (29)	COMAL SPRINGS (30)	COMAL SPRINGS (31)
1934	2014	[illegible]	144.0	220.0	629.6	28.8	598.0	.0	618.0	.0	.0	618.0	2.8
1935	2015	67.4	781.0	848.4	472.0	28.0	444.0	3.0	620.0	.0	-2.0	615.0	.0
1936	2016	67.9	670.0	737.9	555.3	33.7	511.0	1.0	624.9	.0	-3.0	620.9	10.7
1937	2017	[illegible]	339.0	406.8	621.5	32.3	586.0	.0	622.2	.0	-4.0	618.2	3.2
1938	2018	[illegible]	324.0	392.0	601.8	26.8	575.0	2.0	617.5	.0	-1.0	614.5	.0
1939	2019	[illegible]	155.0	223.6	678.9	17.9	661.0	-1.0	603.7	.0	-3.0	601.7	.0
1940	2020	71.5	233.0	304.5	569.9	11.9	558.0	-8.0	569.5	.0	-6.0	591.5	.0
1941	2021	[illegible]	682.0	750.4	550.0	12.0	538.0	3.0	600.6	.0	1.0	598.6	.0
1942	2022	[illegible]	413.0	482.3	601.0	14.0	587.0	-1.0	599.0	.0	-2.0	598.0	.0
1943	2023	[illegible]	212.0	278.5	611.7	9.7	602.0	-1.0	593.8	.0	1.0	595.8	.0
1944	2024	[illegible]	439.0	505.5	566.7	5.7	561.0	.0	590.0	.0	4.0	594.0	.0
1945	2025	[illegible]	437.0	499.8	609.9	4.9	605.0	1.0	590.0	.0	4.0	593.0	.0
1946	2026	59.5	426.0	485.5	563.6	4.6	559.0	-3.0	585.6	.0	2.0	590.6	.0
1947	2027	56.5	310.0	366.5	679.0	.0	679.0	-1.0	582.0	.0	3.0	586.0	.0

C E N T R A L P O O L

(18)	INFLOWS - OUTFLOWS (32)	INFLOWS - OUTFLOWS (33)	INFLOWS - OUTFLOWS (34)	WELL 26 WATER SURFACE ELEV. (35)	WELL 26 WATER SURFACE ELEV. (36)	WELL 26 WATER SURFACE ELEV. (37)	WELL 26 WATER SURFACE ELEV. (38)
			-1810.0	-50.3	672.0	621.7	
1934	-409.7	-181.0	-2038.7	-56.6	669.0	612.4	617.0
1935	376.3	377.0	-2039.3	-56.6	680.0	623.4	617.9
1936	182.6	197.0	-2053.7	-57.0	682.0	625.0	624.2
1937	-214.7	-112.0	-2156.4	-59.9	678.0	618.1	621.5
1938	-209.7	-110.0	-2256.2	-62.7	674.0	611.3	614.7
1939	-455.1	-180.0	-2531.3	-70.3	668.0	597.7	604.5
1940	-265.5	-79.0	-2717.8	-75.5	671.0	595.5	[illegible]
1941	200.4	240.0	-2757.3	-76.6	677.0	600.4	596.0
1942	-118.7	-41.0	-2835.0	-78.8	680.0	601.2	600.8
1943	-333.2	-205.0	-2963.3	-82.3	669.0	586.7	[illegible]
1944	-61.3	25.0	-3049.6	-84.7	676.0	591.3	589.0
1945	-110.2	-22.0	-3137.7	-87.2	673.0	585.6	586.6
1946	-78.1	-15.0	-3200.8	-88.9	679.0	590.1	586.0
1947	-312.5	-140.0	-3373.3	-93.7	668.0	574.3	582.2

Table II
Sheet 4 of 4

STUDY IB

UVALDE POOL

							LEONA SPRINGS			INFLOWS - OUTFLOWS			WELL H-4-6 END OF YEAR		
1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
947												-186.1	-41.4	878.0	836.6
948	1986	44.0	105.5	193.7	53.5	52.0	-1.0	835.6	.0	-61.5	-31.0	-216.6	-48.1	871.0	822.9
949	1987	187.0	86.1	192.7	53.1	33.0	10.0	832.9	.0	100.9	98.0	-213.7	-47.5	885.0	837.5
950	1988	46.0	101.7	202.4	56.7	45.0	-3.0	834.5	.0	-55.7	-41.0	-228.4	-50.6	873.0	822.2
951	1989	21.0	112.5	196.5	54.5	58.0	-4.0	818.2	.0	-91.5	-60.0	-259.9	-57.8	859.0	801.2
952	1990	29.0	105.4	187.8	51.4	54.0	.0	801.2	.0	-76.4	-51.0	-285.3	-63.4	845.0	781.6
953	1991	42.0	111.7	166.9	43.7	68.0	.0	781.6	.0	-69.7	-34.0	-321.0	-71.3	844.0	772.7
954	1992	63.0	96.9	164.6	42.9	54.0	.0	772.7	.0	-33.9	-14.0	-340.9	-75.8	846.0	770.2
955	1993	132.0	101.8	175.2	46.8	55.0	.0	770.2	.0	30.2	50.0	-360.7	-80.2	850.0	769.8
956	1994	16.0	127.2	184.6	50.2	77.0	.0	769.8	.0	-111.2	-89.0	-382.9	-85.1	827.0	741.9

CENTRAL POOL

		INFLOWS						SAN ANTONIO SPRINGS			COMAL SPRINGS		
(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
1948	1986	53.5	121.0	174.5	507.2	42.9	395.0	-2.0	635.0	.0	2.0	639.0	69.3
1949	1987	53.1	308.0	361.1	458.3	41.6	345.0	-2.0	631.6	.0	6.0	639.6	71.7
1950	1988	56.7	138.0	194.7	463.7	39.3	384.0	-2.0	628.7	.0	1.0	631.7	40.4
1951	1989	54.5	106.0	160.5	467.2	30.9	424.0	.0	620.5	.0	1.0	621.5	12.3
1952	1990	51.4	225.0	276.4	462.0	26.0	436.0	.0	614.6	.0	.0	614.6	.0
1953	1991	43.7	118.0	161.7	479.0	24.0	455.0	.0	612.1	.0	1.0	613.1	.0
1954	1992	42.9	87.0	129.9	500.0	16.0	484.0	.0	602.4	.0	-1.0	601.4	.0
1955	1993	46.8	50.0	96.8	471.2	6.2	465.0	.0	590.6	.0	-1.0	589.6	.0
1956	1994	50.2	20.0	70.2	545.2	-.8	546.0	.0	581.1	.0	-4.0	577.1	.0

CENTRAL POOL

	INFLOWS - OUTFLOWS			WELL 26 WATER SURFACE ELEV.			
(18)	(32)	(33)	(34)	(35)	(36)	(37)	(38)
			-901.8	-25.1	668.0	642.9	
1948	-332.7	-234.0	-1000.5	-27.8	658.0	630.2	636.6
1949	-97.2	-59.0	-1038.7	-28.9	664.0	635.1	632.7
1950	-269.0	-220.0	-1087.7	-30.2	656.0	625.8	630.5
1951	-306.7	-222.0	-1172.4	-32.6	646.0	613.4	619.0
1952	-185.7	-89.0	-1269.1	-35.3	650.0	614.7	616.1
1953	-317.2	-221.0	-1365.3	-37.9	646.0	606.1	611.4
1954	-370.1	-226.0	-1509.4	-41.9	637.0	595.1	601.6
1955	-374.5	-236.0	-1647.9	-45.8	631.0	585.2	590.1
1956	-475.0	-238.0	-1864.9	-51.8	627.0	575.2	580.2

Table III
Sheet 1 of 3

STUDY IC

(1)	(2)	(3)	(4)	(5)	(6)	(7)	LEONA SPRINGS (8)	(9)	(10)	INFLOWS - OUTFLOWS (11)	(12)	(13)	WELL H-4-6 END OF YEAR (14)	(15)	(16)
947												-328.5	-73.0	878.0	805.0
948	2014	44.0	110.1	198.0	55.1	55.0	-1.0	804.0	.0	-66.1	-31.0	-363.6	-80.8	871.0	790.2
949	2015	187.0	91.1	198.1	55.1	36.0	10.0	800.2	.0	95.9	98.0	-365.7	-81.3	885.0	803.7
950	2016	46.0	105.7	207.9	58.7	47.0	-3.0	800.7	.0	-59.7	-41.0	-384.3	-85.4	873.0	787.6
951	2017	21.0	117.1	203.6	57.1	60.0	-4.0	783.6	.0	-96.1	-60.0	-420.4	-93.4	859.0	765.6
952	2018	29.0	109.9	197.6	54.9	55.0	.0	765.6	.0	-80.9	-51.0	-450.4	-100.1	845.0	744.9
953	2019	42.0	117.4	179.7	48.4	69.0	.0	744.9	.0	-75.4	-34.0	-491.8	-109.3	844.0	734.7
954	2020	63.0	103.7	180.5	48.7	55.0	.0	734.7	.0	-40.7	-14.0	-518.5	-115.2	846.0	730.8
955	2021	132.0	109.7	194.2	53.7	56.0	.0	730.8	.0	22.3	50.0	-546.2	-121.4	850.0	728.6
956	2022	16.0	137.1	206.2	58.1	79.0	.0	728.6	.0	-121.1	-89.0	-578.2	-128.5	827.0	698.5

