SAN ANTONIO AND BEXAR COUNTY, TEXAS

REPORT ON RECLAMATION AND RE-USE OF MUNICIPAL WASTEWATER

1971

FREESE, NICHOLS AND ENDRESS
CONSULTING ENGINEERS

SAN ANTONIO AND BEXAR COUNTY, TEXAS

REPORT ON RECLAMATION AND RE-USE OF MUNICIPAL WASTEWATER

1971

BEXAR METROPOLITAN WATER DISTRICT
Henry Riemer, General Manager

CITY OF SAN ANTONIO
Gerald C. Henckel, Jr., City Manager

EDWARDS UNDERGROUND WATER DISTRICT
McD. D. Weinert, P.E., General Manager

SAN ANTONIO CITY PUBLIC SERVICE BOARD
O. W. Sommers, P.E., General Manager

SAN ANTONIO CITY WATER BOARD
Robert P. Van Dyke, P.E., General Manager

SAN ANTONIO RIVER AUTHORITY
Fred N. Pfeiffer, P.E., General Manager

FREESE, NICHOLS AND ENDRESS
Consulting Engineers

FREESE, NICHOLS AND ENDRESS

CONSULTING ENGINEERS

March 19, 1971

Colonel McDonald D. Weinert, P.E.
General Manager
Edwards Underground Water District
2402 Tower Life Building
San Antonio, Texas 78205

Dear Colonel Weinert:

We are pleased to submit the accompanying Report On Reclamation and Re-Use of Municipal Wastewater in response to the joint authorization of April 1969 by the Bexar Metropolitan Water District, the City of San Antonio, the Edwards Underground Water District, the San Antonio City Public Service Board, the San Antonio City Water Board, and the San Antonio River Authority. We have enjoyed working on this assignment and hope that we can again be of service in the future.

Yours very truly,

FREESE, NICHOLS AND ENDRESS

By R. S. Gooch
Robert S. Gooch, P.E.

RSG:mg

TELEPHONE 817 332-4364 811 LAMAR STREET FORT WORTH, TEXAS 76102

TABLE OF CONTENTS

SAN ANTONIO AND BEXAR COUNTY, TEXAS

REPORT ON RECLAMATION AND RE-USE OF MUNICIPAL WASTEWATER

1971

1. INTRODUCTION

This study was authorized in April of 1969 by the City of San Antonio, the San Antonio City Public Service Board, the San Antonio City Water Board, the Bexar Metropolitan Water District, the San Antonio River Authority, and the Edwards Underground Water District. It gives consideration to the following principal objectives:

a. Use where practical of treated wastewater for applications which will tend to minimize future withdrawals from the Edwards Underground Reservoir.

b. Effective development of the Medina River watershed for recharge of the Edwards Underground Reservoir and as a supplemental source of surface water supply for San Antonio.

c. Reclamation of Mitchell Lake for esthetic, recreational and other potential uses.

d. Possible gains in recreational use at Lakes Braunig and Calaveras because of improved water quality and at Lake Medina from maintenance of higher water levels.

Included herein are estimates of future wastewater volumes and of the requirements which might be met through use of reclaimed wastewater in lieu of ground water pumpage. The hydrology of the Medina River Basin is outlined in some detail to show the influence of Lake Medina on recharge of the Edwards Underground Reservoir and the amount of surface water which can be obtained at the Applewhite Reservoir site. Attention is given to the character of wastewater treatment which would be required to produce water of suitable quality for the contemplated applications. Finally, economic analyses are presented relative to costs, benefits, and possible methods of financing.

As results of the investigation were reviewed with representatives of the sponsoring organizations, it was found desirable to add further items to the scope of the work. In July of 1970, it was agreed that the study would include discussion of a gravity-flow interconnection between Lakes Mitchell, Braunig and Calaveras. In October 1970, it was decided to give consideration to possible irrigation along the south side of the San Antonio River in southeastern Bexar County and northwestern Wilson County. The first of these items was included because of its potential relevance to power plant operation at the lakes and to over-all quality of waters in the lakes and the San Antonio River. Irrigation to the southeast of San Antonio, although it would not reduce withdrawals from the Edwards Underground Reservoir, is an apparent alternative use for the reclaimed wastewater and was added so that it might be compared with the various applications which would affect the availability of water from the Edwards limestone.

2. PROJECTED FUTURE WASTEWATER QUANTITIES

Table 2.1 is a summary of historical volumes of untreated wastewater reaching the San Antonio sewage treatment plants since 1940 (1). There has been a steady rise in the wastewater load during this period, with a somewhat more rapid rate of increase since about 1963. If the over-all trend is approximated by fitting a straight line through the data points, as in Figure 2.1, the average daily flow rate is found to have increased by around 24 million gallons during each of the three decades represented by the table.

Table 2.1

Historical Volumes of Untreated Wastewater Received At The San Antonio Sewage Treatment Plants: 1940-1969

- Annual Averages in MGD -

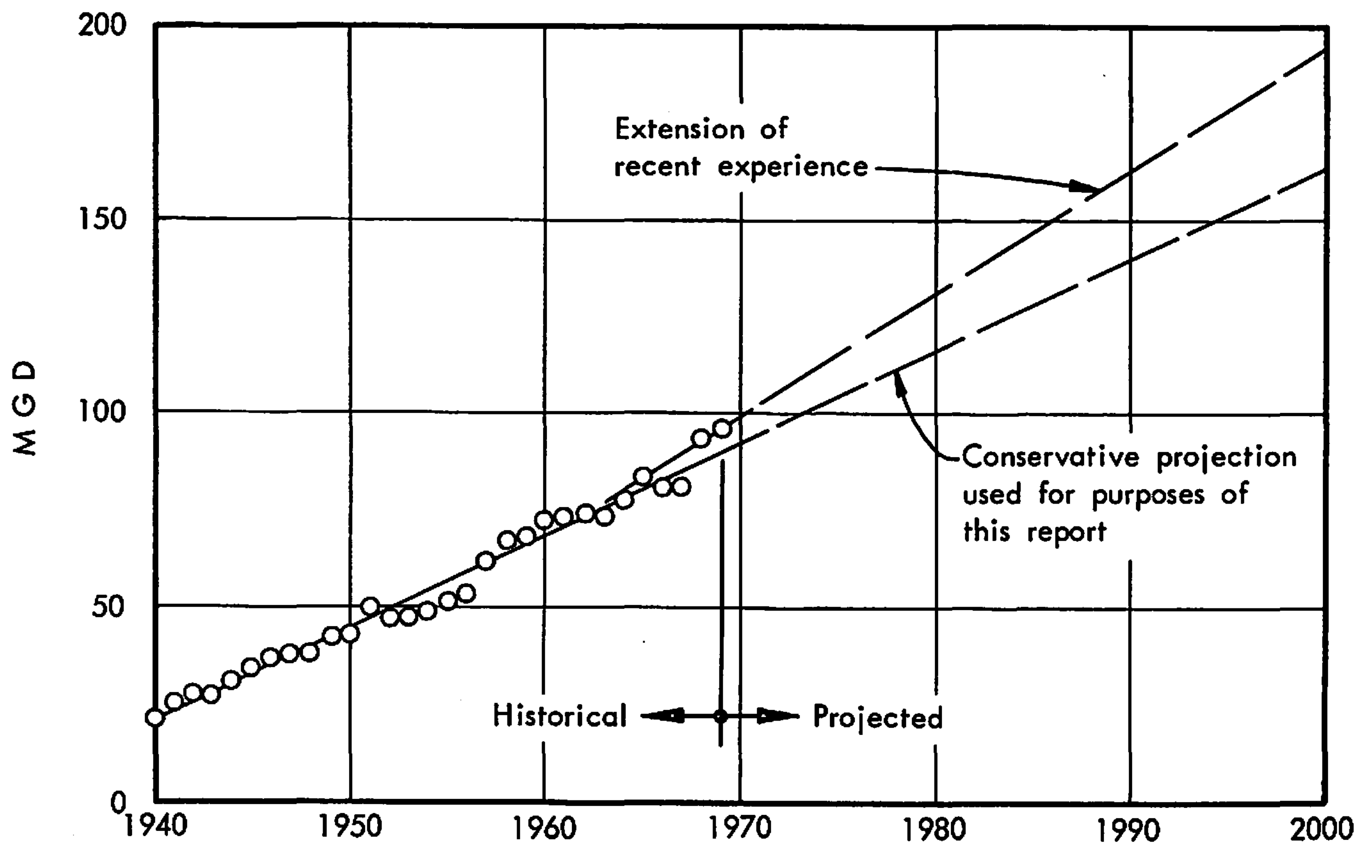
Year	MGD	Year	MGD
1940	21.1	1955	51.0
1941	25.4	1956	53.3
1942	28.0	1957	61.5
1943	27.7	1958	67.0
1944	31.0	1959	68.6
1945	34.5	1960	72.5
1946	36.9	1961	73.6
1947	38.2	1962	74.5
1948	37.7	1963	73.3
1949	42.2	1964	77.3
1950	42.8	1965	84.2
1951	50.0	1966	80.9
1952	47.3	1967	80.1
1953	47.3	1968	93.0
1953	49.0	1969	95.3

---

(1) Numbers in parentheses match references listed in Appendix A.

SAN ANTONIO

PAST AND PROJECTED VOLUMES OF UNTREATED WASTEWATER



FREESE, NICHOLS AND ENDRESS

FIGURE 2.1

It is possible that future increases in wastewater flow will follow the trend suggested by experience of the past few years, which is about 25% steeper than that for the full 30-year span. However, it is considered advisable for purposes of this study to assume a future increase rate based on the average since 1940. The results of this assumption are shown in Figure 2.1 and Table 2.2. They represent what is believed to be a safe projection of the lower limits of wastewater availability which may be expected through the year 2000.

Table 2.2

Projection of Future Wastewater Qualities

	Untreated Wastewater Volumes			Available for Re-Use		
	MGD	Billion Gal/Year	1,000 Ac-Ft/Yr	MGD	Billion Gal/Year	1,000 Ac-Ft/Yr
1970	90	32.9	101	86	31.2	96
1975	102	37.2	114	97	35.4	109
1980	114	41.6	128	108	39.5	121
1985	126	46.0	141	120	43.7	134
1990	138	50.4	155	131	47.9	147
1995	150	54.8	168	143	52.0	160
2000	162	59.1	182	154	56.2	173

In any given year a portion (usually between 3.5% and 5.5%) of the raw wastewater entering the treatment plants will be associated with sludge disposal or otherwise separated from the main stream of treatment so as not to be readily available for re-use. The remainder, however, can be applied to secondary uses if needed. The right-hand half of Table 2.2 shows the net quantities predicted to be available at five-year intervals through the year 2000, based on reclamation of 95% of the incoming flows.

In recent years virtually all of the City's wastewater has been handled by the Rilling Road and Leon Creek treatment plants, with the Rilling Road facilities accounting for over 90% of the total volume treated. Most of the future increase in load, however, is expected to be absorbed by the new Salado Creek plant, which has recently been completed. This factor is important when considering re-use, since the location and amount of any potential application must match the actual distribution of the supply.

3. POTENTIAL DEMAND FOR RECLAIMED WATER

As a rule, it is neither economical nor desirable to reintroduce treated wastewater into a city's distribution system. Direct re-use of municipal sewage is, in effect, a short-circuiting of the customary hydrologic cycle; in order to make such water safe for human consumption, it is necessary to employ advanced treatment processes in lieu of certain aspects of purification that would otherwise take place naturally. In general, the degree and type of treatment required to make reclaimed water suitable from the standpoint of public health will cost more than an equivalent supply of fresh water. For the present, most cities in Texas will be able to obtain their primary supply more economically from other sources.

However, there are some requirements, involving significant quantities of water, for which wastewater that has been given conventional forms of treatment can often be used. Industrial cooling, certain forms of irrigation, and properly controlled recreation are among the more important of these, each potentially applicable to San Antonio.

Cooling Water for Electric Generating Plants

Table 3.1 shows San Antonio's peak power demands and total electric energy requirements by years since 1951, as reflected in annual reports of the City Public Service Board. The power load has grown at a rate of approximately 11% per annum over the past decade and is predicted to continue at that rate through 1985 (3). Condenser cooling at the power plants is an important factor in the area's water supply needs, and it will come to be much more important if the use of electricity continues to increase as anticipated.

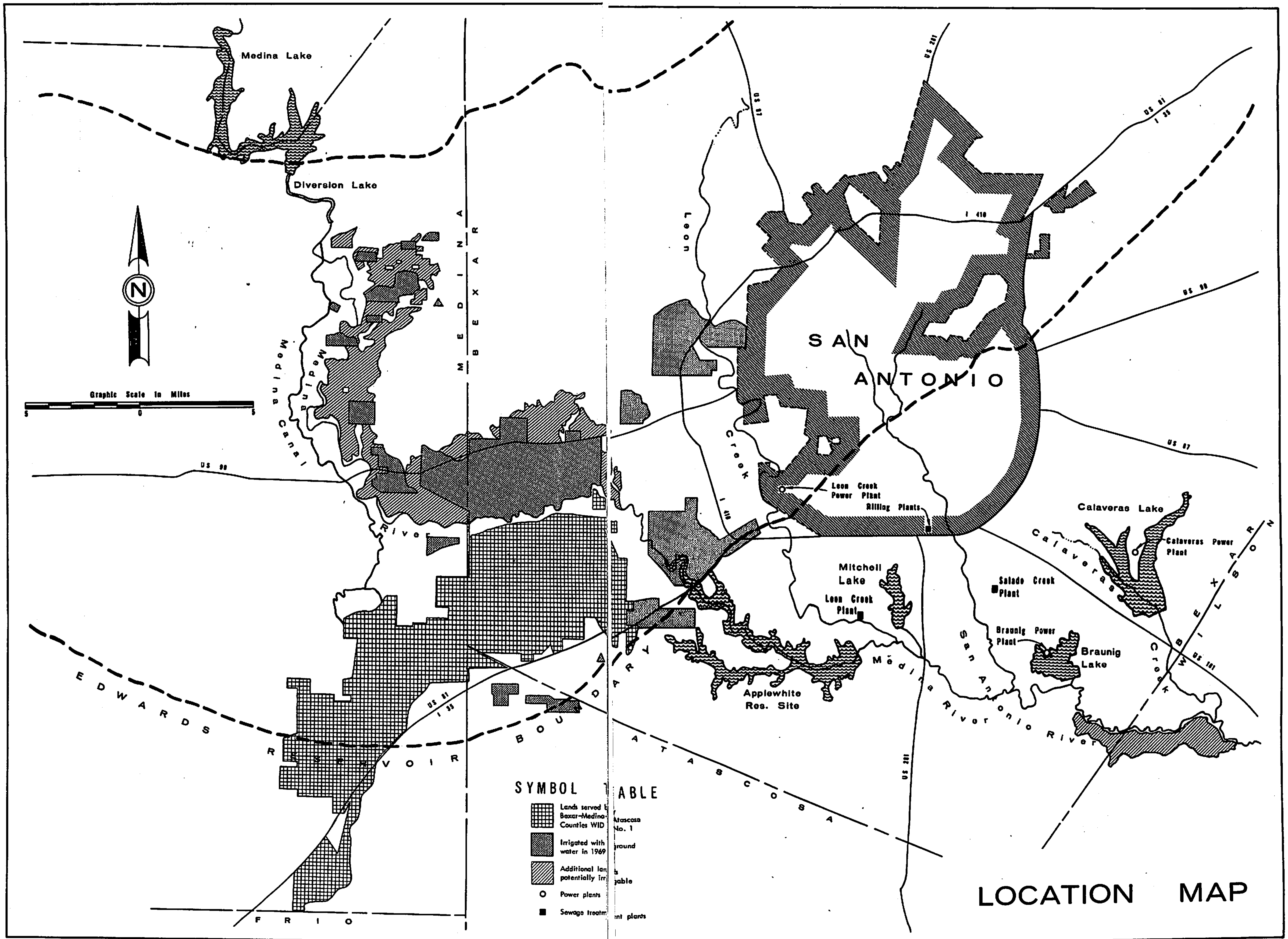
At the present time, three of the City Public Service Board's operational plants, with 823 megawatts of combined capacity, take their cooling water from wells and utilize cooling towers to dispose of excess heat. The remaining 880 megawatts of existing capacity are at the Victor Braunig plant, where condenser cooling water circulates through Braunig Lake and makeup water to keep the lake full is diverted from the San Antonio River (see Figure 3.1).