UVALDE POOL

CENTRAL POOL

(18)	(19)	INFLOWS (20)	(21)	(22)	(23)	(24)	(25)	SAN ANTONIO SPRINGS (26)	(27)	(28)	COMAL SPRINGS (29)	(30)	(31)
1948	2014	55.1	121.0	176.1	587.0	14.0	573.0	-2.0	598.0	.0	2.0	602.0	.0
1949	2015	55.1	308.0	363.1	502.5	9.5	493.0	-2.0	592.6	.0	6.0	600.6	.0
1950	2016	58.7	138.0	196.7	556.8	5.8	551.0	-2.0	588.0	.0	1.0	591.0	.0
1951	2017	57.1	106.0	163.1	602.4	-2.6	605.0	.0	576.9	.0	1.0	577.9	.0
1952	2018	54.9	225.0	279.9	612.2	-6.8	619.0	.0	567.0	.0	.0	567.0	.0
1953	2019	48.4	118.0	166.4	638.4	-9.6	648.0	.0	560.6	.0	1.0	561.6	.0
1954	2020	48.7	87.0	135.7	672.1	-15.9	688.0	.0	545.7	.0	-1.0	544.7	.0
1955	2021	53.7	50.0	103.7	634.5	-22.5	657.0	.0	530.4	.0	-1.0	529.4	.0
1956	2022	58.1	20.0	78.1	743.1	-28.9	772.0	.0	515.5	.0	-4.0	511.5	.0

CENTRAL POOL

(18)	INFLOWS - OUTFLOWS (32)	(33)	(34)	WELL 26 (35)	WATER SURFACE ELEV. (36)	(37)	(38)
			-2194.7	-61.0	668.0	607.0	
1948	-410.9	-234.0	-2371.6	-65.9	658.0	592.1	599.6
1949	-139.4	-59.0	-2452.0	-68.1	664.0	595.9	594.5
1950	-360.1	-220.0	-2592.1	-72.0	656.0	584.0	589.9
1951	-439.3	-222.0	-2809.5	-78.0	666.0	568.0	576.5
1952	-332.2	-99.0	-3052.7	-84.8	650.0	565.2	566.6
1953	-472.0	-221.0	-3303.7	-91.8	646.0	554.2	559.7
1954	-536.4	-226.0	-3614.1	-100.4	637.0	536.6	545.4
1955	-530.8	-236.0	-3908.9	-108.6	631.0	522.4	529.5
1956	-665.1	-258.0	-4316.0	-119.9	627.0	507.1	514.8

Table III
Sheet 2 of 3

STUDY II B

UVALDE POOL

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) LEONA SPRINGS	(9)	(10)	(11) INFLOWS - OUTFLOWS	(12)	(13)	(14) WELL H-4-6 END OF YEAR	(15)	(16)
1947												-258.7	-57.5	878.0	820.5
1948	2000	44.0	108.5	193.7	53.5	55.0	-1.0	819.5	.0	-64.5	-31.0	-292.2	-64.9	871.0	806.1
1949	2001	187.0	89.1	192.7	53.1	36.0	10.0	816.1	.0	97.9	98.0	-292.3	-65.0	885.0	820.0
1950	2002	46.0	103.4	201.7	56.4	47.0	-3.0	817.0	.0	-57.4	-41.0	-308.8	-68.6	873.0	794.4
1951	2003	21.0	114.4	196.2	54.4	60.0	-4.0	800.4	.0	-93.4	-60.0	-342.2	-76.0	859.0	783.0
1952	2004	29.0	106.7	188.7	51.7	55.0	.0	783.0	.0	-77.7	-51.0	-368.9	-82.0	845.0	763.0
1953	2005	42.0	113.7	169.5	44.7	69.0	.0	763.0	.0	-71.7	-34.0	-406.6	-90.4	844.0	753.6
1954	2006	63.0	99.4	166.8	44.4	55.0	.0	753.6	.0	-36.4	-14.0	-429.0	-95.3	846.0	750.7
1955	2007	132.0	104.9	181.0	48.9	56.0	.0	750.7	.0	27.1	50.0	-451.9	-100.4	850.0	749.6
1956	2008	16.0	130.6	191.9	52.8	78.0	.0	749.6	.0	-114.8	-89.0	-477.8	-106.2	827.0	720.6

CENTRAL POOL

(18)	(19)	(20) INFLOWS	(21)	(22)	(23)	(24)	(25)	(26) SAN ANTONIO SPRINGS	(27)	(28)	(29) COMAL SPRINGS	(30)	(31)
1948	2000	53.5	121.0	174.5	530.9	31.3	483.0	-2.0	619.0	.0	2.0	623.0	16.6
1949	2001	53.1	308.0	361.1	456.3	27.3	417.0	-2.0	614.1	.0	6.0	622.1	14.0
1950	2002	56.4	138.0	194.4	490.4	25.4	465.0	-2.0	611.8	.0	1.0	614.8	.0
1951	2003	54.4	106.0	160.4	526.0	15.0	511.0	.0	601.3	.0	1.0	602.3	.0
1952	2004	51.7	225.0	276.7	533.2	9.2	524.0	.0	594.2	.0	.0	594.2	.0
1953	2005	44.7	118.0	162.7	553.7	5.7	548.0	.0	589.9	.0	1.0	590.9	.0
1954	2006	44.4	87.0	131.4	580.0	-2.0	582.0	.0	578.2	.0	-1.0	577.2	.0
1955	2007	46.9	50.0	96.9	549.0	-8.0	557.0	.0	564.2	.0	-1.0	563.2	.0
1956	2008	52.8	20.0	72.8	640.6	-13.4	654.0	.0	551.7	.0	-4.0	547.7	.0

CENTRAL POOL

(32) INFLOWS - OUTFLOWS	(33)	(34)	(35) WELL 26 WATER SURFACE ELEV.	(36)	(37)	(38)
		-1484.4	-41.2	668.0	626.8	
-356.3	-234.0	-1606.7	-44.6	656.0	613.4	620.
-97.1	-59.0	-1644.9	-45.7	664.0	618.3	615.
-296.0	-220.0	-1720.9	-47.8	656.0	606.2	613.
-365.6	-222.0	-1864.5	-51.8	646.0	594.2	601.
-256.5	-89.0	-2032.0	-56.4	650.0	593.6	593.
-391.0	-221.0	-2202.0	-61.2	646.0	584.8	589.
-448.5	-226.0	-2424.5	-67.3	637.0	569.7	577.
-450.1	-236.0	-2638.6	-73.3	631.0	557.7	563.
-567.8	-258.0	-2946.4	-81.9	627.0	545.1	551.

Austin, Texas
July 3, 1972

Memorandum to files

From: Chief, Hydrology Division

Subject: Effects of increased well discharge from the Edwards Underground Aquifer

The springs and the water users can be ranked according to their vulnerability to increasing well discharge. The following discussion assumes that there will be no serious deterioration in water quality even if there is a moderate amount of mining of the aquifer. It is based upon the studies summarized in my memo on the Edwards Underground Aquifer, dated June 30, 1972.

Well discharge for municipal, industrial and domestic use appears to be the item that is least vulnerable to further increases in well discharge. For many decades - well past 2020, the only major adverse effect on this use would appear to be lower piezometric water levels and resulting increases in pumping costs. Municipal and industrial users can afford to pay these costs. Even with considerably higher pumping costs, Edwards water would still be much lower in cost than alternate surface water sources, and probably much lower in cost than the treatment expense that would be involved in recirculating sewage for municipal water supply. Municipal and industrial users can afford to pay much higher pumping costs than irrigators. Thus a minor degree of aquifer mining would curtail irrigation use but not M & I use. A possible long-range problem is that nonirrigation well discharges from the aquifer might someday exceed the average recharge and create an undesirable, and over the very long term, untenable situation. During 1969, nonirrigation well discharge totalled 214,000 acre-feet. This is about 40% of average annual aquifer recharge. The 1969 value is about 110,000 acre-feet larger than the 1939 value. It is unlikely that potential 2020 demands on the aquifer, exclusive of irrigation, will exceed average recharge. Certainly they will not exceed average recharge by a substantial margin. Thus the Edwards can supply all nonirrigation well demands that are placed upon it past year 2020, even if nothing is done in the field of water development or water law.

San Marcos Springs is probably second in security against increasing well discharge. San Marcos Springs has had a continuous, uninterrupted flow historically. The smallest flow on record is 46 c.f.s. on August 15-16, 1956. The operation study for 1969 condition well discharge also shows continuous flow. The operation study for 135% of the 1969 level of well discharge indicates zero flow for San Marcos Springs in 1956 and continuous flow throughout the remainder of the period of study. So long as well discharge in Hays County is relatively small, San Marcos Springs would probably flow most of the time even if well discharge in the Uvalde pool plus Central pool modestly exceeds the combined average recharge to those pools. It appears that flow from San Marcos Springs can be maintained almost all of the time through 2020 if Cloptin Crossing Reservoir is constructed and operated as proposed in the Corps' Edwards Report to increase recharge during drought periods, and if well discharge in Hays County remains small. Small well discharge in Hays County could be maintained by lack of demand or by use of surface water by the city of San Marcos and by industrial users of large amounts of water in the vicinity, or by a law limiting well discharge in Hays County.

Irrigation use of Edwards water occupies a middle position in vulnerability to increasing well discharge. High pump lifts caused by the drop in piezometric water levels that would accompany modest mining of the Edwards could make irrigation uneconomical. Since the wells are expensive, use of wells in place would still be economical for some time after sinking new wells became uneconomical. Pumping head appears to be an important factor in the historic location of irrigation from the Edwards. Most of the irrigation is in the general vicinity of Uvalde and Castroville-San Antonio where depth to water is often less than 100 feet. In Central and western Medina County, where depth to water is often 200 feet or more, irrigation use has been relatively modest. There has been a gradual increase in irrigation in this area, however. Uvalde pool operation studies for a well discharge 35% larger than the 1969 condition well discharge indicate water levels in well H-4-6 that are 70 to 120 feet lower than historic. However, the depth to water would still be smaller than the historic depth to water in much of eastern Uvalde County and western and central Medina County. Continued irrigation from existing wells would be economical, and additional irrigation development from new wells might also be economical. If historic trends continue, this aquifer wide well discharge will be reached by about 1990. Most of the irrigable land with access to Uvalde pool water may be under irrigation before then. Table 1, which lists estimated depth to water in various wells, under various conditions, shows the depth to water is 100 feet or more greater for well I-4-4 in eastern Uvalde County and well I-4-12 in western Medina County under each condition than for the two Uvalde pool wells. Thus, irrigation from the Uvalde pool should outlast irrigation in eastern Uvalde County and western and central Medina County. If Central pool well discharge equals or exceeds average Central pool inflow, this might cause serious declines in water levels in the Uvalde pool. If historic trends in well discharge continue, this might happen about year 2000. However, a decline in irrigation or irrigation development in the more vulnerable areas of the Central pool would tend to delay this situation and slow down the growth in well discharge. Thus, irrigation in the Uvalde pool may be fairly safe to year 2020 even if there is "no development." When the 2020 M & I demands are known and the irrigation potential is better defined, a more accurate reading will be possible. Potential Montell recharge reservoir, operated to achieve its recharge objectives in the Corps report on the Edwards Underground, might improve water levels in the Uvalde pool substantially. An operation study for the Uvalde pool with Montell assumed to be in operation would indicate the extent of the water level improvement.