Table 3.1

San Antonio Electric Power Requirements: 1951-1969

	Kilowatt-Hours Generated	Peak Demand In Kilowatts
1951	740,713	165,956
1952	811,331	186,200
1953	980,995	213,300
1954	1,152,150	245,800
1955	1,273,101	268,700
1956	1,460,490	300,100
1957	1,467,403	333,700
1958	1,574,182	358,800
1959	1,747,944	395,800
1960	2,060,064	438,000
1961	1,990,183	440,700
1962	2,306,681	548,000
1963	2,567,733	571,000
1964	2,636,078	625,000
1965	2,811,698	664,000
1966	3,107,040	759,000
1967	3,512,454	840,000
1968	3,930,183	941,000
1969	4,524,422	1,107,000

Note: These quantities are for the twelve months beginning with February 1 of the year indicated and extending through January 31 of the following year, as given in the annual reports of the City Public Service Board (3).



LOCATION MAP
Medina Lake
Diversion Lake
Graphic Scale in Miles
5
0
5
N
MEDINA
BEXAR
Medina Canal
Medina River
US 90
SAN ANTONIO
Leon Creek
Leon Creek Power Plant
Rilling Plants
Calaveras Lake
Calaveras Power Plant
Calaveras Creek
Mitchell Lake
Leon Creek Plant
Salado Creek Plant
Braunig Power Plant
Braunig Lake
Applewhite Res. Site
Medina River
San Antonio River
EDWARDS RESERVOIR BOUNDARY
ATASCOSA
WILSON
FRIO
US 87
US 281
US 81
I 35
I 410
SYMBOL TABLE
Lands served by Bexar-Medina-Atascosa Counties WID No. 1
Irrigated with ground water in 1969
Additional lands potentially irrigable
Power plants
Sewage treatment plants

FIGURE 3.1

In 1972, the Calaveras plant will go into service, and it also will use lake circulation based primarily on water pumped from the river. Wastewater released from the municipal sewage treatment plants is an appreciable part of the San Antonio River discharge at the point of diversion and comprises nearly all of the flow during dry periods. In effect, the Braunig and Calaveras plants will depend on reclaimed wastewater for their necessary cooling supply.

Existing water rights pertaining to diversions from the San Antonio River into the power plant lakes are summarized in Table 3.2. Under terms of these permits, the City Public Service Board is entitled to pump 60,000 acre-feet per year from the river to Lake Calaveras and can also transfer up to 12,000 acre-feet per year from the river to Lake Braunig. All of

Table 3.2

Summary of Water Rights Associated with Lakes Braunig and Calaveras

	Lake Braunig	Lake Calaveras
Application number and date of filing	2189 4/13/61	2509 4/25/67
Permit number and date of issuance	1990 8/21/61	2325 2/8/68
Amendment number and date of issuance	None	2325a 3/22/68
Maximum annual diversion from the San Antonio River in acre-feet	12,000*	60,000
Allowable consumptive use from reservoir in acre-feet per year	12,000	37,000

*Note: The 12,000 acre-feet per year of Permit 1990 apply to the combined amount of diversions from the San Antonio River plus runoff captured from the small watershed contributing to Lake Braunig.

the Braunig diversions can be applied to consumptive use, but total consumptive use at Lake Calaveras is limited to 37,000 acre-feet per year. Thus, if the full allowable Calaveras diversions are made, a substantial volume of water will necessarily return to the river after passing through the lake. No San Antonio River water can be taken under either permit unless a minimum flow of 10 cubic feet per second is left in the river at the Elmendorf gage, just downstream from the point of diversion.

To support the operation of a power plant cooling lake, sufficient water is needed to replace (a) natural evaporation from the lake surface, (b) additional induced evaporation associated with the cooling process, (c) releases necessary to keep suitable chemical concentrations in the lake water, and (d) other miscellaneous losses, which in the present instance should be small enough to be ignored. The net depth of annual natural evaporation (i.e., gross evaporation adjusted for the compensating effect of rainfall on the lake) in and around San Antonio reaches maximum values of 60" or more in dry years. Induced evaporation accounts for approximately 1/3 gallon of water per kilowatt-hour of electrical energy produced. The engineering report on water supply for the Calaveras project (4) estimates induced evaporation at 9.5 acre-feet per megawatt-year of plant output, which is equivalent to 1.084 acre-feet per 1,000 megawatt-hours, or .353 gallon per kilowatt-hour; that relationship will be used in this study.

To keep concentrations of dissolved inorganic impurities within recommended limits in the cooling lakes after the first few years of operation, it will be necessary to spill or release volumes of water averaging approximately half of the amounts diverted from the San Antonio River, plus a lesser fraction of the lakes' own natural runoff. (Chemical quality criteria and the need for releases to maintain acceptable quality will be discussed more fully in Section 5.) In critical drouth years, there may be no natural runoff from the small watersheds above the cooling lakes, and all supplemental water must come from the San Antonio River. At those times, it should be anticipated that half of the diversions will need to be passed through the reservoirs to get rid of excess dissolved chemicals and protect the quality of the cooling water.

Once the power plants have been developed to full capacity, it will be necessary to keep Lakes Braunig and Calaveras essentially full in order to have adequate lake surface acreage for proper cooling performance when all units are operating. Minor, temporary depletions of storage can be accepted, but the evaporative losses should nearly always be replaced as they occur.

In general, the percentage utilization of a given plant will tend to decrease with time, as newer and more efficient generating units are added elsewhere in the system. The Braunig plant is now scheduled to be completed in 1976, but construction at the Calaveras plant is programmed to continue through 1982 (3). Thus, maximum water usage will develop sooner at the Braunig Lake, and it is unlikely that both plants will experience their maximum water requirements in the same year.

Where major generating plants are depending on a water supply for continued satisfactory operation, it is important to have the water committed to that use and available when needed. Basically, each plant should always have in sight an annual volume of supplemental water equal to the maximum diversions which might be needed under drouth conditions, with due consideration given to diminishing requirements for induced evaporation if a plant's load factor decreases with age. Table 3.3 outlines estimated potential requirements for the Braunig Lake at five-year intervals through the year 2000, and Table 3.4 shows similar information for Lake Calaveras.

According to the customary criteria applied by the Texas Water Rights Commission, only the induced evaporation caused by power plant cooling would be counted as consumptive use, and both of the existing permits are more than sufficient in this respect. However, the 12,000 acre-feet per year diversion limit of the Braunig permit is substantially less than the probable total requirement when replacement of natural evaporation and maintenance of chemical quality are also considered. The 60,000 acre-feet per year allowed by the Calaveras permit will be adequate for normal hydrologic conditions but cannot be expected to hold the lake quality within desirable concentrations if a period of heavy plant output should coincide with a severe drouth.

Sites for other power plant cooling lakes near San Antonio are limited, and the only likely prospect appears to be at Mitchell Lake, which might conceivably be enlarged and used for that purpose in the future. (Further details of this possibility will be discussed in Section 6.) Mitchell Lake could be raised enough to support a generating plant of approximately 1,400 megawatts capacity. If use is to be made of Mitchell Lake for this purpose, it may have to be prior to 1980. New generating units built after that time are expected to be quite large and will possibly be larger than can be served properly by a lake of that size. Table 3.5 shows the estimated water needs associated with the

Mitchell Lake plant, assuming that a 700 MW unit would be in service by 1980 and a second unit of the same size would be added by 1985.

Table 3.3

Projection of Potential Supplemental Water Requirements To Support Lake Braunig Under Drouth Conditions

	Megawatts of Installed Capacity	Potential Annual Load Factor	Potential Diversion Requirement: Nat. Evap. Makeup	Ac-Ft/Yr Ind. Evap. Makeup	Quality Maint.	Total Diversion
1975	880	.50	7,000	4,200	11,200	22,400
1980	1,310	.40	7,000	5,000	12,000	24,000
1985	1,310	.30	7,000	3,700	10,700	21,400
1990	1,310	.30	7,000	3,700	10,700	21,400
1995	1,310	.30	7,000	3,700	10,700	21,400
2000	1,310	.30	7,000	3,700	10,700	21,400

Table 3.4

Projection of Potential Supplemental Water Requirements To Support Lake Calaveras Under Drouth Conditions

	Megawatts of Installed Capacity	Potential Annual Load Factor	Potential Diversion Requirement: Nat. Evap. Makeup	Ac-Ft/Yr Ind. Evap. Makeup	Quality Maint.	Total Diversion
1975	860	.60	18,000	4,900	22,900	45,800
1980	2,452	.55	18,000	12,800	30,800	61,600
1985	3,552	.50	18,000	16,900	34,900	69,800
1990	3,552	.45	18,000	15,200	33,200	66,400
1995	3,552	.40	18,000	13,500	31,500	63,000
2000	3,552	.35	18,000	11,800	29,800	59,600

Table 3.5

Projection of Potential Water Requirements
To Provide Condenser Cooling for a Power Plant at Mitchell Lake
Under Drouth Conditions

	Megawatts of Installed Capacity	Potential Annual Load Factor	Potential Requirement in Ac-Ft/Yr			
			Natural Evap. Makeup	Induced Evap. Makeup	Quality Main-tenance	Total Potential Requirement
1980	700	.60	7,300	4,000	11,300	22,600
1985	1,400	.55	7,300	7,300	14,600	29,200
1990	1,400	.50	7,300	6,600	13,900	27,800
1995	1,400	.45	7,300	6,000	13,300	26,600
2000	1,400	.40	7,300	5,300	12,600	25,200

Water released for quality maintenance at Mitchell Lake would flow downstream and be available for diversion and further use in the Braunig and Calaveras Lakes. Also, construction of a generating plant at Mitchell Lake before 1980 would probably mean deferral for a few years of the ultimate stages of development at Calaveras, so that the new water requirements for power plant cooling at Mitchell Lake would be offset in part by savings in water use at Lake Calaveras until some time after 1985. And, finally, the depletion in flow of the San Antonio River, resulting from power plant operation at Mitchell Lake, would raise slightly the concentrations of total dissolved solids in water diverted from the river into Lakes Braunig and Calaveras; this would cause a corresponding increase in the volume of diversions needed to hold chemical concentrations within tolerances in those lakes. The combined effect of these factors will be set forth in the final portion of this section, as part of the over-all summary of available water and potential uses.

Irrigation: Lands Near Mitchell Lake

There are already long-standing commitments to furnish wastewater from the Rilling Road treatment plants for irrigation of lands in the vicinity of Mitchell Lake (see Figure 3.1). These obligations, stemming mostly from contracts with the landowners, account for approximately 16,200 acre-feet per year (4). As long as these commitments continue in effect, they should be considered to constitute a first claim to that amount of wastewater.

Irrigation: Bexar-Medina-Atascosa Counties WID No. 1

Bexar-Medina-Atascosa Counties Water Improvement District No. 1 furnishes water for 30,000 to 35,000 acres of land, lying mostly between the Southern Pacific Railroad and Interstate Highway 35 to the southwest of San Antonio. The location of this land is shown on the map in Figure 3.1. The District operates Medina Lake, which is its main source of supply, on the Medina River in Bandera and Medina Counties. Water is released from Medina Dam into the smaller Diversion Reservoir immediately downstream and from there is conveyed by canal to the service area.

The dam sites and reservoirs of the two lakes lie within the region which provides recharge for the Edwards Underground Reservoir. Except when Medina Lake is at very low levels, there are noticeable water losses through the dam abutments, as well as considerable seepage from the lakes into sub-surface formations. Historically, the irrigation supply has not been entirely dependable, and the main reservoir has been nearly empty about once every 10 years on the average. Table 3.6 gives the lake contents, diversions and acres irrigated since 1940. It can be seen that

Table 3.6

Lake Medina Contents and Diversions: 1940-1969

	Contents At Start of Year (Ac-Ft)	Minimum End-of-Month Contents During Year Ac-Ft	Month	Diversions In Ac-Ft	Acres Irrigated
1940	49,440	1,770	Oct.	21,549	20,850
1941	25,290	25,070	Jan.	8,466	16,932
1942	135,100	103,900	Aug.	9,311	18,000
1943	136,100	73,520	Dec.	20,667	18,000
1944	73,520	72,360	Jan.	33,834	18,000
1945	78,410	78,880	Aug.	14,120	20,200
1946	82,600	58,200	Aug.	24,890	35,241
1947	84,930	15,600	Dec.	21,917	31,000
1948	15,600	1,380	Aug.	8,232	4,116
1949	4,940	6,290	Jan.	3,217	3,000
1950	24,630	2,160	Oct.		
1951	3,960	4,330	Jan.	0	0
1952	9,180	8,320	Feb.	0	0
1953	27,380	10,890	July	5,850	4,323
1954	36,100	2,160	Dec.	33,700	4,367
1955	2,160	2,720	Jan.	0	0
1956	10,340	6,730	Oct.	0	0
1957	7,020	6,370	Feb.	10,880	1,502
1958	130,500	155,000	Jan.	25,480	7,872
1959	254,000	235,400	Sept.	34,860	9,941
1960	244,700	226,300	July	35,400	13,129
1961	255,700	225,300	Dec.	41,780	12,164
1962	225,300	134,000	Dec.	55,990	25,641
1963	134,000	51,450	Dec.	46,900	25,585
1964	51,450	19,120	Aug.	34,240	20,294
1965	66,300	63,510	Jan.	25,210	14,291
1966	95,030	85,160	July	30,030	16,687
1967	93,310	33,830	Aug.	44,380	29,369
1968	64,440	92,740	Jan.	22,960	9,413
1969	155,000	122,700	Sept.	26,450	10,970

Notes: Lake content at spillway level: 254,000 Ac-Ft. Diversions and acreages based on water use files of Texas Water Rights Commission. No record of diversions or acreage available for 1950.

the storage was drawn down almost to the bottom in 1940 and again in 1948. There were several years during the drouth period of the 1950's when little or no supply was available for the irrigation system. Substantial runoff occurred in 1957 and 1958, and there appears to have been enough water to meet the annual needs since that time. The average diversion rate during the 12 years 1958-1969 was approximately 35,000 acre-feet per year, and the average annual land area served in that period was slightly more than 16,000 acres.

One of the basic concepts of this study has been that, if the irrigation requirements of the Bexar-Medina-Atascosa District could be served satisfactorily with reclaimed wastewater, it might be mutually advantageous for all concerned to exchange a dependable supply of reclaimed water for the present Medina Lake source. It is clear that Medina Lake is already contributing important amounts of recharge to the Edwards Underground Reservoir. Without diversions for irrigation, the lake would tend to remain at higher levels, and the amount of recharge would be increased. San Antonio would benefit from the additional recharge, and the irrigators would benefit from having a supply which could be relied upon to be available every year. For purposes of this investigation, the amount of reclaimed wastewater considered for such use has been estimated at between 25,000 and 35,000 acre-feet per annum. In addition to the water delivered to the Bexar-Medina-Atascosa District, it would also be necessary to put enough water into the conveyance system to compensate for losses from seepage and evaporation between the Rilling Road treatment plant and the main Medina Canal. Such losses have been assumed herein to be 20% of the delivered quantity.

Irrigation: Other Lands West and Southwest of San Antonio

As can be seen from Figure 3.1, there is also considerable other land to the west and southwest of San Antonio which either is now being irrigated or could be irrigated in the future. The Texas Water Development Board compiled summaries of irrigation activity in the State in 1958 and 1964 (5) and is now completing a similar report on conditions in 1969. Table 3.7 reflects the extent of irrigation in Bexar, Medina and Atascosa Counties at the times of those studies, including preliminary data collected for the unpublished 1969 survey. Of the lands indicated by Table 3.7, some 17,400 acres in western Bexar and eastern Medina Counties, in a band running parallel to the Medina River, could be served by a canal system conveying reclaimed water from San Antonio. This land is now using Edwards Reservoir water, and it is estimated that as many as 25,000 acres in the same general area could eventually come to be irrigated from that source. If the reclaimed water could be used here, the resulting decrease in pumpage from the ground water formations would be quite significant. Assuming over-all irrigation of 20,000 acres and allowing 2 feet per acre annually, there would be a requirement for 40,000 acre-feet of reclaimed water per year in this area, with corresponding savings in pumpage from the Edwards Reservoir. As with the supply for the Bexar-Medina-Atascosa District, it would be necessary to provide enough additional wastewater (estimated at about 20% of the volume being delivered) to make up for losses in the conveyance system.