The other four wells listed in Table 1 are in the Central pool. Well discharge 35% larger than the 1969 level would reduce water levels by 40 to 60 feet below historic. This level of well discharge will be reached by about 1990 if present trends continue. Such increases in pumping heads would be economically significant, but not overwhelming, and would not seriously affect irrigation use or development. If well discharge gets much higher than this, water levels will be seriously affected, particularly during drought periods, and this will inhibit irrigation use or development, particularly in eastern Uvalde County and western and central Medina Counties where depth to water is greater than in eastern Medina County and western Bexar County. Reduced irrigation use or development in the more vulnerable areas will tend to slow down growth of well discharge and prolong irrigation in the more favorable areas. It appears that if nothing is done, irrigation use in central and western Medina County may not reach its full potential because of increasing depth to water. If it does reach its full potential before 2020, it may be decreasing by 2020. If Central pool well discharge equals or exceeds average Central pool inflow, irrigation will be in trouble in even the more favored locations in the Central pool. Information on 2020 M & I demands is needed before this possibility can be evaluated fully. Other factors, such as changes in farm prices and changes in tax laws could have an important effect on the economics of irrigation.

If no laws are passed limiting wells and well discharges, irrigation would be one of the main beneficiaries of surface water supply to San Antonio or recycling sewage for municipal use. Concan and Sabinal recharge reservoirs would have only a minor effect on water levels in the Central pool.

Comal Springs has been affected by historic well discharge and is very vulnerable to higher levels of well discharge. Without wells, Comal Springs would have suffered only a moderate reduction in flow during the 1948-1956 drought. Historically, Comal Springs has flowed continuously except during June 13, 1956, through November 2, 1956, when there was no flow. The operation study for 1969 condition well discharge indicates zero flow for Comal Springs in 1955 and 1956, and no flow during part of the year in 1951, 1952, 1953, 1954, 1957, 1963, and 1967. The operation study with a well discharge 35% higher than the 1969 level indicates no flow from Comal Springs during 1950-1959 inclusive and 1962-1965 inclusive, and no flow during part of the year during many other years. Continuous flow would occur during about one-third of the years. If historic trends continue, this level of well discharge will be reached by about 1990. If nothing is done, 2020 well discharges will be larger than this and the flow of Comal Springs smaller and more intermittent. To maintain the 1969 condition flow of Comal Springs, the well discharge will have to be maintained at the 1969 level. This could be accomplished by laws limiting wells and well discharges or by surface water supply to the San Antonio area adequate to supply all increases in San Antonio area demand, plus offset increases in well discharge elsewhere. This might be physically possible through 2020. Information on 2020 M & I demands and on potential irrigation development are needed. To provide a more continuous flow in Comal Springs than would occur under 1969 condition well discharge would require a reduction in well discharge below the 1969 level. This reduction in well discharge would require even more stringent laws or greater substitution of surface water for Edwards water. It is questionable whether substitution of surface water, without ground-water laws that would restrict irrigation, could reduce well discharge from the Edwards enough in 2020 to permit Comal Springs to flow continuously if the 1948-1956 drought were to recur. The main justification for ground-water law would appear to be to protect or promote the flow of Comal Springs.

Leona Springs and underflow historically had no flow during 1952-1956 inclusive, but has had some flow during all other years. The 1969 condition of well discharge operation study for the Uvalde pool indicates only a few years of flow during the 1934-1969 series. The operation study for a 35% higher well discharge than 1969 conditions indicates no discharge from Leona Springs plus underflow. The contrast between the historic situation and the 1969 condition operation study indicates that the operation studies may be overly pessimistic regarding Leona Springs. Still there is no doubt that the steady increase in well discharge from the Uvalde pool that has occurred will reduce the flow of Leona Springs plus underflow below historic levels and that in a pinch Leona Springs will fail before wells fail. Some irrigators are believed to obtain all or part of their water supply from Leona Springs plus underflow.

There does not appear to be any local advocacy of limiting irrigation use of Edwards water to improve the flow prospects for Leona Springs.

San Antonio Springs is the major spring that is most vulnerable to well discharge. Without well discharge, San Antonio Springs would flow most of the time, and the flow would be very substantial during wet years. Historically, San Antonio Springs had no flow during 1949 through 1957, 1964, and 1967. Since 1947, there have been periods of zero flow during most years. The 1969 condition operation study shows flow during only a few years, and the operation study for a well discharge 35% higher than the 1969 condition shows no flow at all from San Antonio Springs. San Antonio Springs has very little water supply value at present. It would take a drastic reduction in well discharge to produce flow from San Antonio Springs most of the time. Such action is not being advocated for the benefit of San Antonio Springs by local interests.

George Schwab

M. George Schwab

Attachment

Depth to water, various wells
(feet)

Well	Historic	1969 condition	1969 condition well discharge x 1.35
Well H-4-6. Ground elev. 951 feet			
Normal (1959-1969)	58 to 89	65 to 124	128 to 182
Maximum (1957)	126	187	244
Well H-5-1. Ground elev. 905 feet			
Normal (1959-1969)	27 to 55	34 to 90	96 to 148
Maximum (1957)	105	166	223
Well I-4-4. Ground elev. 954 feet			
Normal (1959 - 1969)	172 to 246	191 to 259	225 to 286
Maximum (1956)	289	312	349
Well I-4-12. Ground elev. 950 feet			
Normal (1959-1969)	180 to 260	199 to 273	233 to 317
Maximum (1956)	291	314	351
Well J-1-82. Ground elev. 757 feet			
Normal (1959-1969)	47 to 110	66 to 123	100 to 154
Maximum (1956)	135	158	195
Well CY-26. Ground elev. 722 feet			
Normal (1959-1969)	43 to 92	62 to 105	91 to 136
Maximum (1956)	107	130	167

United States Department of the Interior
BUREAU OF RECLAMATION
SOUTHWEST REGION
AUSTIN DEVELOPMENT OFFICE
P.O. BOX 1946
AUSTIN, TEXAS 78767

IN REPLY
REFER TO:

August 30, 1973

Mr. Nat Eisenberg
Post Office Box 280
Castroville, Texas 78009

Dear Mr. Eisenberg:

In response to your request please find enclosed a copy of a letter dated August 6, 1973 addressed to the Regional Directors of the EPA, BOR and BSFW with attachments and a copy of the Edwards Underground Aquifer map.

Sincerely

Norman G. Flaigg
Planning Officer

Enclosures

United States Department of the Interior
BUREAU OF RECLAMATION

COPY

SOUTHWEST REGION
AUSTIN DEVELOPMENT OFFICE
P.O. BOX 1946
AUSTIN, TEXAS 78767

COPY

IN REPLY
REFER TO:

August 6, 1973

To: Regional Director, Environmental Protection Agency, Dallas, Texas

Regional Director, Bureau of Outdoor Recreation Denver, Colorado

Regional Director, Bureau of Sport Fisheries and Wildlife, Albuquerque, New Mexico

From: Planning Officer

Subject: San Antonio-Guadalupe Unit - Texas Basins Project

Reference is made to my letter of February 7, 1972 and to the meeting held in San Antonio on March 29, 1972.

Basic hydrology studies have progressed to a point at which we can report some results and indicate where the studies are going in the future.

Most of the hydrology studies to date have been concerned with the Edwards Underground Reservoir. A simplified summary of the studies is presented for your information. The reservoir has been divided into three pools for convenience of discussion. The reach from the Nueces River to the Frio River has been named the Uvalde Pool; the reach from the Frio River to Comal Springs has been named the Central Pool; and the reach from Comal Springs to San Marcos Springs has been named the San Marcos Pool. Normally the Uvalde Pool contributes to the Central Pool, and the Central Pool contributes to the San Marcos Pool.

The conditions of the Edwards Underground Reservoir have been studied for the period 1934-1969. The annual figures presented in table 1 are averages for each of the three pools.

Data from table 1 indicate that there have been no major long-term ill effects on the Edwards Underground through 1969. If the 1969 demands were to be met for the entire period of study we probably would notice some long-term effects in the spring flow. We would expect that the Leona Springs in the Uvalde Pool would virtually stop flowing. San Antonio Springs would cease, and Comal Springs would be reduced from historic flow of 197,000 acre-feet per year to 109,000 acre-feet per year. San Marcos Springs would be only slightly affected, dropping from 100,000 to 90,000 acre-feet per year.

If we assume future growth in the area to a level of 135 percent of 1969 use, the spring flow would be modified even more. Only Comal Springs and San Marcos Springs would continue with the former discharging 20,000 acre-feet per year and the latter 73,000 acre-feet per year.

If we assumed another future condition wherein Uvalde Pool demands grew to 135 percent of the 1969 level and the Central and San Marcos Pool areas grew to 166 percent of 1969 use, and if San Antonio pumped the formation hard enough to intercept the spills to the San Marcos Pool, there might be no spring flow.

Population projections, prepared for use by Texas agencies, indicate that Bexar County will reach 135 percent of 1969 population by about 1990 and that the growth in water use may be enough to make the flow of Comal Springs intermittent during many years. By 2000 the use might intercept the contribution of the Central Pool to the San Marcos Pool during low run-off years. The Texas projections are about 10 percent higher than the OBERS projections for that area, so there is reasonable agreement in that respect.

This indicates that unless the use of water from the Edwards Underground is regulated, Comal Springs will be reduced to intermittent flow by about 1990, and San Marcos Springs may stop flowing during drought periods after about 2000. In order to maintain spring flow it will be necessary to furnish some of the Central Pool needs from surface water supplies.

Consultations with the river authorities, the Edwards Underground Water District, and the San Antonio City Water Board, as well as State agencies indicate that the most likely reservoirs to be developed are: Cloptin Crossing, Cibolo, Applewhite, Cuero I, Goliad, and Cuero II in the order given. Yields for these reservoirs, computed on an area basis without bypass for water rights and no spring flow or return flow from the San Antonio area, are as follows:

Reservoir	Capacity, top of conservation pool	Average yield 2010 conditions
	(1,000's of acre-feet)	
Medina	254	29 1/
Canyon	386	92
Cloptin Crossing	283	40
Cibolo	200	25
Applewhite	22	10 to 16 2/
Cuero I	1,092	151 3/
Goliad	750	137 3/
Cuero II	1,582	104

1/ Average yield of reservoir operated independently to produce a nonfirm supply.

2/ Has no independent firm yield, but can increase firm yield through association with Edwards Underground aquifer.

3/ With 1990 condition of urban runoff.

Because there has been considerable development of water resources in the study area it is necessary to make some attempt to demonstrate the effects of water rights at their current level of use and at their approximate book value. We have initiated operation studies on these reservoirs to determine their yields under various conditions. For the purpose of these studies the following direct flow water demand assumptions have been made:

Direct Flow Water Demand Assumptions

Area	Approximate current average use	Book value
	(1,000's of acre-feet)	
Victoria demand	87	215
Victoria consumptive use	17	44
Calhoun County demand	73	192

Studying the reservoir yields for two levels of water usage will bracket the span of water usage which could develop under the present rights. Yields were determined for 1969 conditions and for 1969 conditions plus 35 percent increase. Direct flow supplies and reservoir yields for various conditions are presented in table 2. The yields include appropriate spring flows and net San Antonio return flows after depletions by Lakes Braunig and Calaveras.

The yields presented in table 2 will be reviewed and refined after discussion with local interests. When final figures are developed we propose to integrate the surface water supplies and the ground water supplies in various combinations to develop management plans for various objectives, such as, the national development account, the regional development account, and the quality of environment account.

In the meantime, to properly consider the interrelationships of surface and ground water development we need your input regarding the following data for the basins:

Inventory and evaluation for the present and future without development condition.

Archeological, historical, and cultural resources

Biological resources

Geological resources

Human resources

Scenic and unique areas

Opportunities for fish and wildlife preservation and enhancement

Land for open and green space

Opportunities for preservation of natural areas

Other

Present and future capabilities of resources to support:

Wildlife

Fishery

Recreation activities

Wilderness primitive or natural areas

Needs (present and future)

Social

Environmental

Recommended management or development measures for:

M & I water supplies

Recreation

Fish and wildlife

Environmental enhancement

Social needs

We also need your recommendations concerning reservoir development. That is, whether the reservoirs listed would adequately meet the recreational, fish and wildlife, and social needs of the area. You may wish to delete or add reservoirs to those discussed.

Table 3 compares the latest TWDB population projections with those by OBERS for the San Antonio-Guadalupe River Basins. The Texas Water Development Board also has a number of unpublished reports relating to this area which may be helpful. They are:

1. San Antonio Regional Environmental Project, Land Classification Data, 1972.

2. The San Antonio Regional Environmental Study an Input-Output Model by Harry Bradley and Roy Morey, November 17, 1972.

3. Assessment of the Economic Resources of the San Antonio Regional Environmental Study area by William H. Hathaway and J. Randall Threadgill, January 31, 1973.

4. San Antonio Regional Environmental Project, Agricultural Resources, Irrigation No Constraints, June 5, 1973.

5. San Antonio Regional Environmental Project, Projected Water Requirements - Irrigation, December 14, 1972.

The Board has published its population projections in a brochure entitled "Texas Water Development Board, Population Projections, December 1972." Data are given for counties and for towns and cities. Currently the Board is working on projected M & I water requirements. These should be available by September 1973.

If you need additional data please advise me of your needs.

Norman G. Flaigg

Attachments

Table 1. EDWARDS UNDERGROUND RESERVOIR CONDITION (1,000 acre-feet)

	Historic Condition August 1934-1969 Pools			1969 Condition			Possible Future Condition 135% of 1969			Possible Future Condition with Major Development in San Antonio Area (Uvalde pool 135% and Central and San Marcos pools 166% of 1969)		
	Uvalde	Central	San Marcos	Uvalde	Central	San Marcos	Uvalde	Central	San Marcos	Uvalde	Central	San Marcos
Inflow												
Recharge	94	379	49	102	379	49	102	379	49	102	379	49
Spill fr adj. pool	-	66	53	-	59	45	-	47	30	-	86	-
Total Inflow	94	445	102	102	438	94	102	426	79	102	465	49
Outflow												
Wells												
Irrigation	10	39	-	34	71	-	46	121	1	46	145	1
Other	3	147	2	4	216	4	6	266	5	6	320	9
Springs	13	220	100	1	109	90	-	20	73	-	-	?
Spill to adj. pool	66	53	-	59	45	-	47	30	-	47	-	39
Total Overflow	92	459	102	98	441	94	99	437	79	99	465	49

Table 2. DIRECT FLOW SUPPLIES AND RESERVOIR YIELDS 1969 CONDITION
(1,000 acre-feet)

Conditions	Direct Flow Average 1948-1956: Victoria Area Demand	Victoria Area Consump.Use	Calhoun County	Reservoir Yields: Canyon Res.	Cloptin Crossing	Cibolo Res.	Applewhite	Cuero I	Goliad	Cuero II	TOTAL
Current Use	75	16	69								
Book Value	155	38	166								
No. Bypass				92	40	25	10	230	208	124	729
Current Use Bypass				88	38	25	10	186	190	102	639
Book Value Bypass				80	34	23	9	145	169	80	540
Hydro Bypass				38							
DIRECT FLOW SUPPLIES AND RESERVOIR YIELDS 135% of 1969 CONDITION											
Current Use	67	15	69								
Book Value	129	35	166								
No Bypass				92	40	25	10	186	236	108	697
Current Use Bypass				83	36	25	10	158	213	88	613
Book Value Bypass				72	32	23	9	121	177	80	514
Hydro Bypass				36							

Table 3. Population [illegible] 1972

Water Resources Sub Area 1210

	1960	1970	1980	1990	2000	2010	2020
Aransas	7,006	8,902	12,100	16,600	22,400	30,000	39,800
Bandera	3,892	4,747	5,300	5,900	6,600	7,200	7,800
Bee	23,755	22,737	25,500	28,800	31,900	35,100	38,400
Bexar	687,151	830,460	957,400	1,107,100	1,260,900	1,425,100	1,599,900
Caldwell	17,222	21,178	23,700	26,700	29,600	32,500	35,500
Calhoun	16,592	17,831	21,400	25,800	30,600	36,000	42,000
Comal	19,844	24,165	26,100	28,200	30,000	31,700	33,300
Dewitt	20,683	18,660	16,200	14,700	12,200	10,400	8,800
Goliad	5,429	4,869	4,300	3,900	3,400	2,900	2,500
Gonzales	17,845	16,375	15,300	14,300	13,100	12,000	10,900
Guadalupe	29,017	33,554	38,100	43,400	48,600	54,100	59,800
Jackson	14,040	12,975	12,600	12,300	11,800	11,300	10,700
Karnes	14,995	13,462	12,100	10,900	9,600	8,500	7,400
Kendall	5,889	6,964	7,600	8,400	9,100	9,800	10,400
Kerr	16,800	19,454	22,600	26,300	30,200	34,400	38,800
Lavaca	20,174	17,903	15,700	13,800	11,900	10,200	8,700
Refugio	10,975	9,494	9,200	8,900	8,500	8,100	7,600
Victoria	46,475	53,766	63,300	74,800	87,100	100,600	115,400
Wilson	13,267	13,041	12,700	12,400	11,900	11,400	10,800
Total	991,051	1,150,537	1,301,200	1,482,700	1,669,400	1,871,300	2,088,500
Total OBERS-WR SA-1210			1,266,600	1,411,200	1,554,100	1,711,800	1,874,000
% TWDB/OBERS			102.7	105.1	107.4	109.3	111.4

United States Department of the Interior
BUREAU OF RECLAMATION
SOUTHWEST REGION
AUSTIN DEVELOPMENT OFFICE
P.O. BOX 1946
AUSTIN, TEXAS 78767

IN REPLY
REFER TO:

February 15, 1974

Memorandum

To: Cooperating Agencies

From: Planning Officer

Subject: Guadalupe-San Antonio River Basins Study - Tenth Progress Report

Some significant events since my last progress report (December 5, 1973) are:

1. We have almost completed our second round of meetings with the cooperating agencies by meeting with the City Water Board of San Antonio on January 16, 1974 and with the Texas Water Development Board on February 1, 1974. We still need to fill the Nueces River Authority in on our latest studies. Travel restrictions are limiting our ability to get around so we are trying to consolidate and minimize our trips.

2. On January 15, 1974 I escorted Congressman Manual Lujan of New Mexico and his wife on a field trip to the Cibolo and Choke Canyon reservoir sites. Congressman Lujan was appointed as minority member to the Water and Power Resources Subcommittee of the House Interior and Insular Affairs Committee after the death of Congressman Sayler of Pennsylvania. Naturally Congressman Lujan missed the field hearings held by the Subcommittee and consequently he wanted to view the projects on the ground before Congress reassembled.