Irrigation: Lands Southeast of San Antonio

Also shown in Figure 3.1 is an area on the south side of the San Antonio River in southeastern Bexar County and northwestern Wilson County

Table 3.7

Irrigation in Bexar, Medina and Atascosa Counties: 1959, 1964 and 1969

	All Irrigation		With Surface Water		With Ground Water		Mixed Supply		Irrig. Wells
	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	
Bexar									
1958	27,100	39,195	10,500	14,845	16,600	24,350	0	0	102
1964	29,961	61,771	14,700	29,371	15,261	32,400	0	0	133
1969	29,229	34,534	6,573	7,053	7,521	10,311	15,135	17,170	135
Medina									
1958	13,400	21,893	5,400	10,661	8,000	11,232	0	0	40
1964	19,564	38,169	10,500	23,708	9,064	14,461	0	0	54
1969	26,210	81,951	13,100	29,967	13,110	51,984	0	0	117
Atascosa									
1958	23,200	30,915	0	0	23,200	30,915	0	0	201
1964	28,505	43,479	175	201	28,330	43,278	0	0	253
1969	33,050	52,155	175	178	32,875	51,977	0	0	290
All Three									
1958	63,700	92,003	15,900	25,506	47,800	66,497	0	0	343
1964	78,030	143,419	25,375	53,280	52,655	90,139	0	0	440
1969	88,489	168,640	19,848	37,198	53,506	114,272	15,135	17,170	542

where the topography is well suited to irrigation and where it would be physically possible to deliver reclaimed wastewater. At this location there are approximately 4,000 acres of potentially irrigable land, beginning opposite the Braunig Plant Lake and extending some 7 miles along the river to a point past the mouth of Calaveras Creek, near the town of Calaveras. Most of the possible acreage is now under cultivation, and the Water Development Board surveys (5) show a limited amount of irrigation, largely with water pumped from the river.

This area is not underlain by the Edwards limestone and related formations, so that use of reclaimed water here would not save pumpage from the Edwards Underground Reservoir. On the other hand, it would represent a significant volume of new irrigation, without some of the difficulties inherent in changing a major existing irrigation system to operation based on reclaimed wastewater. The land in question is far enough from San Antonio not to be subject to large-scale urban development in the foreseeable future.

The most obvious way to deliver water from the sewage treatment plants to this area would be via the San Antonio River. Water released to flow downstream from the plants could be intercepted by a diversion pump station at the upper end of the irrigation system and lifted into the main canal. Delivery could also be accomplished by conveying the water through the Braunig Plant Lake and thence by pipe line under the San Antonio River and into the canal. The first alternative would involve less initial investment but would not be fully satisfactory unless the City could retain ownership of the water while using the stream channel to transfer it to the point of re-use. The second method would keep the water within conveyance facilities built and owned by the City, and the question of continuity of ownership would not arise; using that method, it would also be possible to operate by gravity flow, without need for pumping, and annual operating costs would be less. In particular, the second alternative would be preferable if large amounts of reclaimed wastewater are routed from one or more of the treatment plants through Lake Braunig for purpose of quality enhancement, without intermediate use of the San Antonio River channel, as will be discussed more fully in Section 6.

The quantity of water needed for delivery at the western end of the irrigation system would be 2 acre-feet per year per acre served, plus about 15% allowance for transmission losses in the main canal, or approximately 9,200 acre-feet per year. Movement of the water from the plants to the beginning of the main canal would involve relatively minor losses over and above those already attributable to the other accompanying flows either in the river or in Lake Braunig.

Downstream Water Rights

Table 3.8 is a list of prior water rights currently in force on the San Antonio and Medina Rivers downstream from San Antonio's sewage treatment plants. Although the Water Rights Commission has given the City Public Service Board permission to divert up to 72,000 acre-feet per year of supplemental water from the river and store it in the power plant lakes, the appropriations shown in Table 3.8 are prior in time and therefore would have first call on public waters of the State if there is not enough to satisfy all demands. The Water Rights Commission has held that, once the wastewater enters a stream channel, it becomes public water and thus subject to normal water rights priorities.

Table 3.8

Summary of Prior Water Rights on the San Antonio and Medina Rivers
Downstream from San Antonio's Sewage Treatment Plants

Application Number	Permit Number	Date of Appl.	Name of Owner	Acre-Feet Per Year
San Antonio River				
Certified Filing	187	1902-13	Martin, W. B., Jr.	400
Certified Filing	623	6/26/14	Yturri, Robert and John	300
245	230	11/27/17	A.D.D. Corp., et al.	150
1065	1109	11/10/26	A.D.D. Corp., et al.	384
1017	948	3/24/26	Ashley, Edward G.	354
1784	1657	11/18/52	Benton, C.E.	34
1377	1289	7/15/39	Bisset, Maud	92
206	197	6/30/17	Blue Wing Club	400
1947	1809	12/ 5/55	Cannon, Lola, et al.	350
1719	1589	8/ 1/51	Carroll, R. C.	81.5
1962	1820	2/27/56	Clarke, Robt. Irby, et al.	680
236	227	10/30/17	Creighton, Marguerite, B., et al.	304
1956	1487	1/13/49	Davenport, Mrs. Frank J.	140
939	883	7/ 1/25	Fahrenthold, Clyde H.	24
1887	1762	3/23/55	Hensley, Verdie E.	232
1034	969	5/10/26	Hoover, Giles N.	82
1299	1220	6/11/34	Hosek, Willie	35
1955	1813	1/13/56	Irby, R. N.	800
2075	948A	12/12/57	Johnson, H. H. Jr., et al.	200
1617	1507	3/29/49	Kelman, Philipp	38
1792	1664	1/20/53	Kolenda, Nick	150
1375	1287	5/26/39	Kowalik, E. V.	34
220	211	8/30/17	Labus, Frank & J. A.	200
1983	1839	7/16/56	Lott, Campbell	70
1581	1474	10/ 8/48	Maha, Mrs. Otto H.	18
932	874	6/ 8/25	McDonald, J. R.	30
1916	1785	6/13/55	Moczygemba, Sam	73
1392	1303	5/ 1/40	Morris, Ben B.	270
1289	1211	6/16/33	Nitsche, Arnold G.	47.5
943	885	7/11/23	Ocker, D. & A.D.D. Corp.	80
1403	1312	11/ 7/40	Pawelek, Benjamin	100
980	915	10/ 5/25	Pawelek, Louis B.	100
1537	1431	11/14/47	Pogue, C. M.	) 1,050
1837	1705	3/22/54	Pogue, C. M.	)
1648	1541	4/25/50	Ramsey Farms	586.2
1597	1490	1/20/49	Ramsey, Robert H., et al.	554.2
1750	1621	3/17/52	Richardson, A. D.	115
234	223	10/ 3/17	Schneider, E.W.	226
1542	1441	12/ 1/47	Seale, S. W.	92

Table 3.8, Continued

Application Number	Permit Number	Date of Appl.	Name of Owner	Acre-Feet Per Year
262	248	1/30/18	Sickenus, Victor Fred	176
1376	1288	5/26/39	Urbanczyk, Benedict P.	64
2041	1881	4/ 9/57	Welder, James F., Heirs	861.8
1738	1613	1/10/52	West, J. A.	200
			Total	10,178.2
Medina River				
1823	1693	10/26/53	Kappmeyer, T.G.	53
2	2	9/30/13	Pickett, Melvin	350
			Total	403
			Over-All Total	10,581.2

The aggregate total of the indicated prior rights, all of which are for irrigation, is 10,581 acre-feet per year. There will be a need to release considerably more than this amount from the power plant lakes in order to avoid undue concentrations of dissolved minerals in the cooling water. Thus, it is not anticipated that the downstream demands associated with existing permits will have any adverse effect on the rights of the City of San Antonio to use the reclaimed water.

Water for Navigation Lockage

Table 3.9 reflects the annual volumes of water required to support navigation on the San Antonio River, based on preliminary estimates by the Galveston District of the U. S. Army Corps of Engineers (6). The locks are listed in upstream-to-downstream order; lock No. 12 would be at the head of navigation, and lock No. 1 would be at the end nearest the Gulf of Mexico.

Table 3.9

Estimated Water Requirements for Navigation On the San Antonio River

- Quantities in Acre-Feet per Year -

Lock No.	1985	2010	2035
12 (Upstream end)	188,000	223,000	293,000
11	210,000	250,000	327,000
10	215,000	255,000	332,000
9	219,000	259,000	336,000
8	225,000	265,000	342,000
7	0	0	0
6	221,000	258,000	334,000
5	221,000	258,000	334,000
4	210,000	245,000	315,000
3	158,000	182,000	230,000
2	162,000	186,000	234,000
1	77,000	86,000	104,000

Although treated sewage is not the only source of supply for meeting navigation requirements, it often constitutes the bulk of the flow in upper reaches of the river. Thus, the quantities shown in Table 3.9 stand for reclaimed wastewater in large part, and navigation would not be feasible without substantial amounts of continuous return flow from the San Antonio area. To date, there has not been a definitive study of the navigation project, and it is uncertain whether there now remains enough uncommitted wastewater to make it feasible.

Summary of Potential Wastewater Use Versus Availability

Table 3.10 outlines the projected supply of reclaimed wastewater in comparison with predictable requirements for irrigation around Mitchell Lake and for power plant cooling at Lakes Braunig and Calaveras. Line "g" of the table shows annual volumes of re-usable wastewater that are

Table 3.10

Summary of Projected Reclaimed Wastewater Availability In Excess of Predictable Needs for Lake Braunig, Lake Calaveras, and Local Irrigation

- Quantities in 1,000 Acre-Feet per Year -

	1975	1980	1985	1990	1995	2000
a. Estimated total re-usable wastewater	109.0	121.0	134.0	147.0	160.0	173.0
b. Irrigation requirements near Mitchell Lake	16.2	16.2	16.2	16.2	16.2	16.2
c. Potential requirement for diversion to Lake Braunig	22.4	24.0	21.4	21.4	21.4	21.4
d. Potential requirement for diversion to Lake Calaveras	45.8	61.6	69.8	66.4	63.0	59.6
e. Releases from Lake Braunig for quality maintenance	11.2	12.0	10.7	10.7	10.7	10.7
f. Minimum required flow at the Elmendorf gaging station	7.3	7.3	7.3	7.3	7.3	7.3
g. Excess of basic supply over and above potential requirements (a - b - c - d)	24.6	19.2	26.6	43.0	54.9	75.8
h. Excess of Lake Braunig releases over required Elmendorf flow (e - f)	3.9	4.7	3.4	3.4	3.4	3.4

expected to be available for other uses at 5-year intervals through the year 2000. Line "h" indicates the amounts which, although included in the power plant cooling water diversions, would return to the river after passage through Lake Braunig and would then be subject to further use if irrigation is undertaken below Lake Braunig. It is assumed that at least 7,300 acre-feet per year would pass on downstream to maintain the required 10 cfs minimum flow at the Elmendorf gaging station and thus would not again be available. Outflows from Lake Calaveras are not considered accessible for further use. The Calaveras releases and the minimum Elmendorf flows total substantially more than the existing prior water rights along the river and should be sufficient to satisfy such requirements.

Table 3.11 is a similar comparison of water supply and requirements if Mitchell Lake should be used for a power plant site. As mentioned earlier, power plant operation at Mitchell Lake would raise chemical concentrations in the river and thereby increase the amounts of diversions needed to maintain quality conditions in Lakes Braunig and Calaveras. Also, if a new plant is built at Mitchell Lake prior to 1980 as assumed in Table 3.11, it probably would defer temporarily the final stages of development of the Calaveras generating plant. Both of these factors are reflected in the diversions for Lake Braunig and Lake Calaveras in Table 3.11.

Tables 3.10 and 3.11 are based on drouth conditions and do not count on natural runoff either from the watersheds of the power plant lakes or from the San Antonio River drainage above the Braunig diversion point. Normally, there would be some natural runoff, at least in certain months of the year. However, most of the uses being considered here are

Table 3.11

Summary of Projected Reclaimed Wastewater Availability To Meet Predictable Needs for Lake Braunig, Lake Calaveras, and Irrigation Near Mitchell Lake Plus Power Plant Cooling at Mitchell Lake

\- Quantities in 1,000 Acre-Feet per Year -

	1975	1980	1985	1990	1995	2000
a. Estimated total re-usable wastewater	109.0	121.0	134.0	147.0	160.0	173.0
b. Irrigation requirements near Mitchell Lake	16.2	16.2	16.2	16.2	16.2	16.2
c. Potential natural and induced evaporation loss at Mitchell Lake	-	11.3	14.6	13.9	13.3	12.6
d. Potential Requirement for diversion to Lake Braunig	22.4	27.3	24.9	24.3	23.8	23.5
e. Potential requirement for diversion to Lake Calaveras	45.8	60.9	72.7	75.3	70.2	65.4
f. Releases from Lake Braunig for quality maintenance	11.2	15.3	14.2	13.6	13.1	12.8
g. Minimum required flow at the Elmendorf gaging station	7.3	7.3	7.3	7.3	7.3	7.3
h. Excess of basic supply over and above potential requirements (a - b - c - d - e)	24.6	5.3	5.6	17.3	36.5	55.3
i. Excess of Lake Braunig releases over required Elmendorf flow (f - g)	3.9	8.0	6.9	6.3	5.8	5.5

predicated on the supply being dependable even in dry years, and the comparison should therefore be made on that basis. The power plant cooling water must be reliable. The concept of using reclaimed wastewater in the Bexar-Medina-Atascosa District presumes that it would be continuously available, in contrast to the present Medina River source. If reclaimed wastewater is to be suitable for irrigation on other lands west of San Antonio, it would need to be as dependable as the present ground water supply in that area.

It is apparent from Table 3.10 that the amounts of wastewater available on a dependable basis for additional irrigation will be appreciably less than the potential usage west of San Antonio until about 1990 or after, even if there is no further increase in requirements for power plant cooling beyond those for the Braunig and Calaveras generating plants. If reclaimed wastewater is used for condenser cooling at a new power plant on Mitchell Lake (Table 3.11), there may not be enough remaining uncommitted water to justify undertaking major irrigation to the west until nearly the year 2000. Sufficient water is available on an annual basis to support the lesser amount of irrigation southeast of San Antonio, although the balance of uncommitted water would be relatively small until about 1985 if Mitchell Lake is also utilized for power plant cooling.

Because of seasonal differences in supply and demand, it will not be practical to utilize 100% of the annual supply for any of the purposes envisioned herein. Output from the municipal sewage treatment plants is approximately uniform throughout the year but slightly lower than average during the summer months. Cooling water demands are highest in those same summer months, although diversions to the power plant lakes can in general be accommodated to the supply by adjusting the timing of releases for quality maintenance. Irrigation needs are also heaviest during the summer growing season, when the wastewater flow is least; significant amounts of reservoir storage space would be needed to avoid losing wastewater produced in the winter, when it could not all be used on the land.

Thus, the annual supply cannot as a rule be matched exactly with the annual requirements. In most practical cases there will be times during the year when output of the wastewater reclamation plants is more than can currently be utilized, and when it is not feasible to provide storage for the excess. At those times, part of the over-all reclaimed water supply will unavoidably flow downstream and pass beyond reach insofar as local re-use is concerned.

Table 3.12 shows projected monthly schedules of wastewater availability for service to Lake Braunig, Lake Calaveras and the proposed southeast irrigation under drouth conditions as of 1980 and 1985, the dates that would be most critical. The table indicates estimated monthly demands for irrigation near Mitchell Lake and for replacement of losses due to natural and induced evaporation at the power lakes. Also shown is the minimum flow which must be allowed to go past the Elmendorf gaging station in accordance with the Braunig and Calaveras water rights permits. Column (f) reflects the balance of the supply of reclaimed wastewater remaining after satisfying those primary requirements. Part of the remaining water would be needed to pass through the lakes for quality maintenance, and part would be available for irrigation.

The total yearly volumes needed for quality protection would be

Table 3.12

Projected Monthly Schedules of Wastewater Availability
For Power Plant Cooling at Lake Braunig and Lake Calaveras
And Irrigation Southeast of San Antonio: Drouth Conditions, 1980 and 1985

- 1,000 Acre-Feet -

	(a) Total Available Wastewater	(b) Irrig. Nr. Mitchell Lake	(c) Required To Keep Lakes Full: Braunig	(d) Required To Keep Lakes Full: Calaveras	(e) Minimum Elmendorf Flow	(f) Balance of Wastewater (a-b-c-d-e)	(g) S.E. Irrig. Reqmt.
1980							
Jan	10.8	.3	.5	1.3	.6	8.1	.0
Feb	10.0	.3	.5	1.2	.5	7.5	.2
Mar	11.0	1.3	.8	2.1	.7	6.1	.8
Apr	10.7	1.4	.9	2.2	.6	5.6	.9
May	11.4	2.4	1.0	2.5	.7	4.8	1.3
Jun	9.4	2.6	1.4	3.7	.6	1.1	1.5
Jul	8.6	3.0	1.7	4.3	.6	-1.0	1.8
Aug	8.7	2.4	1.5	4.0	.6	.2	1.3
Sep	10.3	1.0	1.4	3.5	.6	3.8	.6
Oct	9.8	.6	1.0	2.6	.6	5.0	.4
Nov	10.0	.6	.8	1.9	.6	6.1	.3
Dec	10.3	.3	.5	1.5	.6	7.4	.1
Total	121.0	16.2	12.0	30.8	7.3	54.7	9.2
1985							
Jan	12.0	.3	.4	1.5	.6	9.2	.0
Feb	11.2	.3	.4	1.4	.5	8.6	.2
Mar	12.2	1.3	.7	2.4	.7	7.1	.8
Apr	11.7	1.4	.8	2.5	.6	6.4	.9
May	12.6	2.4	.9	2.8	.7	5.8	1.3
Jun	10.4	2.6	1.3	4.1	.6	1.8	1.5
Jul	9.5	3.0	1.5	4.8	.6	-.4	1.8
Aug	9.7	2.4	1.3	4.5	.6	.9	1.3
Sep	11.3	1.0	1.3	3.9	.6	4.5	.6
Oct	10.9	.6	.9	3.0	.6	5.8	.4
Nov	11.2	.6	.7	2.2	.6	7.1	.3
Dec	11.3	.3	.5	1.8	.6	8.1	.1
Total	134.0	16.2	10.7	34.9	7.3	64.9	9.2

Notes: Negative values in Column (f) indicate net depletions of cooling lakes due to evaporative losses and other primary demands exceeding available reclaimed wastewater flows. Amounts shown for months following negative values in Column (f) would be used as necessary to re-fill the depleted storage.

approximately equal to the diversions required to replace evaporation and keep the lakes full: 42,800 acre-feet in 1980 and 45,600 acre-feet in 1985. The month-to-month distribution of diversions for quality maintenance could be fairly flexible, and could usually be adapted to coincide with times when there is excess flow. Thus, although the monthly figures in Column (f) of the table do not follow the same pattern as makeup requirements for evaporative losses, there is enough water overall to keep the chemical concentrations within reasonable bounds. More thorough analysis of this aspect will be covered in Section 5 and Appendix C. It will also be possible to utilize some of the quality maintenance releases from Lake Braunig to make up all or part of the minimum discharge at the Elmendorf gage.