3. In January the Assistant Secretary for Fish and Wildlife and Parks requested the Fish and Wildlife Service to give him some specific answers on the Choke Canyon reservoir and its relationship to the estuaries. He placed a deadline of January 30, 1974 on his request.

4. The final impact statement on the Cibolo project was completed and forwarded to our Washington office on February 8, 1974.

Our last round of meetings primarily covered additional hydrologic studies. Some of these studies concerned a variable future demand on the Edwards aquifer and others were concerned with the yield of a number of reservoirs under various operating criteria recognizing two conditions for releasing water for water rights. In general your comments indicate that we do not need to make more studies of this nature as we appear to have bracketed the available supplies for the assumed conditions.

We are now studying estimates of future population and water demands. We propose to bracket this area also with a high and a low population projection and estimates of municipal and industrial needs.

For a high population projection we propose to use the December 1972 figures prepared by the Texas Water Development Board. While these do not represent an official State projection they are the best available at this time. For a low population projection we propose to use the OBERS projections recommended by the Water Resources Council and modify them to fit our study area. It is almost mandatory for Federal agencies to use the OBERS data.

The Texas Water Development Board has prepared estimates of municipal water requirements for nine different conditions. We have selected one of these (median rainfall and constant price condition) which probably represents their "average" condition, as our high projection. In these projections per capita consumption increase ranged from 143 percent to 210 percent over the 50-year period.

To provide a range we have selected alternative per capita water consumption values which increase only about 15 percent in 50 years over the 1970 values. Applying these values to the OBERS projections provides us with a "low" municipal water demand. The high projection is about 127 percent of the low projection in the year 2020.

For projections for the high and low industrial demands we have selected the Series A (for high) and Series C (for low) projections of the Texas Water Development Board. Since these are state-wide series, their application to the much smaller study area produces some odd combinations of "high" and "low" values.

Estimates of irrigation demands were assembled as shown on the attached table. In general most of the counties were assigned acreages consistant with the acreages reported in 1969. Considerable increase was projected for Uvalde and Medina counties. Because of the imponderables in predicting future irrigation growth we felt it was futile to predict a high and a low for this demand.

Future requirements for cooling water for generation of electrical energy were estimated also. Past projections have been based on assumptions such as 7 percent or 10 percent increase per year. In view of the present energy crisis, the scarcity of fuel, the increasing cost of energy, it is likely that those projections will be drastically revised. We have attempted to prepare "middle of the road" projections for this demand.

Attached are tables showing:

1. High Population Projection
2. Low Population Projection
3. High Water Demand Projection
4. High Industrial Water Demand Projection
5. Low Municipal Water Demand Projection
6. Low Industrial Water Demand Projection
7. Estimated Future Irrigation Development and Water Demands
8. Cooling Water Demand

Please review these tables and furnish your comments. If I do not hear from you I will assume that you feel that the range we have selected is reasonable.

Using the data from the above mentioned tables the total basin demand can be determined for the "high" and "low" projections. Attached are tables showing:

9. 2020 Demand for Water with High M & I Projections

10. 2020 Demand for Water with Low M & I Projections

These tables indicated that regardless of whether a high or low projection is used, there will be heavy reliance on additional surface water supplies in the next 50 years.

These demand data are useful in determining the future load that could develop on the Edwards Underground Reservoir. These loadings, using the low municipal and industrial water demands, are determined for each county as shown in the following tables. The division between surface and ground water supplies is based on the existing surface water development. The 1970 water use includes some surface water use in most of the counties.

Uvalde County

	Acre-feet				
	1970	2020	Assumed 2020 supply		
Purpose	Use	Demand	Surface	Ground	Total
All other	5,900	-	-	-	-
Elec. gen.	-	-	-	-	-
Industrial	-	329	-	329	329
Irrigation	69,700	120,000	-	120,000	120,000
Municipal	-	6,239	-	6,239	6,239
Total	75,600	126,568	-	126,568	126,568

Medina County
Acre-feet

Purpose	1970 Use	2020 Demand	Assumed 2020 supply Surface	Ground	Total
Elec. gen.	-	-	-	-	-
Industrial	956	3,208	-	3,208	3,208
Irrigation	40,000	106,000	26,000	80,000	106,000
Municipal	2,981	4,740	-	4,740	4,740
Total	43,937	113,948	26,000	87,948	113,948

Bexar County
Acre-feet

Purpose	1970 Use	2020 Demand	Assumed 2020 supply (no project) Surface	Ground	Total
Elec. gen.	16,000	145,000	124,000*	8,000	132,000
Industrial	22,536	55,586	-	55,586	55,586
Irrigation	50,000	50,000	20,000	30,000	50,000
Municipal	151,781	309,378	-	309,378	309,378
Total	240,317	559,964	144,000	402,964	546,964

*Return flows from San Antonio

Comal County
Acre-feet

Purpose	1970 Use	2020 Demand	Assumed 2020 supply Surface	Ground	Total
Elec. gen.	-	-	-	-	-
Industrial	5,112	5,027	-	5,027	5,027
Irrigation	500	500	200	300	500
Municipal	4,034	7,712	-	7,712	7,712
Total	9,646	13,239	200	13,039	13,239

Hays County
Acre-feet

Purpose	1970 Use	2020 Demand	Assumed 2020 supply Surface	Ground	Total
Elec. gen.	-	-	-	-	-
Industrial	1,410	2,312	-	2,312	2,312
Irrigation	2,500	2,500	1,000	1,500	2,500
Municipal	3,971	7,134	-	7,134	7,134
Total	7,881	11,946	1,000	10,946	11,946

Combining these figures for the five-county area results in the following table:

2020 Water Demands - Acre-feet
Unlimited Loading on Edwards
Low Projection for M & I

County	Elec. Gen.	Industrial	Irrigation	Municipal	Total
Uvalde	-	329	120,000	6,239	126,568
Medina	-	3,208	80,000	4,740	87,948
Bexar	8,000	55,586	30,000	309,378	402,964
Comal	-	5,027	300	7,712	13,039
Hays	-	2,312	1,500	7,134	10,946
Total	8,000	66,462	231,800	335,203	641,465

The total demand for these assumptions is greater than the recharge of the Edwards even leaving out the drouth of the 1950's. This demand probably would dry up most of the spring flow. For comparison, the high M & I projections result in the following table:

2020 Water Demands - Acre-feet
Unlimited Loading on Edwards
High Projection for M & I

County	Elec. Gen.	Industrial	Irrigation	Municipal	Total
Uvalde	-	262	120,000	10,050	130,312
Medina	-	3,092	80,000	6,595	89,687
Bexar	8,000	43,794	30,000	431,518	513,312
Comal	-	6,152	300	11,671	18,123
Hays	-	2,613	1,500	22,533	26,646
Total	8,000	55,913	231,800	482,367	778,080

This demand is, of course, greater than the low projection and places an impossible loading on the Edwards. We can safely say that with almost any reasonable projection the Edwards is in deep trouble. Note that the "high" industrial demand for these counties is less than the "low" demand.

The 2020 projections can be compared with the 1970 draft on the Edwards Underground Reservoir which is reported by the Edwards Underground Water District to be as follows:

	Acre-feet		
County	Irrigation	All other	Total
Uvalde	69.7	5.9	75.6
Medina	14.0	2.5	16.5
Bexar	25.5	198.1	223.6
Comal	0.3	7.6	7.9
Hays	0.4	4.7	5.1
Total	109.9	218.8	328.7

We plan to make this type of analysis for each county in the basin to determine the surface water needs in 2020. Also we plan to assume a level of development for the Edwards, compute the spring flow and return flow for that condition, and recompute the reservoir yields. We would appreciate your advice on what level of development to assume for the EUG. The annual recharge level would be the easiest assumption to evaluate and might be the most realistic for a first run on the problem.

Also included with this report is a brief summary report on the investigation to date.

Norman G. Flaigg

Norman G. Flaigg

Enclosures

cc: Alamo Area Council of Governments
San Antonio, Texas

Capitol Area Planning Council
Austin, Texas

City Manager, City of San Antonio
San Antonio, Texas

Edwards Underground Water District
San Antonio, Texas

Golden Crescent Council of Governments
Victoria, Texas

Guadalupe-Blanco River Authority
Seguin, Texas

Nueces River Authority
Uvalde, Texas

Regional Director
Bureau of Reclamation
Amarillo, Texas

San Antonio City Water Board
San Antonio, Texas

San Antonio River Authority
San Antonio, Texas

Texas Parks and Wildlife Department
Austin, Texas

Texas Water Development Board
Austin, Texas

Upper Guadalupe River Authority
Kerrville, Texas

Guadalupe-San Antonio Study Area - High Population Projection
(TWDB December 1972 Data)

Counties	Population 1970	1980	1990	2000	2010	2020
Basin area						
Bandera	4,747	5,300	5,900	6,600	7,200	7,800
Bexar	830,460	957,400	1,107,100	1,260,900	1,425,100	1,599,900
Caldwell	21,178	23,700	26,700	29,600	32,500	35,500
Calhoun	17,831	21,400	25,800	30,600	36,000	42,000
Comal	24,165	26,100	28,200	30,000	31,700	33,300
DeWitt	18,660	16,200	14,200	12,200	10,400	8,800
Goliad	4,869	4,300	3,900	3,400	2,900	2,500
Gonzales	16,375	15,300	14,300	13,100	12,000	10,900
Guadalupe	33,554	38,100	43,400	48,600	54,100	59,800
Hays	27,642	34,800	44,100	54,900	67,800	83,200
Karnes	13,462	12,100	10,900	9,600	8,500	7,400
Kendall	6,964	7,600	8,400	9,100	9,800	10,400
Kerr	19,454	22,600	26,300	30,200	34,400	38,800
Victoria	53,766	63,300	74,800	87,100	100,600	115,400
Wilson	13,041	12,700	12,400	11,900	11,400	10,800
Total	1,106,168	1,260,900	1,446,400	1,637,800	1,844,400	2,066,500
Other EUG counties						
Medina	20,249	22,300	24,700	26,900	29,100	31,300
Uvalde	17,348	18,800	20,500	21,900	23,300	24,900

Guadalupe-San Antonio Study Area - Low Population Projection
(Based on OBERS Data)

Counties	Population 1970	1980	1990	2000	2010	2020
Basin area						
Bandera	4,747	5,400	6,000	6,700	7,300	8,000
Bexar	830,460	932,200	1,058,500	1,189,500	1,332,500	1,468,000
Caldwell	21,178	22,200	23,200	24,100	25,100	26,000
Calhoun	17,831	20,800	24,000	27,000	30,000	33,000
Comal	24,165	27,500	30,500	33,700	36,800	40,000
DeWitt	18,660	16,600	15,000	12,200	9,100	8,000
Goliad	4,869	4,600	4,500	4,300	4,200	4,000
Gonzales	16,375	14,800	13,400	11,800	10,400	9,000
Guadalupe	33,554	35,000	36,200	37,500	38,800	40,000
Hays	27,642	31,000	33,400	36,700	40,000	43,000
Karnes	13,462	11,600	10,000	8,400	6,600	5,000
Kendall	6,964	7,300	7,700	8,200	8,600	9,000
Kerr	19,454	21,700	24,000	26,300	28,600	31,000
Victoria	53,766	62,000	73,000	79,000	88,000	96,000
Wilson	13,041	11,800	10,600	9,400	8,200	7,000
Total	1,106,168	1,224,500	1,370,000	1,514,800	1,674,200	1,827,000
Other EUG counties						
Medina	20,249	21,700	23,300	24,900	26,500	28,000
Uvalde	17,348	18,400	19,600	20,700	21,800	23,000

Guadalupe-San Antonio Study Area - High Municipal Water Demand Projection
(TWDB median rainfall and constant price condition)

Counties	Acre-feet per year					
	1970	1980	1990	2000	2010	2020
Basin area						
Bandera	579	702	846	1,019	1,191	1,393
Bexar	151,781	186,540	238,254	298,842	366,043	431,518
Caldwell	2,758	3,667	4,578	5,654	6,793	8,093
Calhoun	2,097	2,725	3,652	4,815	6,215	7,591
Comal	4,034	6,365	7,650	9,000	10,436	11,671
DeWitt	2,438	2,348	2,332	2,263	2,143	2,014
Goliad	671	688	709	702	679	658
Gonzales	2,443	2,445	2,549	2,600	2,628	2,630
Guadalupe	4,449	6,217	8,017	10,105	12,633	15,440
Hays	3,971	6,068	8,667	12,153	16,697	22,533
Karnes	2,065	2,107	2,136	2,137	2,124	2,049
Kendall	915	1,171	1,425	1,703	2,002	2,285
Kerr	3,846	5,298	6,960	9,003	11,401	14,124
Victoria	8,511	11,361	14,770	18,923	23,771	28,519
Wilson	2,059	2,412	2,655	2,844	3,043	3,191
Total	192,617	240,114	305,200	381,763	467,799	553,709
Other EUG counties						
Medina	2,981	3,334	4,058	4,849	5,679	6,595
Uvalde	4,081	5,161	6,264	7,430	8,684	10,050

Guadalupe-San Antonio Study Area - High Industrial Water Demand Projection
(TWDB Series A Data)

Counties	1970	1980	1990	2000	2010	2020
	Acre-feet per year					
Basin area						
Bandera	2	2	2	3	3	3
Bexar	22,536	26,188	29,850	34,519	39,126	43,794
Caldwell	137	159	180	209	237	267
Calhoun	25,235	35,869	48,980	66,693	87,766	112,675
Comal	5,112	5,432	5,636	5,917	6,076	6,152
DeWitt	706	599	500	421	342	275
Goliad	-	-	-	-	-	-
Gonzales	748	678	597	526	452	380
Guadalupe	634	689	730	780	813	831
Hays	1,410	1,704	1,897	2,126	2,363	2,613
Karnes	16	15	14	13	11	10
Kendall	8	9	10	11	12	14
Kerr	100	118	137	161	185	211
Victoria	26,391	37,923	51,856	70,426	92,133	117,483
Wilson	75	70	64	58	51	44
Total	83,110	109,455	140,453	181,863	229,570	284,752
Other EUG counties						
Medina	956	1,282	1,626	2,099	2,496	3,092
Uvalde	186	203	217	235	250	262

Guadalupe-San Antonio Study Area - Low Municipal Water Demand Projection
(Based on OBERS projection and modified per capita usage)

Counties	Acre-feet per year					
	1970	1980	1990	2000	2010	2020
Basin area						
Bandera	579	678	773	894	998	1,121
Bexar	151,781	175,599	205,181	237,350	273,353	309,378
Caldwell	2,758	2,986	3,199	3,431	3,658	3,906
Calhoun	2,097	2,518	2,986	3,450	3,968	4,476
Comal	4,034	4,717	5,402	6,120	6,889	7,712
DeWitt	2,438	2,214	2,068	1,723	1,326	1,193
Goliad	671	655	656	646	650	632
Gonzales	2,443	2,273	2,118	1,918	1,737	1,544
Guadalupe	4,449	4,787	5,113	5,423	5,785	6,098
Hays	3,971	4,587	5,092	5,760	6,457	7,134
Karnes	2,065	1,834	1,625	1,403	1,132	880
Kendall	915	990	1,070	1,177	1,263	1,362
Kerr	3,846	4,427	5,031	5,661	6,348	7,054
Victoria	8,511	10,147	12,275	13,638	15,586	17,541
Wilson	2,059	1,918	1,770	1,623	1,452	1,271
Total	192,617	220,330	254,359	290,217	330,602	371,302
Other EUG counties						
Medina	2,981	3,284	3,630	3,992	4,367	4,740
Uvalde	4,081	4,455	4,900	5,314	5,743	6,239

Guadalupe-San Antonio Study Area - Low Industrial Water Demand Projection
(Based on TWDB Series C Data)

Counties	Acre-feet per year					
	1970	1980	1990	2000	2010	2020
Basin area						
Bandera	2	2	3	3	3	4
Bexar	22,536	27,701	32,935	39,799	47,233	55,586
Caldwell	137	181	217	270	327	393
Calhoun	25,235	33,674	43,374	54,110	65,150	76,469
Comal	5,112	5,400	5,044	5,005	4,981	5,027
DeWitt	706	617	508	428	350	284
Goliad	-	-	-	-	-	-
Gonzales	748	800	753	709	653	587
Guadalupe	634	792	883	995	1,080	1,155
Hays	1,410	1,661	1,754	1,907	2,088	2,312
Karnes	16	15	15	15	15	14
Kendall	8	10	12	14	17	20
Kerr	100	130	169	224	289	371
Victoria	26,391	37,702	46,468	56,880	67,079	77,132
Wilson	75	81	78	76	72	65
Total	83,110	108,766	132,213	160,435	189,337	219,419
Other EUG counties						
Medina	956	1,287	1,628	2,104	2,563	3,208
Uvalde	186	210	234	266	296	329

Guadalupe-San Antonio Study Area - Estimated Future Irrigation Development
and Water Demands - 2020 Conditions

Counties	Approx. acres irrigated 1969	Acres: Surface water	Acres: Ground water	Acres: Total	Acre-feet: Surface water	Acre-feet: Ground water	Acre-feet: Total
Basin area							
Bandera	400	300	200	500	300	200	500
Bexar	29,000	10,000	15,000	25,000	20,000	30,000	50,000
Caldwell	400	500	500	1,000	500	500	1,000
Calhoun	9,000	8,000	1,000	9,000	40,000	5,000	45,000
Comal	300	200	300	500	200	300	500
DeWitt	900	700	700	1,400	700	700	1,400
Goliad	2,700	3,000	500	3,500	3,000	500	3,500
Gonzales	2,800	1,500	1,500	3,000	1,500	1,500	3,000
Guadalupe	2,400	1,000	1,500	2,500	1,000	1,500	2,500
Hays	2,400	1,000	1,500	2,500	1,000	1,500	2,500
Karnes	1,500	500	1,000	1,500	500	1,000	1,500
Kendall	600	300	300	600	300	300	600
Kerr	1,500	1,000	500	1,500	1,000	500	1,500
Victoria	5,500	500	5,000	5,500	2,500	25,000	27,500
Wilson	17,000	2,000	18,000	20,000	2,000	18,000	20,000
Total	76,400	30,500	47,500	78,000	74,500	86,500	161,000
Other EUG counties							
Medina	26,000	13,000	40,000	53,000	26,000	80,000	106,000
Uvalde	35,600*	1,000	60,000	61,000	2,000	120,000	122,000

*About 31,300 acres irrigated from Edwards Underground Reservoir.