The irrigation demands, on the other hand, would basically have to be satisfied during the months when they occur, or not at all. When the remaining balance of the available wastewater, after meeting the uses indicated in Columns (b) through (e) of Table 3.12, is less than the indicated irrigation requirement (i.e., where Column (f) is less than Column (g)), the only way to satisfy the irrigation demand fully is by taking water from storage. This condition is encountered in June, July and August of the 1980 tabulation and in July and August of the 1985 summary. As indicated by negative values in Column (f), the cooling lakes would already be drawn down slightly during July because the evaporative losses would exceed the water available for diversion, without leaving any of the wastewater flow in those months for quality maintenance or irrigation. In order to be sure of having the irrigation water on a fully dependable basis, it would be necessary to have available approximately 3,300 acre-feet from storage as of 1980 and 2,200 acre-feet as of 1985. Since July and August are times of minimal runoff even in normal years, the storage would have to be available if new wastewater irrigation southeast of San Antonio is to be feasible.

Table 3.13 presents information similar to that of Table 3.12, but including allowance for development of Mitchell Lake as a power plant site. As would be expected, the need for regulating storage to allow irrigation in the summer months becomes more pronounced if part of the supply is allocated to use at Mitchell Lake. The storage levels in the cooling lakes are indicated to fall slightly in July and August, with or without irrigation demands, due to evaporative losses exceeding the wastewater supply. To give full reliability to the irrigation operations, with Mitchell Lake used for power plant cooling, about 3,700 acre-feet of supporting storage would be needed as of 1980 and 3,500 acre-feet as of 1985.

Table 3.13

Projected Monthly Schedules of Wastewater Availability For Power Plant Cooling at Lakes Mitchell, Braunig and Calaveras And Irrigation Southeast of San Antonio: Drouth Conditions, 1980 and 1985

- 1,000 Acre-Feet -

	(a) Rilling Reclaimed Wastewater	(b) Irrig. Nr. Mitchell Lake	(c) Needed to Replace Evaporative Losses in the Cooling Lakes	(d)	(e)	(f) Leon Cr. & Salado Cr. Wastewater	(g) Minimum Elmendorf Flow	(h) Balance (a-b-c-d-e +f-g)	(i) Southeast Irrigation Req'm'ts
			Mitchell	Braunig	Calaveras				
1980									
Jan	8.0	.3	.4	.5	1.0	2.8	.6	8.0	.0
Feb	7.5	.3	.4	.5	1.0	2.5	.5	7.3	.2
Mar	8.2	1.3	.8	.8	1.8	2.8	.7	5.6	.8
Apr	7.9	1.4	.8	.9	1.9	2.8	.6	5.1	.9
May	8.5	2.4	.9	1.0	2.2	2.9	.7	4.2	1.3
Jun	7.0	2.6	1.4	1.4	3.3	2.4	.6	.1	1.5
Jul	6.4	3.0	1.6	1.7	3.9	2.2	.6	-2.2	1.8
Aug	6.5	2.4	1.5	1.5	3.5	2.2	.6	- .8	1.3
Sep	7.6	1.0	1.3	1.4	3.1	2.7	.6	2.9	.6
Oct	7.3	.6	1.0	1.0	2.3	2.5	.6	4.3	.4
Nov	7.5	.6	.7	.8	1.6	2.5	.6	5.7	.3
Dec	7.6	.3	.5	.5	1.2	2.7	.6	7.2	.1
Total	90.0	16.2	11.3	12.0	26.8	31.0	7.3	47.4	9.2

Continued on the next page .....

Table 3.13, Continued

	(a) Rilling Reclaimed Wastewater	(b) Irrig. Nr. Mitchell Lake	(c) Needed to Replace Evaporative Losses in the Cooling Lakes: Mitchell	(d) Braunig	(e) Calaveras	(f) Leon Cr. & Salado Cr. Wastewater	(g) Minimum Elmendorf Flow	(h) Balance (a-b-c-d-e +f-g)	(i) Southeast Irrigation Req'm'ts
1985									
Jan	8.0	.3	.6	.4	1.3	4.0	.6	8.8	.0
Feb	7.5	.3	.6	.4	1.3	3.7	.5	8.1	.2
Mar	8.2	1.3	1.0	.7	2.1	4.0	.7	6.4	.8
Apr	7.9	1.4	1.0	.8	2.2	3.8	.6	5.7	.9
May	8.5	2.4	1.2	.9	2.6	4.1	.7	4.8	1.3
Jun	7.0	2.6	1.7	1.3	3.7	3.4	.6	.5	1.5
Jul	6.4	3.0	2.0	1.5	4.4	3.1	.6	-2.0	1.8
Aug	6.5	2.4	2.0	1.3	4.0	3.2	.6	- .6	1.3
Sep	7.6	1.0	1.6	1.3	3.5	3.7	.6	3.3	.6
Oct	7.3	.6	1.3	.9	2.7	3.6	.6	4.8	.4
Nov	7.5	.6	.9	.7	1.9	3.7	.6	6.5	.3
Dec	7.6	.3	.7	.5	1.5	3.7	.6	7.7	.1
Total	90.0	16.2	14.6	10.7	31.2	44.0	7.3	54.0	9.2

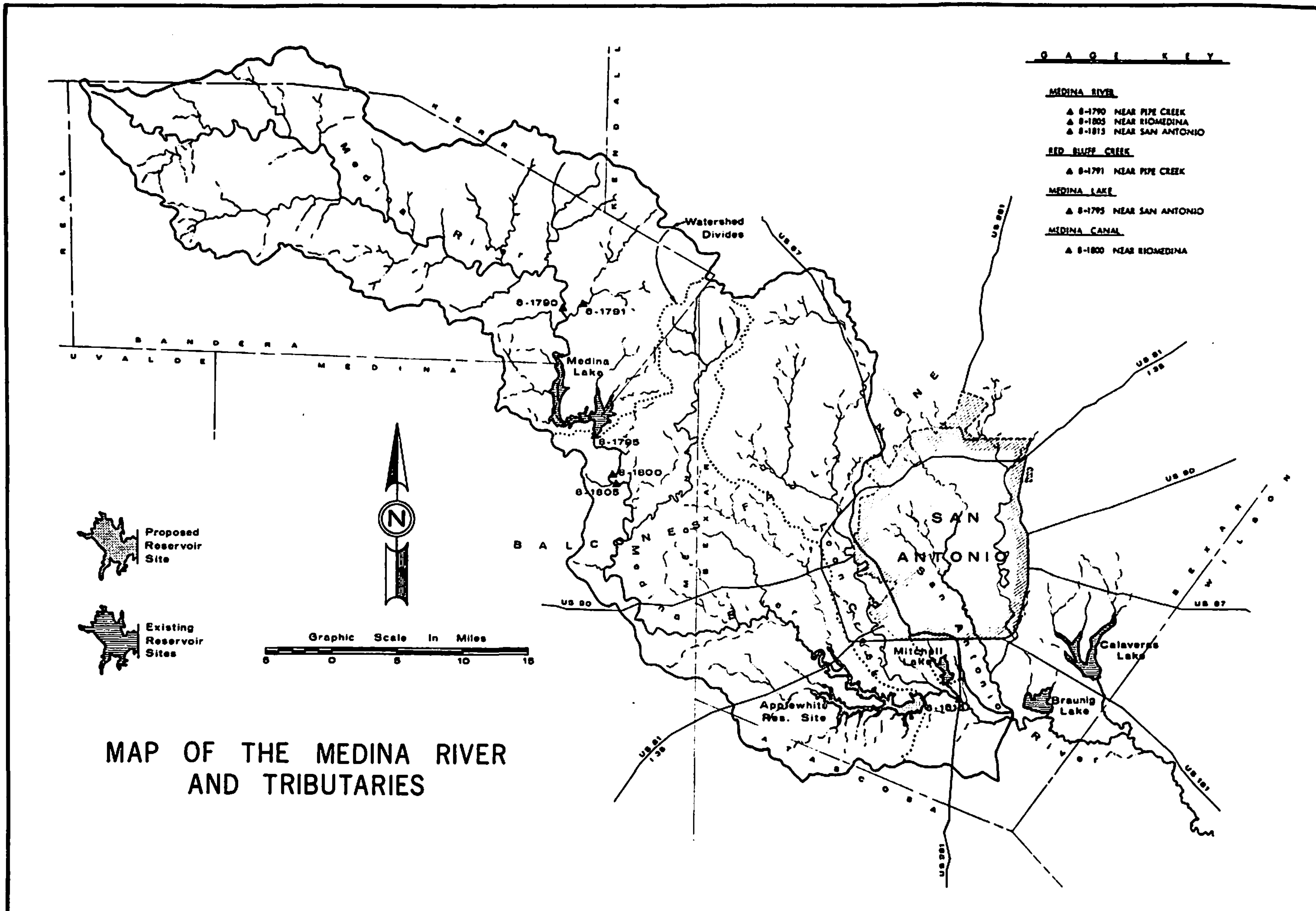
Notes: Negative values in Column (h) indicate net depletions of cooling lake storage due to evaporative losses and other primary demands exceeding available reclaimed wastewater flows. Amounts shown for months following negative values in Column (h) would be used as necessary to re-fill the depleted storage.

4. HYDROLOGY OF THE MEDINA RIVER

The Medina River flows from its headwaters in northwest Bandera County to its confluence with the San Antonio River in southern Bexar County (see Figure 4.1). The terrain in the 1,354 square mile drainage area varies from steep, rugged hills in the upper and middle portions to gently rolling hills in the lower portion. The watershed is crossed by the Balcones fault zone. Measurements of rainfall, runoff, evaporation and other factors affecting surface reservoir performance have been collected and recorded for selected sites in the drainage basin and surrounding area for the past several decades. Various state and federal agencies responsible for collecting such data have published regular summaries of their observations.

Runoff

The basic source of runoff information is the Water Resources Data series (7) of the U. S. Geological Survey. The key stream gaging stations and their available records are summarized in Table 4.1. By correlation of simultaneous records at various gages, and by comparative drainage area measurements, it is possible to obtain good estimates of the historical runoff from 1937 to date. This period of time is long enough to present a balanced coverage of wet and dry years, and it includes the drouth of the 1950's, which is the worst that has been experienced on the river basins near San Antonio since detailed hydrologic records have been maintained. Descriptions of the derivations of the runoff data for Medina Lake and Applewhite Reservoir site, together with summaries of the resulting values, are included in Appendix B.



MAP OF THE MEDINA RIVER AND TRIBUTARIES

FIGURE 4.1

Table 4.1

List of Key Stream Flow and Reservoir Gaging Stations

	Period of Record
Medina River near Pipe Creek	10/1922 - 6/1935 and 1/1953 to Date
Red Bluff Creek near Pipe Creek	4/1956 to Date
Medina Lake	5/1913 to Date
Medina Canal near Riomedina	3/1922 - 5/1934 and 7/1957 to Date
Medina River near Riomedina	1/1922 - 9/1934 and 1/1953 to Date
Medina River near San Antonio	10/1929 - 12/1930 and 7/1939 to Date
Guadalupe River at Comfort	5/1939 to Date
Guadalupe River near Spring Branch	6/1922 to Date

Net Evaporation

Evaporation and rainfall gages have been operated for a number of years by the U. S. Weather Bureau (now the Environmental Science Services Administration). Measurements obtained at these installations are published in monthly and annual bulletins (8, 9). Statewide patterns of losses due to evaporation from surface reservoirs have been evaluated by the Water Development Board for the period from 1940 through 1965 and published as the Board's Report No. 64 (10). These sources, supplemented by Weather Bureau data where necessary, have been used to establish the net evaporation rates for this study. Compilations of the resulting data and descriptions of the derivations are in Appendix B.

Recharge

Medina Lake was built to impound irrigation water for what is now Bexar-Medina-Atascosa Counties Water Improvement District No. 1. Much of the lake is on the outcrop of the Edwards limestone (11), and a significant amount of the inflow goes into the Edwards Underground Reservoir before it can be utilized for irrigation. Diversion Lake, which is just below the main dam, is also located on the outcrop of the Edwards.

Robert L. Lowry, in a study conducted for the San Antonio City Water Board (12), used historical records to evaluate the rate at which water will enter the Edwards limestone at Medina Lake and Diversion Lake. The results indicate that, for a given lake content, losses will be considerably greater on a rising stage than for a falling stage. This was attributed to a certain amount of the water escaping into temporary bank storage in the cavernous limestone walls of the main reservoir when the water level is rising and later returning to the reservoir on a falling stage. William F. Guyton (13) extended Lowry's content-seepage curves to lower reservoir surface elevations. The relationship between seepage losses and reservoir stage, as determined by Lowry, is reproduced in Figure 4.2.

Seepage Past Diversion Dam

A part of the seepage loss reappears in the river below Diversion Dam and continues downstream. This water is not included in the recharge relationships reflected by Figure 4.2. Records from the gaging station near Riomedina show that the base flow in the stream varies moderately from one year to another, with the average rate of discharge ranging around 22 cfs (cubic feet per second), or some 16,000 acre-feet per year,

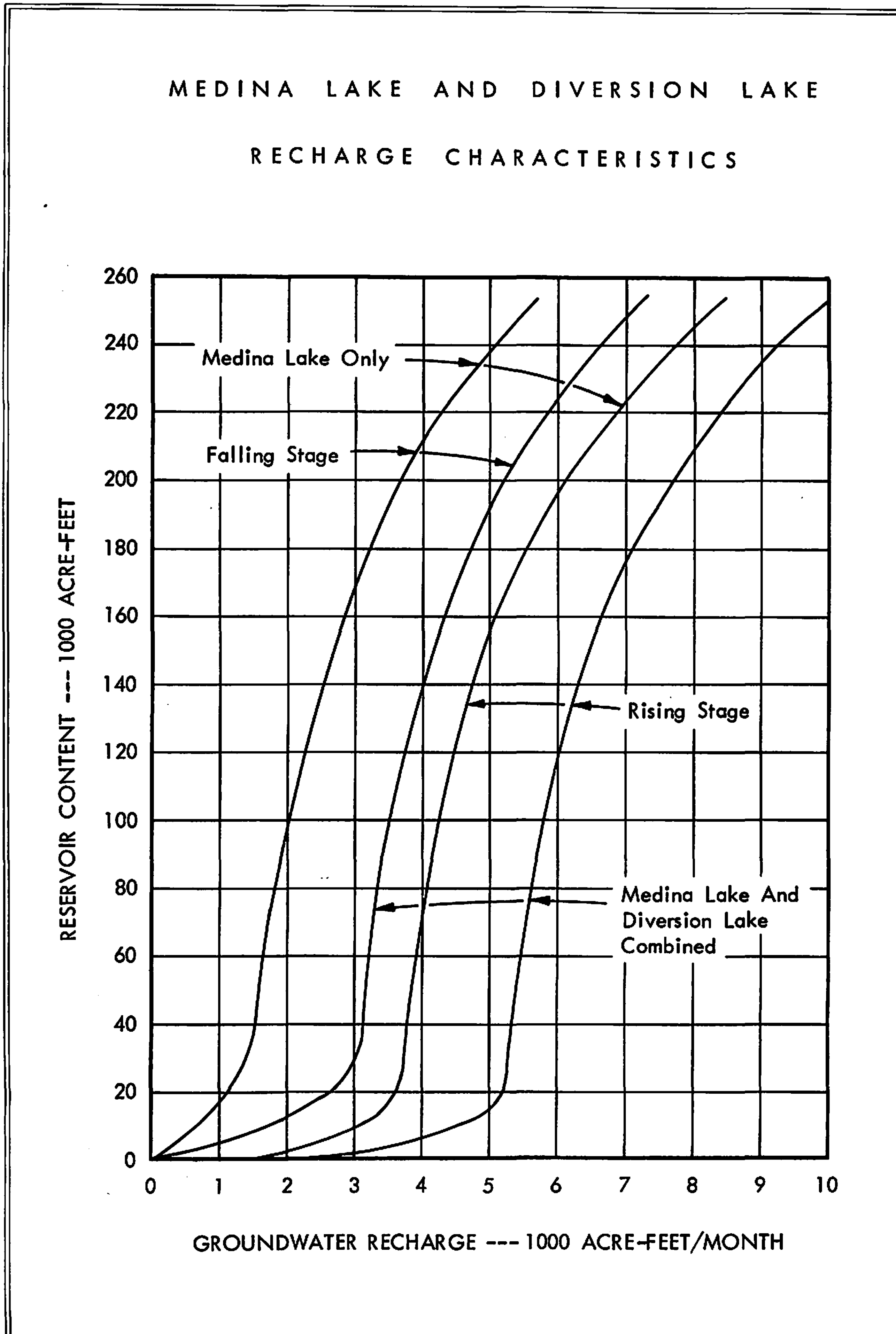

MEDINA LAKE AND DIVERSION LAKE
RECHARGE CHARACTERISTICS
Medina Lake Only
Falling Stage
Rising Stage
Medina Lake And
Diversion Lake
Combined
RESERVOIR CONTENT --- 1000 ACRE-FEET
GROUNDWATER RECHARGE --- 1000 ACRE-FEET/MONTH
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0
1
2
3
4
5
6
7
8
9
10

FIGURE 4.2

when there is a normal amount of water in Diversion Lake.

Area and Capacity Characteristics

The reservoir storage capacity and surface area data used herein are also tabulated in Appendix B. The relationships for Medina Lake and Mitchell Lake are from determinations made previously by engineers associated with those projects. The characteristics of the Applewhite site and the Big Sous site are based on planimeter measurements of recent U. S. Geological Survey maps.

Sedimentation

Sediment production in the Medina River basin is relatively low (14). The drainage area of Medina Lake is predominantly in the Edwards Plateau land resource area, which has the lowest sedimentation rate in the State. Based on a silt survey conducted in 1948 (15), the total loss in capacity in the 58 years since its construction is approximately 14,500 acre-feet, or 6%. The drainage area of Applewhite Reservoir site is partly in the Rio Grande Plain land resource area, which also has a relatively low sediment production rate. Approximately 5,300 acre-feet of sediment should accumulate in the Applewhite Reservoir Site during its first 50 years.

Medina Lake Studies

Using the hydrologic data derived from historical records, together with the recharge characteristics of Figure 4.2, Medina Lake operation was analyzed (a) with a steady irrigation demand of 35,000 acre-feet per year and (b) with no diversions for irrigation. The lake's performance was simulated mathematically by digital computer for the 32-year period from 1937 through 1968, and the results are summarized in Tables C-1 and

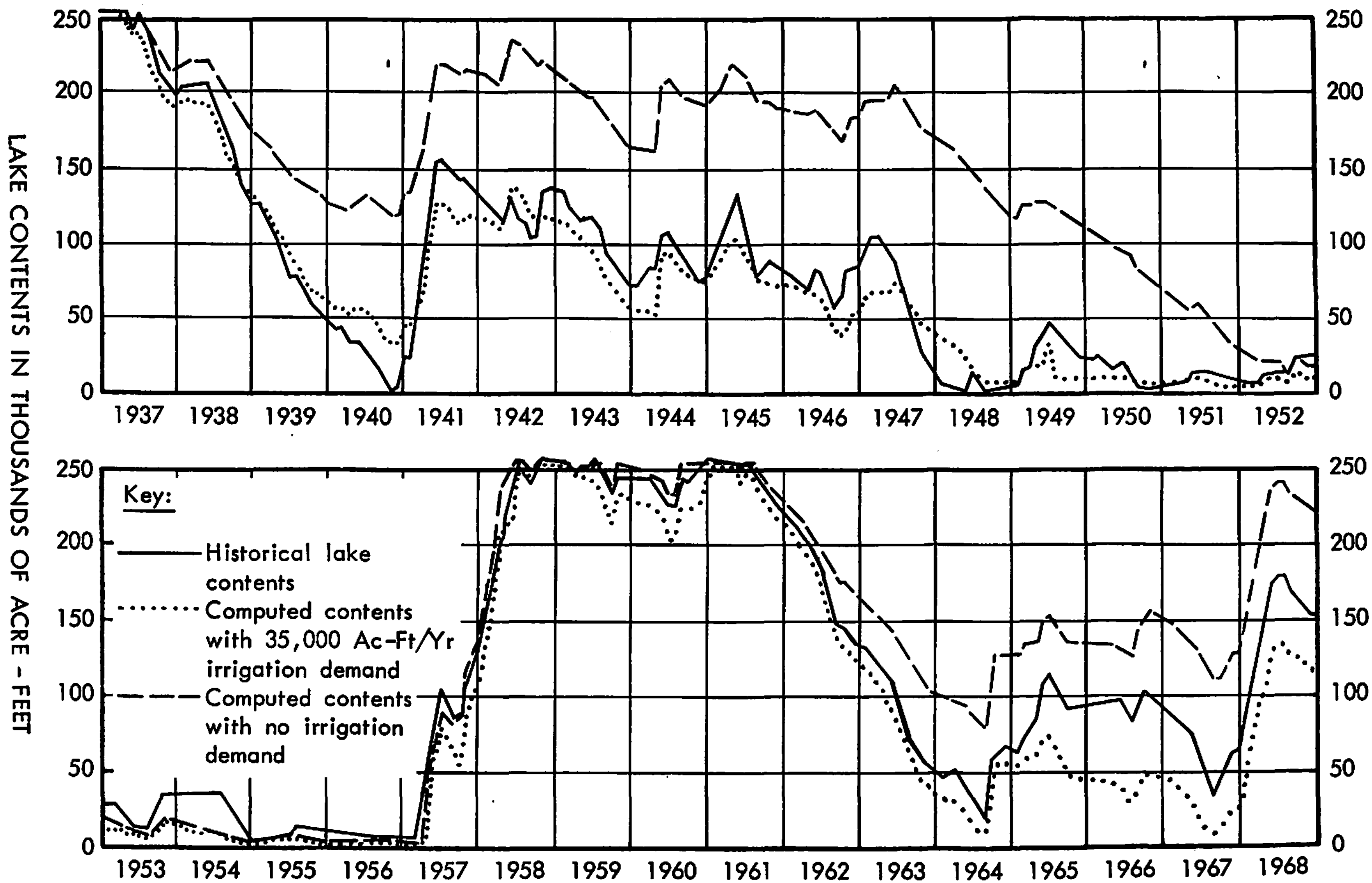
C-2 of Appendix C. The computations were carried out in one-month steps, but the summaries have been reduced to annual quantities in order to save space.

The over-all results of the studies are compared in Table 4.1, and the lake levels throughout the 32-year interval are shown graphically in Figure 4.3. In addition to the results of the computer runs, Figure 4.3 also shows the historical contents of Medina Lake during the same period. Although the actual conditions under which the lake was operated during

Table 4.1

Comparative Results of Medina Lake Studies

	Units	With Irrigation	Without Irrigation
Period of study		1937-1968	1937-1968
Number of years in study		32	32
Medina Lake capacity	Acre-Feet	254,000	254,000
Content at start of study	Acre-Feet	254,000	254,000
Content at end of study	Acre-Feet	116,717	222,206
Irrigation demand	Ac-Ft/Yr	35,000	None
Average runoff	Ac-Ft/Yr	93,760	93,760
Average irrigation water available	Ac-Ft/Yr	26,313	--
Average evaporative loss	Ac-Ft/Yr	7,590	11,604
Average groundwater recharge	Ac-Ft/Yr	47,482	61,459
Average seepage going on downstream	Ac-Ft/Yr	12,811	14,379
Average spills	Ac-Ft/Yr	3,853	7,311
Average year-end content during study	Acre-Feet	80,096	144,785



MEDINA LAKE CONTENTS UNDER VARIOUS OPERATING CONDITIONS : 1937 - 1968

FREESE, NICHOLS AND ENDRESS

FIGURE 4.3

those years did not always correspond to the assumptions of the irrigation analysis, the close agreement between these two plots tends to confirm the basic validity of the computations.

As anticipated, discontinuation of irrigation diversions would increase the recharge and would keep the lake at higher levels much of the time. The gain in recharge was found to average approximately 14,000 acre-feet per year, or some 30% more than that which would be expected to occur with the irrigation operation. At the same time, holding Medina Lake at higher elevations would increase evaporative losses, spills, and the amount of seepage passing on downstream below Diversion Dam.

Applewhite Reservoir Site

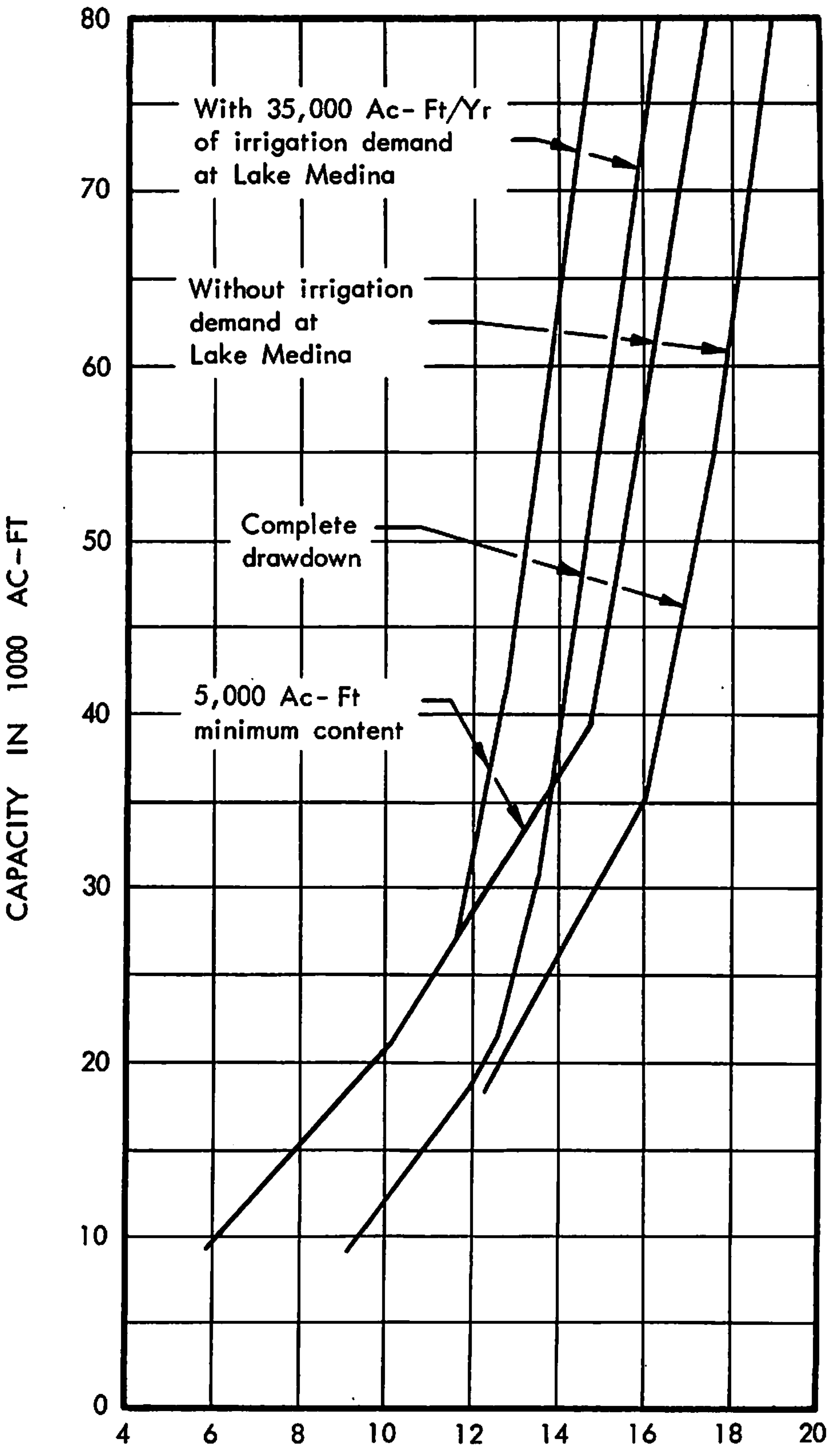
The Applewhite site is located on the Medina River south of San Antonio, at a point not far upstream from the mouth of Leon Creek and about three miles west of U. S. Highway 281 (see Figure 4.1). The total drainage area at this location is 1,058 square miles, of which 424 square miles lie downstream from Diversion Dam. It would be possible to impound some 100,000 acre-feet of water in the Applewhite Reservoir if hydrologically justified, but operation studies indicate that less than half that much will be enough to develop most of the potential yield.

Figure 4.4 shows the yield that could have been maintained continuously during the study period for a range of storage capacities, both with and without irrigation demand at the Medina Lake system further upstream. Two of the four curves in the figure show performance based on complete drawdown of the storage under critical conditions, and the other two assume a minimum reservoir content of 5,000 acre-feet at the low point of the definitive drouth. There is little gain in dependable yield for

APPLEWHITE RESERVOIR SITE

YIELD VS. CAPACITY

-- Uniform Demand --



FREESE, NICHOLS AND ENDRESS

FIGURE 4.4

increases in conservation storage beyond about 40,000 acre-feet, regardles of the method of operation at Lake Medina or the minimum storage level at Applewhite. Yields for a capacity of 40,000 acre-feet are summarized in Table 4.2.

Table 4.2

Continuous Yield Available From Applewhite Reservoir
With 40,000 Acre-Feet of Conservation Storage Capacity

- Based on Hydrologic Data for 1937-1968 -

	Ac-Ft/Yr	MGD
With 35,000 Ac-Ft/Yr of irrigation demand on the Lake Medina system upstream		
a. Using all Applewhite storage	14,100	12.6
b. Using all but approximately 5,000 acre-feet of Applewhite storage	12,700	11.3
With no irrigation demand on Lake Medina		
a. Using all Applewhite storage	16,400	14.6
b. Using all but approximately 5,000 acre-feet of Applewhite storage	14,800	13.2

Because of the major ground water supply available to San Antonio from the Edwards Reservoir, the limitation of continuous dependability need not necessarily apply to the Applewhite project. It will be practical to operate the reservoir beyond the dependable yield much of the time, as long as the potential deficit during severe drouth years can be made up by pumpage from the ground water system. This mode of utilization would noticeably increase the average surface water use, since the natural runoff will support heavier demands during most years, with only occasional shortages due to abnormally dry conditions.

Table 4.3 gives the maximum, average and minimum annual demands that could have been supplied from 40,000 acre-feet of storage at the Applewhite site during the period 1937-1963 if the mode of operation had been as follows:

a. The maximum demand would be applied as long as the lake is more than 60% full.

b. The demand is reduced to 67% of maximum when the lake is between 60% and 35% of full content.

c. The demand is reduced to 33% of maximum when the lake falls below 35% of full content.

d. The lake is not drawn down below a minimum content of approximately 5,000 acre-feet.

Summaries of the Applewhite Reservoir operation studies represented by Tables 4.2 and 4.3, with minimum reservoir content of approximately 5,000 acre-feet, are included in Appendix C. The 5,000 acre-feet minimum is considered a more realistic basis of evaluation than complete utilization of the storage volume. A number of practical limitations make it generally undesirable to empty a lake completely during a drouth, and it is probable that the Applewhite project would not be drawn down all the way if avoidable.

Under the set of criteria adopted for these analyses, the effect of operating Applewhite at more than its dependable yield in times of plentiful runoff is to increase the average water supply contribution by 70% or more. The operating rules envisioned in Table 4.3 are, of course, not the only, or necessarily the best, ones for use of the Applewhite

Table 4.3

Supply Available From Applewhite Reservoir
If Operated To Make Use of Average And Above-Average Runoff

- Based on Hydrologic Data for 1937 through 1968 -

	Units	With 35,000 Ac-Ft/Yr Of Irrigation At Lake Medina	Without Irrigation At Lake Medina
Period of study		1937-1968	1937-1968
Number of years in study		32	32
Applewhite Reservoir capacity	Acre-Feet	40,000	40,000
Content at start of study	Acre-Feet	40,000	40,000
Minimum content during study	Acre-Feet	4,916	5,088
Maximum annual yield:	Ac-Ft/Yr	27,000	28,300
	MGD	24.1	25.2
Average annual yield:	Ac-Ft/Yr	23,974	25,650
	MGD	21.4	22.9
Minimum annual yield:	Ac-Ft/Yr	8,908	9,341
	MGD	7.9	8.3

Reservoir in conjunction with the Edwards Underground Reservoir. Further detailed study would be required to establish the optimum method of operation in this respect. For present purposes, the pertinent fact is that the average Applewhite yield from the variable-demand operation would be increased by approximately 1,700 acre-feet per year if Lake Medina and Diversion Lake were to be used for recharge instead of irrigation.