Guadalupe-San Antonio Study Area
In-Basin
Cooling Water Requirements#
for Generation of Electrical Energy

1000's of Acre-feet per year

Year	San Antonio Load Center* Low	San Antonio Load Center* High	Victoria Load Center** Low	Victoria Load Center** High
1970	35	35	6	6
1980	42	44	9	10
1990	58	67	25	31
2000	89	108	40	51
2010	110	158	54	70
2020	132	189	69	92

Includes induced and natural evaporation
* Bexar County
** Calhoun and Victoria counties

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Guadalupe-San Antonio River Basins Study - 2020 Demand for Water with High M & I Projections

Counties	High Industrial	High Municipal	Irrigation	Electric Generation	Total
	Acre-feet per year				
Basin area					
Bandera	3	1,393	500	-	1,896
Bexar	43,794	431,518	50,000	189,000	714,312
Caldwell	267	8,093	1,000	-	9,360
Calhoun	112,675	7,591	45,000	62,000	227,266
Comal	6,152	11,671	500	-	18,323
DeWitt	275	2,014	1,400	-	3,689
Goliad	-	658	3,500	-	4,158
Gonzales	380	2,630	3,000	-	6,010
Guadalupe	831	15,440	2,500	-	18,771
Hays	2,613	22,533	2,500	-	27,646
Karnes	10	2,049	1,500	-	3,559
Kendall	14	2,285	600	-	2,899
Kerr	211	14,124	1,500	-	15,835
Victoria	117,483	28,519	27,500	30,000	203,502
Wilson	44	3,191	20,000	-	23,235
Total	284,752	553,709	161,000	281,000	1,280,461
Other EUG counties					
Medina	3,092	6,595	106,000	-	115,687
Uvalde	262	10,050	122,000	-	132,312

Guadalupe-San Antonio River Basins Study - 2020 Demand for Water with Low M & I Projections

Counties	Low Industrial	Low Municipal	Irrigation	Electric Generation	Total
	Acre-feet per year				
Basin area					
Bandera	4	1,121	500	-	1,625
Bexar	55,586	309,378	50,000	132,000	546,964
Caldwell	393	3,906	1,000	-	5,299
Calhoun	76,469	4,476	45,000	49,000	174,945
Comal	5,027	7,712	500	-	13,239
DeWitt	284	1,193	1,400	-	2,877
Goliad	-	632	3,500	-	4,132
Gonzales	587	1,544	3,000	-	5,131
Guadalupe	1,155	6,098	2,500	-	9,753
Hays	2,312	7,134	2,500	-	11,946
Karnes	14	880	1,500	-	2,394
Kendall	20	1,362	600	-	1,982
Kerr	371	7,054	1,500	-	8,925
Victoria	77,132	17,541	27,500	20,000	142,173
Wilson	65	1,271	20,000	-	21,336
Total	219,419	371,302	161,000	201,000	952,721
Other EUG counties					
Medina	3,208	4,740	106,000	-	113,948
Uvalde	329	6,239	120,000	-	126,568

Bureau of Reclamation
Summary Report
on Status of
Guadalupe-San Antonio River Basins Study
February 1974

Introduction

The investigation is the result of a request by five local organizations having responsibility of water resource planning and development in the Guadalupe and San Antonio River Basins.

Purpose

It is a comprehensive multiple objective study involving local, state and Federal agencies seeking to find an acceptable plan of management of the surface and ground water resources of the area which will most nearly meet the needs and desires of the inhabitants of basins.

Scope

The study area includes all or part of 15 counties comprising the bulk of the two basins. All or parts of Bandera, Bexar, Caldwell, Calhoun, Comal, DeWitt, Goliad, Gonzales, Guadalupe, Hays, Karnes, Kendall, Kerr, Victoria and Wilson counties are included in the basin. Also Medina and Uvalde counties are included in the study so that the Edwards Underground Reservoir can be evaluated as it affects the basins under study.

Public involvement

This investigation was authorized to start July 1, 1971. The study was formally initiated in an interagency and public meeting on March 29, 1972 in San Antonio. So far 21 other meetings have been held with river authorities, state and Federal agencies and environmental groups. Oral reports have been made on two occasions to the Natural Resources Committee of the Greater San Antonio Chamber of Commerce.

Major accomplishments to date

The basic part of this study is a thorough understanding of the surface and ground water systems in the basin. The bulk of the studies to date has been in the field of hydrology. Previous hydrologic studies of the area have been reviewed. Previous basin natural runoff studies have been extended through the years 1966-1970 to bring them up to date. A thorough examination of the historic performance of the Edwards Underground Reservoir has been made, and an operation study has been made for the present level of use and for a higher future level of use. Design flood studies were made for various gaging stations. Surface water supply yield studies have been made for the most desirable reservoirs in the watershed.

Economic studies were made to determine the depth from which irrigators could afford to pump water.

Field surveys were made to determine the irrigable lands over the Edwards Underground Reservoir in Uvalde, Medina, and Bexar counties.

Population projections and data on water demands for municipal and industrial purposes were collected and studied. High and low population projections have been selected and municipal and industrial water demands have been selected or prepared for those projections. Estimates of future irrigation requirements have been prepared as well as estimates for cooling water for generation of electrical energy.

One potential project in the basin, the Cibolo Project, has been previously studied yet it still requires a considerable amount of work. The project report was submitted to the State of Texas for comment and it was necessary to prepare and present testimony for a hearing held by the Texas Water Rights Commission. A draft environmental impact statement has been prepared and distributed for comment. A draft of the final environmental impact statement has been prepared and submitted. The Water and Power Resources Subcommittee of the House Interior and Insular Affairs Committee held a field hearing on the project in June. Testimony supporting the project was prepared and presented at the hearing.

Another completed project investigation of indirect interest is the Nueces River Project. The controversy over the R & M and Choke Canyon sites was resolved in favor of the latter by the Texas Water Rights Commission in the fall of 1972. Testimony was prepared and presented at that hearing. A bill for the authorization of this project is before Congress too. In November 1973 the Water and Power Resources Committee of the House Interior and Insular Affairs Committee held a field hearing in Three Rivers. Testimony was prepared and presented at that hearing. A draft impact statement was prepared and distributed for comment. A draft of a final impact statement has been prepared and is being reviewed.

NOTES FOR MARCH 30, 1976, MEETING

Prepared by
Bureau of Reclamation
Southwest Region
Herring Plaza, Box H-4377
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In connection with
San Antonio-Guadalupe River Basin Studies

PREVENTING OVERDEVELOPMENT OF THE EDWARDS UNDERGROUND AQUIFER

Overdevelopment of the Edwards Underground Aquifer can be defined as well discharge in excess of average recharge over a prolonged period of time. Overdevelopment can be prevented by limiting well discharge to an amount that is smaller than recharge. This can be accomplished in two ways: one, a voluntary substitution of surface water for ground water by certain entities such as the San Antonio metropolitan area; or two, a ground water law that places a mandatory upper limit on the well discharge of all water users.

Voluntary substitution of surface water

Bureau studies assume that the San Antonio metropolitan area, New Braunfels, and San Marcos will voluntarily substitute surface water for Edwards underground water as needed to prevent total average well discharge from exceeding 500,000 acre-feet per year. For voluntary substitution to be possible, adequate supplies of substitute surface water must be available and the demands on the aquifer by users who cannot substitute surface water for ground water must be smaller than average recharge.

Preventing the overdevelopment of the Edwards by surface water substitution faces three major obstacles. First, it would be difficult to develop and implement an acceptable method of sharing the high costs of surface water among the beneficiaries. Second, substituting surface water for aquifer water would be difficult if additional supplies of surface water were ever unavailable. Third, surface water substitution would fail to protect the Edwards should the demands on the Edwards by those who have no surface water alternative ever exceed the average recharge.

If the city of San Antonio were to pay the whole cost for substitute surface water while irrigators west of San Antonio continued to expand, San Antonio might feel that the irrigators were getting a free ride at San Antonio's expense. San Antonio would be paying for expensive surface water supplies to offset the increased use of the aquifer by irrigators to the west. All aquifer users would benefit to some degree from the substitution of surface water for aquifer water. It is equitable that all beneficiaries should contribute to the high cost of the substitute surface water. Determining the appropriate contribution from each water user would require difficult and involved legal, hydrologic, and economic studies and implementing the resulting cost sharing method would be politically controversial.

Bureau plans for voluntary substitution of surface water for aquifer water call for holding well discharge to 500,000 acre-feet a year through the year 2020. This annual limit includes the installation of supplemental wells at Comal and San Marcos Springs, which may exercise a restraining force on full development of these wells. If the annual discharge of the Edwards is to be held to 500,000 acre-feet a year, Bureau estimates show that at least 70 percent of the municipal and industrial water supply for Bexar, Comal, and Hays Counties must be supplied by surface water.

Limiting the aquifer discharge to 500,000 acre-feet could create difficulties. The Texas Water Development Board, for example, estimates that if all of the land that could be irrigated by the Edwards were actually irrigated, the discharge for irrigation alone would be 423,000 acre-feet a year. If the trend of the period 1958-69 continues, the board predicted that this full irrigation development would occur by the year 2042. If irrigation use approaches this magnitude, it might be impossible to hold the Edwards discharge to 500,000 acre-feet.

There are other demands on the Edwards that simply cannot be met by surface water substitution. Some water users, for instance, are scattered throughout the area; their needs could not be economically met by surface water development. It would be impractical to put the San Antonio metropolitan area, the city of New Braunfels, and the city of San Marcos completely on surface water. These communities would continue to need ground water for summer peaking periods and for dry years when demands are higher than normal. Surface water could not be used to maintain the flows of Comal and San Marcos Springs. Supplemental wells would have to pump from the Edwards to maintain these springs.

In most Bureau plans, adequate surface water would be available for substitution through 2020, and potential additional supplies would be available in the Guadalupe Basin beyond 2020. In actual practice some of the potential supply might not be available for substitution because of political or water right considerations.

Some other considerations involved in a voluntary substitution plan are:

1. What level of well discharge should be allowed?

2. What provision should be made for Comal and San Marcos Springs?

3. Should one level of limitation to well discharge apply to the whole aquifer, or should different segments have different limits?

4. Under what aquifer conditions should surface water be substituted for well water?

Bureau plans propose an upper limit on well discharge of 500,000 acre-feet per year. This is the highest level that appears realistic because it is probable that even under conditions of severe aquifer drawdown, some recharge would be discharged from San Marcos Springs and because it is possible that in the future recharge might fall below the historical average. A somewhat lower level of well discharge could be advocated for the same reasons. Bureau plans call for the highest realistic level of well discharge because of the high cost of substitute surface water.