5. WASTEWATER TREATMENT AND WATER QUALITY CRITERIA

At the present time, San Antonio has three major sewage treatment plants, located as shown on Figure 3.1, with the following capacities:

Rilling Road Plants	94 MGD
Leon Creek Plant	12 MGD
Salado Creek Plant	24 MGD
Total capacity	130 MGD

The Rilling Road facilities, which have been in service longest, actually consist of three distinct plants on a common site. The Salado Creek plant is the newest and has just been completed. All employ the conventional activated sludge process. The Leon Creek plant is designed to dispose of waste activated sludge by means of drying beds after thickening and anaerobic digestion. The Salado Creek plant will utilize oxidation ponds for this purpose following aerobic digestion and thickening. Waste activated sludge from the Rilling Road plants is conveyed by pipeline to storage in Mitchell Lake.

Water quality requirements differ for the three types of wastewater re-use contemplated herein. In the case of electric generating plant condenser cooling, the primary concern is to avoid excessive concentrations of dissolved minerals in the circulating water. For recreation purposes, bacterial quality is the most significant factor, due to the importance of public health protection. Irrigation use involves chemical limitations because of the effect of certain compounds on plant growth, and for some crops the sanitary quality of the water may also be critical.

There is already a degree of established precedent for each of these forms of wastewater utilization at San Antonio. The Braunig power plant has been getting a large part of its cooling water from treated sewage flows since it began operation in 1967, and Lakes Braunig and Calaveras are open to public recreational use. Irrigation of forage crops has been practiced successfully with effluent from the Rilling Road treatment plants since the 1930's. Thus, what is being contemplated is in many respects an extension and enlargement of past operations rather than something basically new.

Cooling Water Quality Criteria

Regular measurements of chemical quality have been made by the U. S. Geological Survey on the San Antonio River near Elmendorf since October of 1966 (16). The point of measurement is immediately downstream from the small tributary on which the Braunig Plant Lake is located, and the records reflect the quality of water available for diversion to both Braunig and Calaveras Lakes. A substantial part of the flow in the river at this location in recent years has been treated wastewater released from the Leon Creek and Rilling Road sewage treatment plants. Records from the U.S.G.S. station (16) are included in Appendix D.

In 1968, a national technical advisory committee submitted to the Secretary of the Interior a detailed report on water quality criteria; that report was subsequently published by the Federal Water Pollution Control Administration (now the Environmental Protection Agency) as part of its program for establishment of adequate water quality standards throughout the country (17). Table 5.1 compares the recommended federal criteria for power plant cooling water with observed conditions in the San Antonio River near Elmendorf. The river records given in the table are time-weighted averages (i.e., attributing equal weight to each day's measurement regardless of the rate of flow) and should therefore represent closely the composite quality of regular day-to-day diversions.

Table 5.1

Chemical Quality of Water in the San Antonio River Near Elmendorf, Compared with Quality Standards for Condenser Cooling Use

- Milligrams per Liter -

	Records For Water Year 1967	Recommended Limits (14)
Silica (SiO_2)	17	50
Calcium (Ca)	80	200
Bicarbonate (HCO_3)	265	600
Sulfate (SO_4)	77	680
Chloride (Cl)	83	600
Dissolved Solids	509	1,000
Hardness as $CaCO_3$	273	850

In the regular course of operation, large amounts of water will be evaporated from the cooling lakes. Since evaporation does not remove any of the dissolved minerals, the result will be to raise the chemical concentrations, and the process will stabilize only if water is spilled or released from storage to carry off impurities at a rate that will balance the amounts brought in with diversions from the river.

Based on the data shown by Table 5.1, the limiting chemical quality factor in this instance is the level of total dissolved solids. It is apparent that, as the cooling lakes approach concentrations approximately twice those of the original water, the total solids may begin to exceed the recommended limit of 1,000 milligrams per liter. In order to maintain satisfactory conditions in this respect, it will be desirable to release or spill enough to minimize further chemical build-up once the stored waters reach that stage. Except for times of heavy natural runoff from the Braunig and Calaveras watersheds, releases for quality protection would need to be approximately half of the amount of river diversions, if dissolved solids in the lakes are to be held to around 1,000 mg/l.

Operation studies reflecting the performance of the Braunig and Calaveras Lakes under drouth conditions as of the years 1980 and 1985 are included in Appendix C as Tables C-7 and C-8. In these studies, the plant capacities and annual load factors are assumed to correspond to those shown in Tables 3.3 and 3.4, and monthly patterns of reclaimed wastewater availability are as given in Table 3.12. The lakes are assumed initially to contain total dissolved solids at 1,000 milligrams per liter. In the early part of the year, when there is a plentiful supply of water, the chemical concentrations are lowered by bringing in additional diversions and making heavy releases for quality improvement. During the summer months, the mineral impurities rise to maximum levels slightly over 1,000 mg/l of total dissolved solids. Then, in the fall and early winter, enough water is again available to bring the concentrations back down to near the point of beginning.

Variation of quality maintenance diversions to fit the seasonal pattern of water availability will allow the solids concentration to go higher than the desirable maximum of 1,000 mg/l if it is already at that level at the start of the year and hydrologic conditions are as severe as assumed in the studies of Appendix C. However, the excess is not great and could be accepted under such conditions. Normally, the additional quality improvement gained from natural runoff would keep the total solids concentrations below the recommended limit.

A similar set of quality routings for Mitchell Lake is covered in Table C-9 of Appendix C, corresponding to the evaporation rates and reclaimed water flows indicated for 1980 and 1985 in Tables 3.5 and 3.13 of the text. For these analyses, it is assumed that the remaining supply of reclaimed water from the Rilling plants, after satisfaction of local irrigation needs and direct release of 5 cfs to the San Antonio River, would be passed into Mitchell Lake. This would lead to discharges from Mitchell Lake in excess of the amounts needed to keep total dissolved solids below 1,000 mg/l. By repeated trials, levels of total solids were determined for Table C-9 such that the end-of-year concentrations were approximately equal to those at the start. Thus, they represent limiting equilibrium conditions which would tend to develop in the lake after a period of drouth operation. The highest resulting concentrations are less than 700 mg/l.

Tables C-10 and C-11 of Appendix C represent water quality performance of Lakes Braunig and Calaveras, respectively, with Mitchell Lake operating as a power plant site; the basic flow balance applicable to these studies is as indicated in Table 3.13. Performance of the two existing power plant lakes, if Mitchell Lake should also be adapted as a source of cooling water, would be basically similar to the conditions reflected in Tables C-7 and C-8, which assume that Mitchell Lake is not used for that purpose, except that diversions from the river would have to be greater in order to hold to desirable quality levels. The peak concentrations of total solids at the end of the summer season are shown to be somewhat higher in Tables C-10 and C-11 than in Tables C-7 and C-8, but the difference is small.

One point which should be noted is that the standards established by the Texas Water Quality Board for the section of the San Antonio River above Cibolo Creek (18) set limits of 120 milligrams per liter for chlorides and 700 milligrams per liter for total dissolved solids. It is not yet certain whether quality restrictions might be placed on operation of the power plant cooling lakes due to these standards, and it has been assumed herein that there would be none. However, the limitation of 700 milligrams of total solids per liter could conceivably be interpreted in such manner as to increase the volumes of makeup water required for the power plant lakes.

Quality Criteria for Recreational Use

The primary emphasis of criteria relating to water quality for recreational use centers on bacterial conditions, as reflected by the MPN (most probable number) of fecal coliform bacteria per 100 milliliters of liquid. Recommended MPN limits are based on studies of the relationship between bathing water quality and health, which have indicated that some detectable hazard can be expected when the fecal coliform count rises above a given level. In its official publication on water quality requirements (18) the Texas Water Quality Board established the following general policy for recreational waters:

> "Water oriented recreation, including water contact sports, is a desirable use of the waters of the state everywhere. Water

contact activities in natural waters are not opposed by the state health agency where routine sanitary surveys support such activities, and where, in addition, as a flexible guide-line to be used in the light of conditions disclosed by the sanitary survey, the geometric mean of the number of fecal coliform bacteria is less than 200 per hundred milliliters and not more than 10% of the samples during any thirty (30) day period exceed 400 fecal coliform bacteria per hundred milliliters. This policy is advisory only and in no way limits the responsibilities and authorities of local health agencies."

This is the only direct mention of recreational use in the Texas standards. The federal criteria, which were published the following year (17), subdivide recreation activities into two classifications according to the resulting degree of health hazard: (a) primary contact recreation, including swimming, diving, water skiing and other activities where there is considerable risk of swallowing the water and (b) secondary contact recreation such as boating, fishing or shoreline activities where participants may occasionally get wet but where there is little probability that they will take in significant amounts of water. The recommended limits in Reference (17) for primary contact recreation are the same as those in the Texas requirements (18). For secondary contact situations, however, the federal report sets the limiting geometric mean of the MPN at 1,000 fecal coliform bacteria per 100 milliliters, with the further requirement that in no more than 10% of the samples taken during a given month are MPN values of fecal coliform bacteria to exceed 2,000 per 100 milliliters. In view of the emphasis on flexibility and local determination in the Texas standards, it is considered probable that something like the two-level gradation set out in the federal criteria will be accepted by the State Health Department wherever local health authorities find it to be applicable and justified.

Existing conditions at Braunig Lake are an excellent guide to the probable future outlook for recreation at both Braunig and Calaveras Reservoirs, and also at Mitchell Lake if the latter is reclaimed for recreational or other uses. During the latter half of 1969, and extending into early 1970, regular chemical and bacteriological observations were conducted at Braunig Lake by Mr. W. N. Wells, P.E., with the assistance of the City Public Service Board and the San Antonio River Authority. The data collected by Mr. Wells in measurements taken from August 16, 1969, to January 26, 1970, are summarized in various tables of Appendix D.

Based on these field observations, the bacterial quality of Lake Braunig appears to be within accepted limits for primary contact recreation. The geometric means of MPN determinations for total coliform organisms during the five months of testing were 70 and 42 at the two locations where numerous tests were made. On the one day when MPN tests were carried out at other places in the lake, the observations at the two regular sampling points were found to be representative of the lake as a whole.

Dissolved oxygen concentrations were satisfactory in the upper ten feet of the lake throughout the period and at increasing depths during the fall and winter months. Nitrogen and phosphorus were present in amounts sufficient to support heavy growths of algae and aquatic plants if the other needs of such life forms are also fulfilled at any given time.

Except for potential difficulties with algae and water weeds, the analyses at Lake Braunig indicate favorable conditions at least for the present recreational use and encourage the belief that the same will also be true at Calaveras Lake. Current regulations allow power boating and fishing at both lakes and also permit sailing and water skiing on Lake Calaveras. Although the tests show bacterial conditions that are within the limits of federal and state standards for primary contact water sports, it would not be prudent to permit public swimming without very cautious and detailed investigation. In particular, it is possible that the existing secondary treatment methods do not completely remove viruses from the water. Experience elsewhere (19) has shown that some viruses survive conventional treatment with the activated sludge process followed by stabilization pond detention and chlorination. In all probability, the lakes could not be accepted for public swimming use unless the wastewater is subjected to a tertiary stage beyond the treatment being given by the existing facilities.

Irrigation Quality Criteria

The water quality requirements established by the Texas Water Quality Board (18) state that:

> "The suitability of water for irrigation will be based on the irrigation water classification system developed by the University of California at Davis and the U. S. Salinity Laboratory at Riverside, California. Class I irrigation water is desirable and will be assumed wherever possible. Class II or Class III irrigation water may be satisfactory under conditions of soil, climate, irrigation practices and crops where impairment and deterioration will not ensue.

"The SAR (sodium adsorption ratio) should not exceed 8 for waters safe for irrigation. Sampling and analytical procedures and schedules are not specified, but will be as appropriate for adequate protection of irrigation waters.

"The attached resolution of the Texas State Department of Health will apply as to the sanitary quality of irrigation waters."

The irrigation water classifications referred to are summarized in Table 5.2. The resolution by the State Department of Health reads as follows:

"By authority vested in the Commissioner of Health by Articles 4465A and 4466 to make, publish and enforce rules consistent with this law, and adopt standards for foods, food products, beverages, drugs, etc., and the modern methods of analysis authorized as official by the Federal Department of Agriculture, I hereby make and adopt the following rules and standards for food crops which might be consumed in the raw state.

"The use of raw or partially treated sewage or the effluent from a sewage treatment plant is prohibited for use as irrigation water on any food crop which might be consumed in the raw state. Such practice is the deliberate exposure of food to filth as defined by Paragraph (a) 4 - Section 10, Art. 4476-5 of our civil statutes."

(Signed by the State Commissioner of Health)

The chemical quality of the reclaimed water at San Antonio is within the specified limits for Class I irrigation in all respects except the chloride content. Chlorides in effluent from both the Rilling and Leon

Table 5.2

Summary of Classifications of Irrigation Waters Referenced by Texas Water Quality Requirements

Class	Percent Sodium	Boron in Milligrams Per Liter	Chlorides		Sulfates		Specific Conductivity EC x 10^6 @ 25°C	Total Salts in mg/l
			meq/l	mg/l	meq/l	mg/l		
I	Less than 30 - 60%	Generally less than .5 mg/l; however, tolerant plants will not be injured by 1 - 1.5 mg/l.	Less than 2-2.5	Less than 70-90	Less than 4-10	Less than 190-480	Formerly suggested limit of about 500 but more recently 1,000 accepted	Up to about 700
II	30-75%	.5 - 2.0 mg/l, although for tolerant plants up to 3.35 mg/l may be satisfactory	2-16	70-570	4-20	190-960	500 - 3,000	350 - 2,100
III	More than 70-75%	More than 2 mg/l, although water with more than 1.0 mg/l may be highly unsatisfactory for sensitive plants	More than 6-16	More than 210-570	More than 12-20	More than 580-960	More than 2,500 to 3,000	More than 1,700 to 2,100

Notes: Percent sodium is calculated as 100 times the sodium ion concentration divided by the sum of the sodium, calcium, magnesium and potassium ion concentrations, with all concentrations expressed in milliequivalents per liter.

Chlorides and sulfates were expressed only in terms of milliequivalents per liter in the original table. Comparable values in milligrams per liter have been added for purposes of this report.

Creek Plants are often slightly higher than the 90 mg/l limit set for Class I water (see Appendix D), but not enough higher to be likely to cause problems. The chloride concentration is usually under 100 mg/l, and the over-all average for 1969 was 92 mg/l. From the standpoint of chemical quality, it is excellent irrigation water, as might be expected from over 30 years of satisfactory experience irrigating lands south of the Rilling Road Plants.

However, the water cannot now be used on any crops which are likely to be consumed without first being cooked. This criterion is clearly set out by the policy statement of the State Health Department, which in effect forbids use of any municipal wastewater for such purposes regardless of the degree of treatment. If irrigation of food crops that might be eaten raw is to be considered, it will have to be based on (a) adoption of a tertiary treatment process which will significantly change the bacterial quality of the treated water and (b) amendment of the Health Department guideline to recognize the acceptability of water produced by the more advanced treatment.

6. RECLAMATION OF MITCHELL LAKE

Mitchell Lake, with a surface area of 850 acres and a capacity of 7,020 acre feet, lies just south of the city limits of San Antonio and west of U. S. Highway 281 (see Figure 6.1). The lake is nine miles south of the central business district. Beginning about 1902 and up to the latter part of 1930, all of San Antonio's untreated wastewater except that used for irrigation from the outfall canal was discharged into Mitchell Lake, which served as an oxidation pond for the untreated waste and as storage of irrigation water. Beginning with the operation of the first Rilling Road treatment plant in the latter part of 1930, substantially all of the volume of discharge into the lake was treated effluent. For the past 30 years or so, Mitchell Lake has functioned as a large oxidation pond for the economical disposal of excess activated sludge and digester supernatant liquor from the Rilling Road treatment plants. It also has value in some years for the emergency storage of untreated and partially treated wastes during treatment plant outages. The excess activated sludge, digester supernatant, and any untreated or partially treated wastes are conveyed from the plants into the upper end of the lake by pipeline. The nutritive material discharged to the lake causes prolific algae growths. The water is often about the color of split pea soup, and normally there is some odor around the lake.

Some 4,000 acres of land, mostly grass land, are irrigated from Mitchell Lake and from the canal systems fed with treated effluent by the Rilling Road plants. Locations of the lake, the treatment plants, and the associated irrigation system are shown in Figure 6.1. About ten to fifteen per cent of the irrigated lands use water pumped directly from

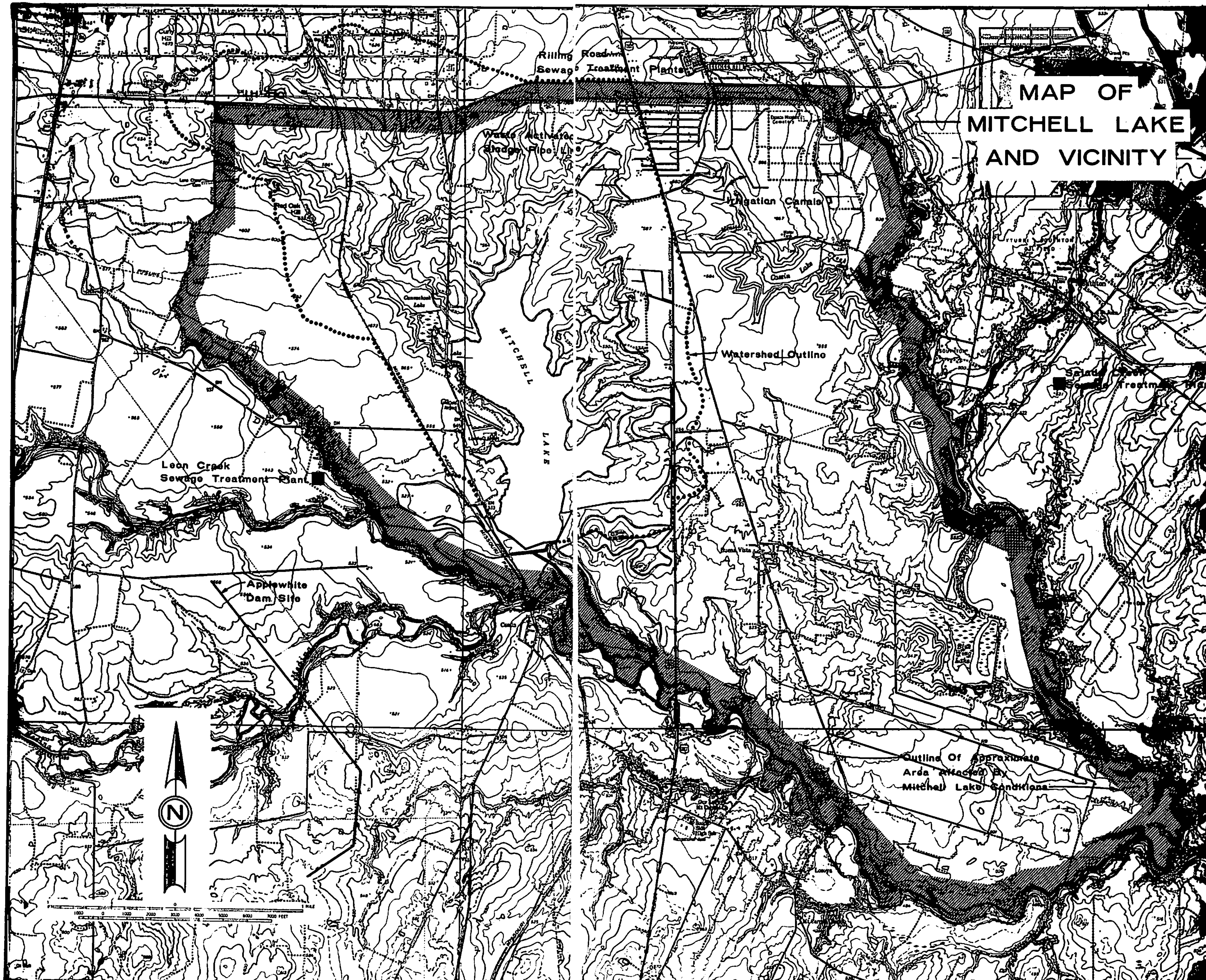

MAP OF
MITCHELL LAKE
AND VICINITY
Rilling Road
Sewage Treatment Plant
Waste Activated
Sludge Pipe Line
Irrigation Canals
Watershed Outline
MITCHELL LAKE
Leon Creek
Sewage Treatment Plant
Applewhite
Dam Site
Outline Of Approximate
Area Affected By
Mitchell Lake Conditions
N

FIGURE 6.1

Mitchell Lake and lie to the southwest, between the lake and Leon Creek. The remaining eighty-five to ninety per cent of the irrigated lands using treated effluent are served by canal systems east of the lake and west of the San Antonio River.

The following Tables 6.1 through 6.4 show an approximate water balance for Mitchell Lake for the years 1967, 1968 and 1969, and available analytical data for the discharges from the Rilling Road treatment plants to Mitchell Lake, for the water in Mitchell Lake, and for the discharges into the Medina River. The Mitchell Lake waters (and, consequently, discharges from the lake) are high in nutrients, algae, settleable suspended solids and bacteria. Presently, the discharges are permitted on an emergency basis when there is a stormwater overflow from the lake.

There are no nuisance conditions inherent in irrigation with the treated wastewater. However, as yet there has been no significant residential or other development of lands surrounding the lake and the irrigation system. As shown by Figure 6.1, there is an area bounded on the north by Interstate Loop 410, on the west by South Zarzamora Road (extended), on the south by Comanche Creek, Leon Creek and the Medina River and on the east by the San Antonio River, which for geographic reasons is basically related to Mitchell Lake. These lands are potentially attractive for residential use, and there are also possibilities for industrial use, particularly along the Missouri Pacific tracks in the western section. It may become desirable in the future to abandon the wastewater irrigation and to modify or discontinue use of the lake for disposal of excess activated sludge.

If Mitchell Lake remains in service as an oxidation and holding

Table 6.1

Approximate Water Balance: Mitchell Lake

- Quantities in Millions of Gallons -

	1967	1968	1969
Inflow into Lake			
From Rilling Road Plants:			
Excess activated sludge	871	820	606
Digester supernatant	108	120	183
Primary effluent	0	193	5
Untreated waste	0	377	2
Calculated canal overflows and irrigation drainage	517	699	684
Estimated stormwater (including rain on lake surface	1,632	2,554	1,515
Total estimated inflow	3,128	4,763	2,995
Withdrawals, Losses and Releases			
Discharge to Medina River	1,560	2,719	1,103
Estimated lake evaporation (gross)	1,574	1,336	1,433
Approximate irrigation use from lake	340	323	453
Total estimated outgo	3,474	4,378	2,989
Gain (or loss) in Lake Storage	(346)	385	6

Table 6.2

Analytical Data: Discharges From Rilling Road Plants

- Average Values in Parts per Million -

	1967	1968	1969
Excess Activated Sludge			
Five Day BOD	2,711*	2,613*	3,617*
Suspended Solids	4,630±	4,530±	4,530±
Digester Supernatant			
Five Day BOD	2,711*	2,613*	3,617*
Suspended Solids			
Primary Effluent			
Five Day BOD	197	217	235
Suspended Solids	138	138	128
Untreated Waste			
Five Day BOD	229	246	270
Suspended Solids	221	217	213
Treated Waste (Canal Overflows)			
Five Day BOD	8.6	22.3	13.8
Suspended Solids	11.7	29.8	17.2

*Combined excess activated sludge and digester supernatant.

Table 6.3

Analytical Data: Monthly Samples of Mitchell Lake Water

- Parts Per Million Except As Noted -

	1964			1965			1966			1967		
	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min
Dissolved Solids	689	774	591	769	970	558	716	799	660	808	850	760
Chloride	125	141	108	153	211	97	140	153	123	165	190	145
Sulfate	56	77	41	93	158	48	71	85	59	86	146	62
Chlorine Demand	12.4	17	3.5	7.2	14.2	2	8.7	14	1.5	11.7	16	2
DO	3.6	9.4	.3	2.6	8.5	0	3.2	8.0	0	1.8	5.4	.6
BOD_5	53	84	29	67	110	19	33	90	11	49	175	20
NH_3 - N	3.4	8	.4	8.8	17.5	.2	5.3	19.5	.2	4.2	15	.2
NO_2 - N	1.13	5.5	.1	.61	3.0	.1	1.41	5.8	.1	3.94	33	.1
NO_3 - N	3.0	7.3	.4	1.2	5.0	.4	3.3	6.5	.2	3.7	8.5	.1
Phenol. Alkalinity	.3	4	0	2.7	12	0	.5	6	0	0	0	0
Total Alkalinity	253	310	218	252	318	196	248	299	210	232	302	134
Suspended Solids												
Total	81	154	41	81	140	42	82	131	9	83	120	19
Volatile	71	116	37	58	89	27	62	96	6	52	102	6
Fixed	10	46	2	24	52	1	20	69	0	32	88	4
Orthophosphate	45	69	26	42	66	21	51	75	34	63	93	41
MPN/1000*	86	240	15	1134	8800	15	128	240	.9	108	240	4

*Most probable number of coliform bacteria per 100 milliliters, divided by 1,000.

Table 6.4

Analysis of Water Discharged From Mitchell Lake

- Parts per Million -

Date	Five Day BOD	Total Susp. Solids	Date	Five Day BOD	Total Susp. Solids
11- 4-64	46	56	9-24-67	31	50
11- 4-64	47	54	9-25-67	42	53
11- 5-64	40	61	9-25-67	41	58
11- 5-64	36	54	9-26-67	43	30
11- 6-64	32	60	9-26-67	36	27
2- 5-65	48	80	9-27-67	33	89
2- 5-65	42	58	9-27-67	41	66
2- 6-65	60	75	9-28-67	40	56
2- 9-65	40	79	1-18-68	76	50
2- 9-65	25	75	1-18-68	76	84
2-10-65	36	63	1-19-68	76	149
5-16-65	65	148	1-19-68	30	62
5-17-65	51	160	1-20-68	32	60
5-17-65	40	168	1-20-68	38	44
5-18-65	60	80	1-21-68	34	24
5-18-65	63	83	1-21-68	34	46
5-19-65	68	87	1-22-68	62	54
5-19-65	68	88	1-22-68	62	54
5-20-65	41	87	1-23-68	32	78
5-20-65	62	72	1-23-68	38	28
5-21-65	56	73	1-24-68	44	24
5-21-65	52	86	7-11-68	36	118
11- 3-65	77	40	7-12-68	36	112
12- 4-65	77	40	4-12-68	34	142
12- 4-65	77	-	7-13-68	31	126
12- 5-65	79	-	7-14-68	40	118
12- 5-65	78	-	7-14-68	35	145
12- 6-65	74	-	7-15-68	32	142
12- 6-65	74	-	5- 4-69	22	52
4-25-66	45	96	5- 5-69	18	35
4-25-66	48	69	5- 5-69	49	65
4-26-66	46	71	5- 6-69	71	72
9-21-67	62	34	5- 6-69	62	58
9-22-67	48	34	5-16-69	72	69
9-22-67	36	40	5-17-69	60	80
9-23-67	37	37	2-24-70	25	66
9-23-67	34	52	2-25-70	30	88
9-24-67	62	41	2-25-70	35	116

pond, several possibilities for improving its operation might be adopted, including the following:

a. Placement of the waste activated sludge in the deeper part of the lake. Most odors now come from the shallow part, where the sludge and supernatant liquor are discharged.
b. Modification of low sections of the shoreline by dredging and filling.
c. Induced aeration to bring septic zones back to aerobic conditions.
d. Interception and bypassing of storm runoff, which now enters the lake and causes overflows.
e. Regular boat operation to break up floating algae blankets.
f. Harvesting and disposal of algae.

On the other hand, if use of the lake as an oxidation and holding pond is discontinued altogether, another method for disposal of waste activated sludge would have to be provided at the Rilling Road plants. There are several possible alternatives, each with its particular advantages and/or limitations. No one method will be ideal or best in all respects, and the final choice would involve a large element of judgment as to the relative importance of various technical, economic and social factors. The Rilling site is being surrounded by urban development and will inevitably become part of the built-up area of San Antonio. Sludge disposal processes which would be chosen at a more remote location will not necessarily be appropriate for an in-city plant. Four of the more important guidelines for any basic modification of the Rilling sludge disposal system would be:

a. To avoid commitment of major additional plant land acreage for sludge disposal
b. To prevent nuisance conditions in the surrounding area
c. To minimize requirements for manual labor
d. To hold down the final volume of solids which must be removed from the plant site by truck.

Specifically, it would be desirable to avoid increased dependence on sludge drying beds. It is believed that primary consideration should be given to burning the waste activated sludge in multiple-hearth incinerators and removing the excess fly ash to a landfill. Centrifuge thickening would be necessary as a first step, due to the relatively low solids content of the sludge, followed by dewatering in vacuum filters or filter presses prior to incineration. Special provision would also be required for the supernatant liquor from the primary digesters, now being discharged to Mitchell Lake. Return of the supernatant to the primary settling tanks would tend to upset and reduce the effectiveness of the existing treatment plants unless it were given intermediate chlorination or other treatment to achieve partial oxidation prior to return.

The water level in Mitchell Lake can be raised readily by as much as twelve feet (from elevation 524 to elevation 536). This change would increase the surface area of the lake from the present 850 acres to 1,390 acres and would increase the lake capacity from 7,020 acre-feet to 20,280 acre-feet. The maximum depth would be increased from 18 feet to 30 feet, and the average depth would be increased from 8.3 feet to 14.6 feet.

These values compare with Braunig Lake's surface area of 1,330 acres, capacity of 27,000 acre-feet and average depth of 20.3 feet. A 12-foot increase in the normal water level would require the addition of approximately twelve feet to the height of the existing earthen dam, extension of the dam easterly with a levee section approximately 700 feet in length and approximately 8 feet in average height, and also an extension from the west end of the dam with a northwesterly levee section approximately 450 feet in length and approximately 10 feet in average height. A new spillway would be required, and Pleasanton Road would have to be raised or re-routed.

With the enlarged surface area, Mitchell Lake could provide condenser cooling for a power plant of approximately 1,400 megawatts capacity. Makeup water could be provided readily from the Rilling Road plants through the existing underground conduit. Operation as a cooling lake, however, would require effective control of algae, so as not to interfere with the cooling water flow.

It has also been proposed that Lakes Mitchell, Braunig and Calaveras might be interconnected by gravity pipe lines and the resulting multi-lake system linked directly to the sewage treatment plants (20). Such an arrangement (see Figure 6.2) would allow reclaimed water to be routed through the power plant lakes and conveyance facilities built and owned by City agencies before reverting to the status of public waters when ultimately released from Lake Calaveras into the San Antonio River. The pumping costs associated with river diversions would be eliminated. Detention in the lakes would further reduce bacterial and phosphate levels before the water reached the river.