Considerations have been given to restrict the Edwards discharge to 350,000 acre-feet a year to assure that Comal and San Marcos Springs would not go dry. Limiting discharge to even this reduced amount, however, would not help Comal Springs during a severe, prolonged drought like the one in 1948-56. During such a drought, Comal Springs would still go dry even with the reduced discharge. The springs did go dry in

1956, and well discharge at that time was considerably lower than what it is today. The economic cost of reducing discharge to such a low level that Comal Springs would flow even during a severe drought would be prohibitive.

The situation at San Marcos Springs is not quite so bleak. It is estimated that the springs would flow continuously if the Edwards discharge were limited to 350,000 acre-feet and the city of San Marcos switched completely from ground water to surface water.

The cost of reducing well discharge to 350,000 acre-feet would be extremely high. A reduction this large would probably guarantee the life of San Marcos Springs, but it would not assure that Comal Springs would flow continuously. If, therefore, some provision is to be made for maintaining the flows of Comal and San Marcos Springs during moderate and severe droughts, supplemental wells are the surest, most direct, and most economical way.

Some good arguments can be made for placing different limits on well discharge for different segments of the aquifer, provided that the sum of the limits is less than the average recharge. Setting a different limit for Hays County is particularly appealing since about half of the aquifer water in Hays County comes from local sources that are not available to water users in New Braunfels, San Antonio, etc. As long as San Marcos Springs are flowing, well discharge in Hays County has very little effect on water levels in the aquifer. Some weaker arguments could be made for putting different limits on the Uvalde Pool and Central Pool well discharges.

It has been suggested that limits on well discharge should be imposed only during times when aquifer water levels are critically low, and that these limits should be removed when the water levels rise again. Since operating costs for substitute surface water are usually quite a bit higher than costs for ground water supplies, this makes economic sense. One Bureau plan proposes that water not be taken from Cuero Reservoir to San Antonio when Comal Springs has a flow of over 16 cubic feet per second. The pump lift involved in transporting water from Cuero Reservoir to San Antonio is about 1,000 feet; the ground water lift in San Antonio when Comal Springs are flowing is less than 100 feet. Comal Springs and San Marcos Springs (for Hays County) might provide convenient and highly visible indicators of favorable or unfavorable aquifer water levels. Thus, water users in Hays County could be allowed unrestricted use of ground water whenever San Marcos Springs flow exceeded some amount. Similarly, water users in Comal, Bexar, Medina, and Uvalde Counties could be allowed unrestricted use of ground water whenever Comal Springs flow exceeded some amount. There might be some extra well field costs to enable use of more ground water when ground water levels are favorable.

Ground water law - The well discharge from the aquifer could also be limited to a value less than recharge by enactment of a ground water law putting mandatory limits on well discharges. Devising an acceptable ground water law would be politically difficult. One principal advantage a ground water law would have over voluntary substitution is its authority to limit well discharge independently of the availability of substitute surface water. The main problem with a ground water law would be devising an acceptable method to allocate the limited ground water supply among existing and potential users of ground water. Many possibilities exist. One is the appropriative method, which means first in time of use is first in right. This would favor and protect existing uses of ground water at the expense of potential uses. Another is the correlative method, under which the available well discharge would be allocated on an acreage basis, regardless of existing uses. This would favor potential uses of ground water at the expense of some existing uses. A fair ground water law might involve some compromise between the appropriative doctrine and the correlative doctrine. Because it is impossible to predict exactly how a future ground water law would affect potential future users of ground water, most Bureau planning is based on the principle of voluntary substitution.

Many details of a ground water law need to be worked out. Some are:

1. Should rights to use ground water be salable or transferable?

2. What level of well discharge should be allowed?

3. What provision will be made for Comal and San Marcos Springs?

4. Under what aquifer conditions should the limits on well discharge be imposed? Should the limits be suspended when water levels in the aquifer are high as perhaps evidenced by flow from Comal and San Marcos Springs?

Implementing the plans

It appears that the most practical way to implement an area-wide plan providing for surface water substitution of Edwards Aquifer water would be to form a master conservancy district responsible for the entire area of influence. This district would require legislative approval and taxing authority to finance its operations. The district would probably operate on an ad valorem tax base with other supplemental methods devised as needed to finance future surface water facility construction and operations. Tax rates would be assigned commensurate with benefits derived from implementing the plan.

In order to properly control and manage an integrated ground and surface water plan, the district would have to function under a ground water law that would make limitation measures possible. Such a ground water law would require legislative action which could be provided at the time the district is established.

In addition, this conservancy district would be required to monitor the Edwards and protect it from overdevelopment and pollution.

BUREAU OF RECLAMATION
BRIEFING FOR COOPERATIVE STUDIES
30 March 1976

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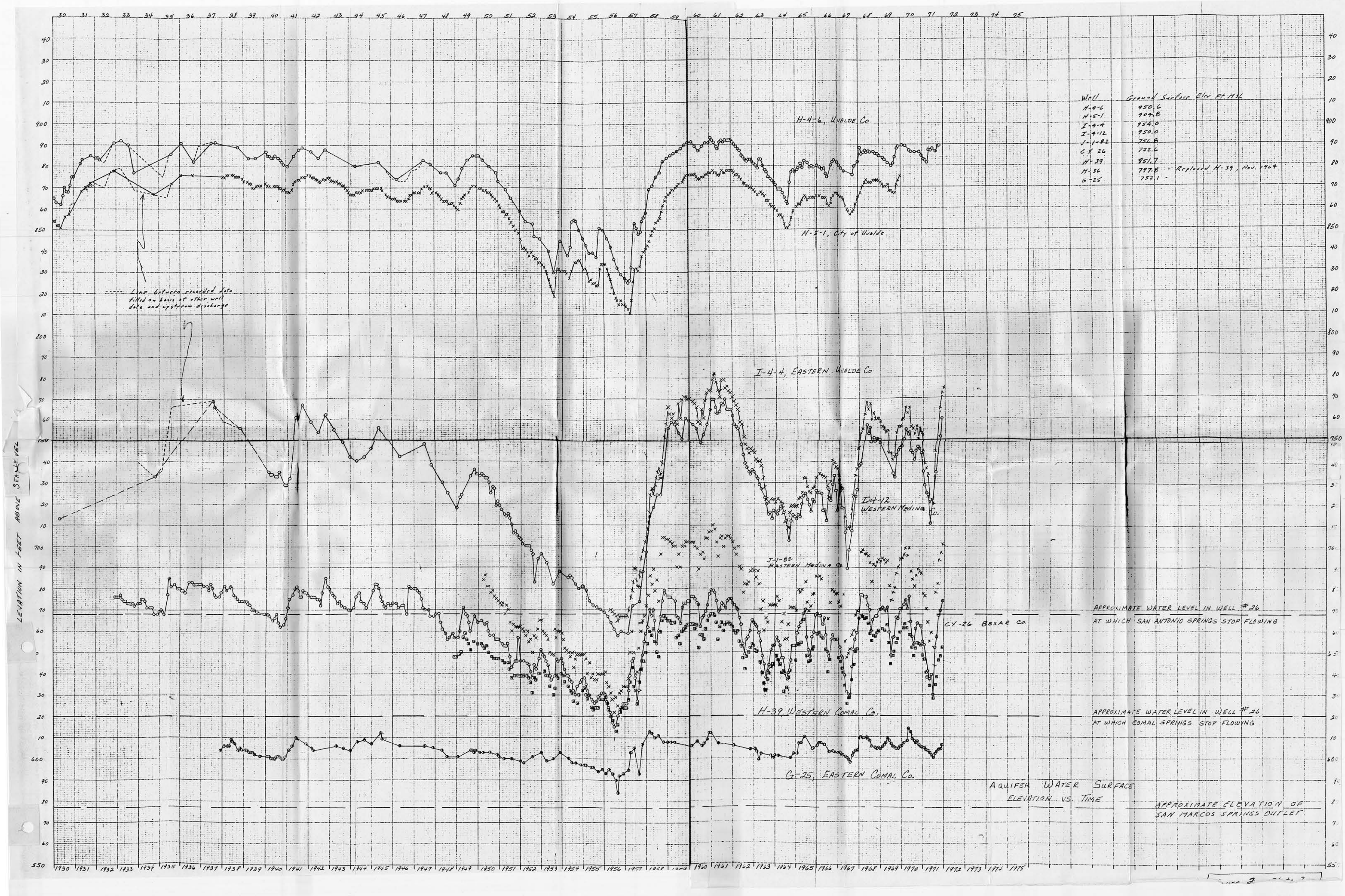

ELEVATION IN FEET ABOVE SEA LEVEL
Well / Ground Surface Elev Ft MSL
H-4-6 950.6
H-5-1 904.8
I-4-4 954.0
I-4-12 950.0
J-1-82 756.8
CY 26 722.6
H-39 851.7
H-36 797.8 - Replaced H-39, Nov. 1964
G-25 752.1 -
H-4-6, Uvalde Co.
H-5-1, City of Uvalde
Line between recorded data filled on basis of other well data and upstream discharge
I-4-4, Eastern Uvalde Co
I-4-12 Western Medina Co.
J-1-82 Eastern Medina Co
CY-26 Bexar Co.
APPROXIMATE WATER LEVEL IN WELL #26 AT WHICH SAN ANTONIO SPRINGS STOP FLOWING
H-39, Western Comal Co.
APPROXIMATE WATER LEVEL IN WELL #26 AT WHICH COMAL SPRINGS STOP FLOWING
G-25, Eastern Comal Co.
AQUIFER WATER SURFACE ELEVATION VS. TIME
APPROXIMATE ELEVATION OF SAN MARCOS SPRINGS OUTLET

Note: Large-format version of the original plate is on the following page.

LEVATION IN FEET ABOVE SEA LEVEL
Well | Ground Surface Elev Ft MSL
H-4-6 950.6
H-5-1 904.8
I-4-4 954.0
I-4-12 950.0
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