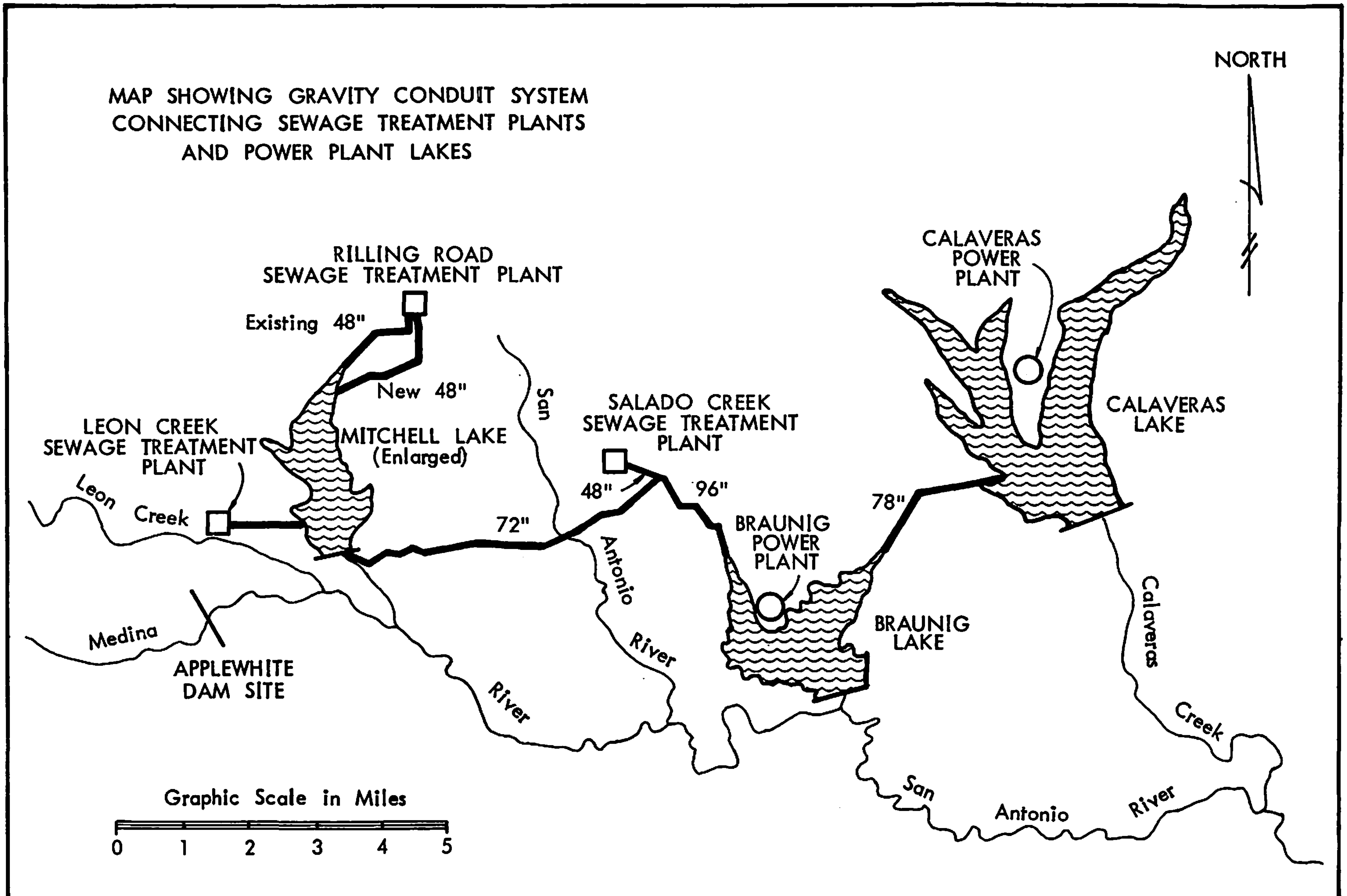

MAP SHOWING GRAVITY CONDUIT SYSTEM
CONNECTING SEWAGE TREATMENT PLANTS
AND POWER PLANT LAKES
NORTH
RILLING ROAD
SEWAGE TREATMENT PLANT
Existing 48"
New 48"
LEON CREEK
SEWAGE TREATMENT
PLANT
MITCHELL LAKE
(Enlarged)
Leon
Creek
San
SALADO CREEK
SEWAGE TREATMENT
PLANT
48"
96"
72"
Antonio
River
CALAVERAS
POWER
PLANT
CALAVERAS
LAKE
78"
BRAUNIG
POWER
PLANT
BRAUNIG
LAKE
Medina
APPLEWHITE
DAM SITE
River
Calaveras
Creek
San
Antonio
River
Graphic Scale in Miles
0
1
2
3
4
5

FIGURE 6.2

Tables C-12 and C-13 in Appendix C are studies of the chemical quality performance of Lakes Braunig and Calaveras, operating jointly with Mitchell Lake in this manner. They are based on drouth conditions as of 1985, with the water requirements and seasonal patterns of supply and demand given in Table 3.13. As in the analysis for Mitchel Lake (Table C-9), initial concentrations of total solids for Tables C-12 and C-13 were chosen by repeated trials, such that the concentrations at the end of the year are essentially the same as at the start. Thus, the analyses reflect limiting equilibrium conditions in times of critical drouth. Discharges from the Leon Creek sewage treatment plant and 5 cfs of the flow from the Rilling plants were assumed to be released into Leon Creek and the San Antonio River, respectively, without going through the inter-connected power lake system. Part of the Rilling outflow was also allocated to nearby irrigation. Most of the Rilling plant discharges and all of the flow from the Salado Creek plant were counted as passing through the cooling lakes. Concentrations of total dissolved solids were assumed to be 500 mg/l in the reclaimed wastewater.

This mode of operation would produce much better chemical conditions in Lake Braunig, as revealed by comparison between Tables C-12 and C-10. However, for the volumes of flow predicted for 1985, it would cause the peak level of dissolved chemicals to be about 10% higher in Lake Calaveras than would be the case with the lakes operating independently (1,186 mg/l of total dissolved solids with the lakes in tandem vs. 1,060 mg/l with separate diversions from the river). This unexpected result is due to the fact that direct linkage of the cooling reservoirs would raise the tonnage of dissolved minerals flowing into Lake Calaveras but would not significantly increase the volume of water available to that lake. If each reservoir functions separately, releases from Lake Braunig for quality maintenance will go into the San Antonio River and will carry away substantial tonnages of dissolved salts; if the excess water from Lake Braunig is conveyed to Lake Calaveras, those impurities are added to the mineral load on the larger lake. Thus, with the wastewater flow passing through the three reservoirs in series, water quality at Lake Calaveras could be kept at satisfactory levels only if the amount of additional water routed through the lake is enough to offset the increased input of dissolved minerals. Based on the estimated future availability of reclaimed wastewater, such would not be the case either during 1980 or 1985, and only after 1985 would there be enough more water to resolve the difficulty.

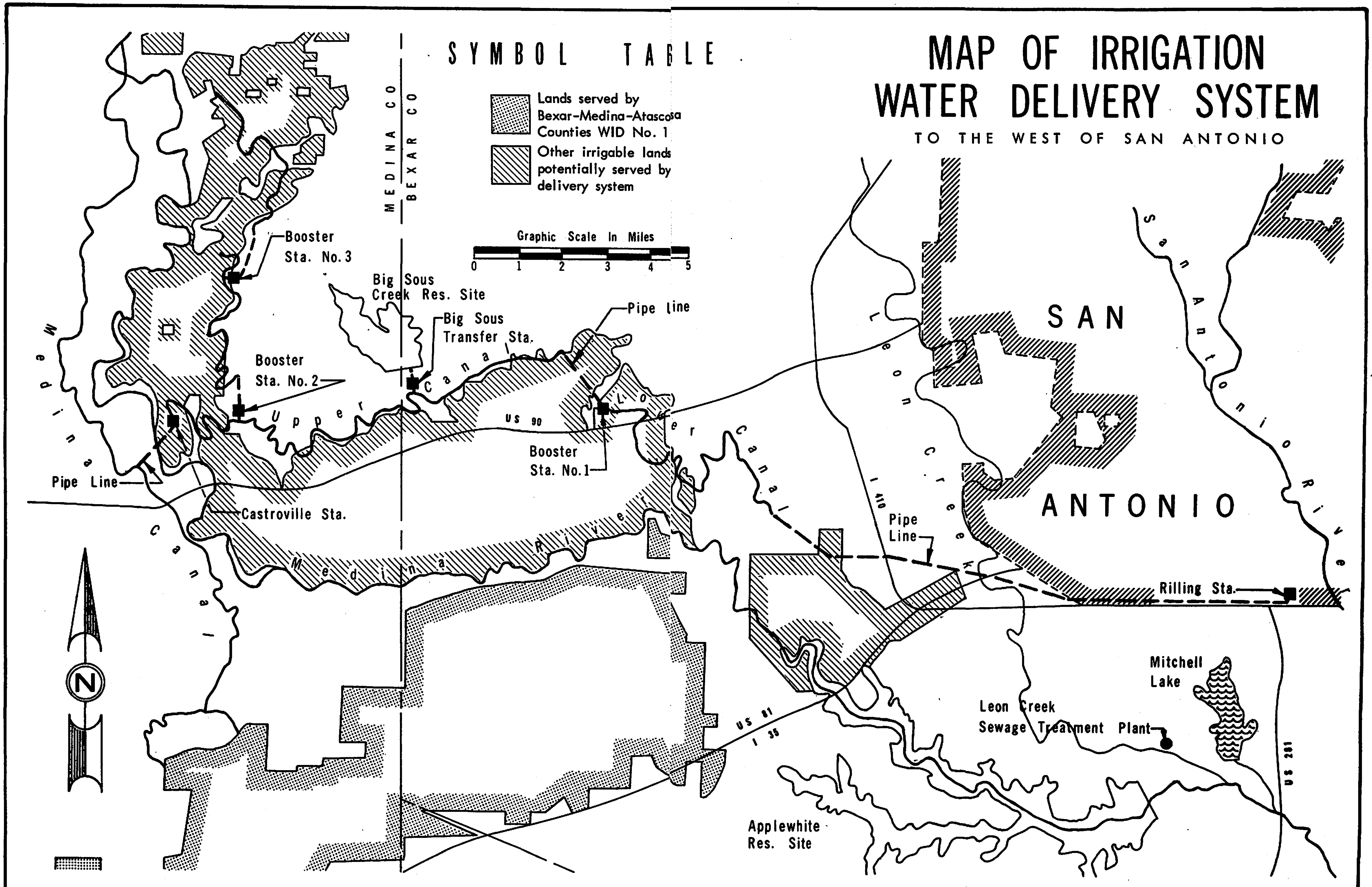
7. DELIVERY FACILITIES FOR IRRIGATION WATER

As indicated by the comparative projections of availability and potential demand in Section 3, it is not expected that there would be enough uncommitted wastewater to support extensive irrigation west of San Antonio until about 1990 or later. Lesser irrigation requirements southeast of San Antonio could be accommodated sooner and would be physically possible in the near future if backed by regulating storage. Delivery facilities are discussed in the following pages for both the western and southeastern irrigation areas, although the western system is not a prospect for the immediate future.

Delivery Facilities West of San Antonio

Because of seasonal variations in demand, the peak delivery rate for irrigation would be 2.3 to 2.5 times the annual average. In order to allow as much as possible of the western delivery facilities to be sized and operated at the average rather than the maximum rate, there should be a regulating reservoir somewhere near the downstream end of the system, in the vicinity of the points of use. With enough capacity in such a reservoir, water could be brought from the Rilling Road plants at an essentially uniform rate, stored during months when requirements are less than the deliveries, and withdrawn from storage when the demand is heaviest.

Figure 7.1 is a map of the canals, pipe lines, pump stations, regulating reservoir, and other facilities which would be involved in movement of reclaimed wastewater westward from the Rilling Road plants, either to serve irrigable lands along the Medina River or to be placed in the main canal of the Bexar-Medina-Atascosa Counties Water Improvement District No. 1 just west of Castroville. There are also some lands



MAP OF IRRIGATION
WATER DELIVERY SYSTEM
TO THE WEST OF SAN ANTONIO
SYMBOL TABLE
Lands served by Bexar-Medina-Atascosa Counties WID No. 1
Other irrigable lands potentially served by delivery system
Graphic Scale In Miles
0 1 2 3 4 5
MEDINA CO
BEXAR CO
Booster Sta. No. 3
Big Sous Creek Res. Site
Big Sous Transfer Sta.
Pipe line
Booster Sta. No. 2
Upper Canal
Lower Canal
US 90
Booster Sta. No. 1
Pipe Line
Castroville Sta.
Medina Canal
Medina Lake
Medina River
SAN ANTONIO
Leon Creek
San Antonio River
I 410
Pipe Line
Rilling Sta.
US 81
I 35
Mitchell Lake
Leon Creek Sewage Treatment Plant
Applewhite Res. Site
US 281
N

FIGURE 7.1

closer to San Antonio which might conveniently be served. Table 7.1 is a summary of the principal system characteristics for average delivery rates ranging from 25,000 to 40,000 acre-feet per year.

The first part of the system, passing through areas that are already urbanized or will be built up in the future, would need to be underground in a pipe line. Other, shorter sections of pipe would also be needed following the booster pump stations and at Castroville where the water would be pumped across the Medina River and released into the Bexar-Medina-Atascosa canal. A site for the regulating reservoir is available on Big Sous Creek, at the Bexar County - Medina County line. Area and capacity data for this site are shown in Table B-11 of Appendix B. A transfer pump station at the Big Sous Dam would pump water from the canal into the reservoir during months of low irrigation usage. It should be noted that, in Table 7.1, the column with demand of 40,000 acre-feet per year assumes that all of the water will be used to serve the area along the Medina River and does not include the Castroville Pump Station to place water in the Bexar-Medina-Atascosa Canal.

Table 7.2 outlines operation of the Big Sous Reservoir when the system is delivering 35,000 acre-feet per year under unusually dry climatological conditions, showing the effect of the storage reservoir in regulating uniform flows from the Rilling Road plants to meet varying monthly requirements. Performance for other demand rates would be basically similar and would differ only in the quantities conveyed and stored throughout the year. Evaporative losses from the surface of the regulating reservoir require the incoming flows to exceed the volume going on beyond the transfer pump station by about 5%. There also will be losses due to evaporation

Table 7.1

Facilities To Deliver Irrigation Water from the Rilling Road Plants to the Vicinity of Castroville

Average delivery rate (Ac-Ft/Yr)	25,000	30,000	35,000	40,000
Average flow rate (cfs)	34.5	41.4	48.3	55.2
Maximum delivery rate (cfs)	86.3	103.5	120.8	138.0
Total canal length (miles)	23.3	23.3	23.3	21.7
Pipe line sizes				
Initial conduit (64,500')	36"	39"	42"	45"
After Booster No. 1 (7,300')	36"	39"	42"	45"
After Castroville Sta. (6,000')	45"	48"	48"	-
Hydraulic grades (MSL datum)				
Rilling Plants	570	570	570	570
Start of lower canal	710	710	710	710
Booster No. 1 intake	705	705	705	705
Start of upper canal	817	817	817	817
Canal opposite Big Sous Reservoir	810	810	810	810
Castroville Sta. intake	800	800	800	-
Medina Canal	880	880	880	-
Big Sous Reservoir capacity (Ac-Ft)	9,500	11,000	13,000	15,000
Maximum water elev. in Big Sous Reservoir	889	892	896	900
Pump station horsepower				
Rilling Station	2,150	2,510	2,770	3,030
Booster No. 1 Station	810	970	1,120	1,260
Big Sous Transfer Station	500	620	760	890
Castroville Station	1,420	1,700	2,100	-

and seepage from the canal itself, and flows through the system should be enough more than the ultimate delivery rate to provide for such depletions. In the calculations reflected by Table 7.1, the Rilling Station was assumed to pump 20% more than the indicated deliveries. Similarly, in Table 7.2, flow going on past the Big Sous Transfer Station is indicated as being about 5% more than the required delivery volume.

Table 7.2

Big Sous Regulating Reservoir Operation Under Unusually Dry Conditions

- Values in Acre-Feet -

	Canal Flow Reaching Big Sous Station	Transfers To Or From (-) Big Sous Reservoir	Net Evapo-ration Losses	Natural Runoff Into Reservoir	Canal Flow Beyond Big Sous Station	End-of-Month Reservoir Content
Jan	3,210	2,520	50	0	690	10,560
Feb	3,210	2,500	70	0	710	12,990
Mar	3,210	190	180	0	3,020	13,000
Apr	3,210	0	200	0	3,210	12,800
May	3,220	-2,080	250	0	5,300	10,470
Jun	3,220	-2,700	330	0	5,920	7,440
Jul	3,220	-3,720	260	0	6,940	3,460
Aug	3,210	-2,040	120	0	5,250	1,300
Sep	3,210	1,090	90	0	2,120	2,300
Oct	3,210	1,820	90	0	1,390	4,030
Nov	3,210	1,870	90	0	1,340	5,810
Dec	3,210	2,350	70	0	860	8,090
Total	38,550	1,800	1,800	0	36,750	

Lands along the east bank of the Medina River are generally higher with distance north of Castroville, and it would be necessary to lift the water again to serve that section. Two additional lifts, designated as Booster Station No. 2 and Booster Station No. 3, are indicated in Figure 7.1. Each lift raises the water about 50 feet, and this combination allows service to be extended some 7 miles further north.

The canals and the reservoir have been located in areas where the Edwards limestone is overlain by substantial thickness of more recent formations (21, 22, 23). The formations through which the system would pass, primarily the Navarro group, the Taylor marl and the Anacacho limestone, would not be expected to contribute recharge to the Edwards. Although detailed geologic investigations should be part of any definitive design of the irrigation facilities, preventing contamination of the Edwards by entry of the reclaimed water is not anticipated to be a difficult problem.

Delivery Facilities Southeast of San Antonio

Figure 7.2 shows the potential irrigation area in southeastern Bexar County and northwestern Wilson County, together with routes for delivery of water from the treatment plants to the upper end of the main canal. It will be noted that the main canal would be located close to the San Antonio River, and that most of the land to be served would be on the south side of the main canal. This is due to the fact that there is a slight ridge near the river. Much of the natural drainage flows from the ridge toward a system of intermittent creeks at the base of the rougher terrain about 1 or 1-1/2 miles to the south; in effect, the predominant slope of much of the land is away from the river rather than toward it.

There are two basic alternatives with respect to the means of delivery, one via the San Antonio River and its tributaries and the other through Lake Braunig. Use of the river would require less initial investment, but it is not certain that the City could retain control of the water once it is discharged into a natural watercourse. Although the

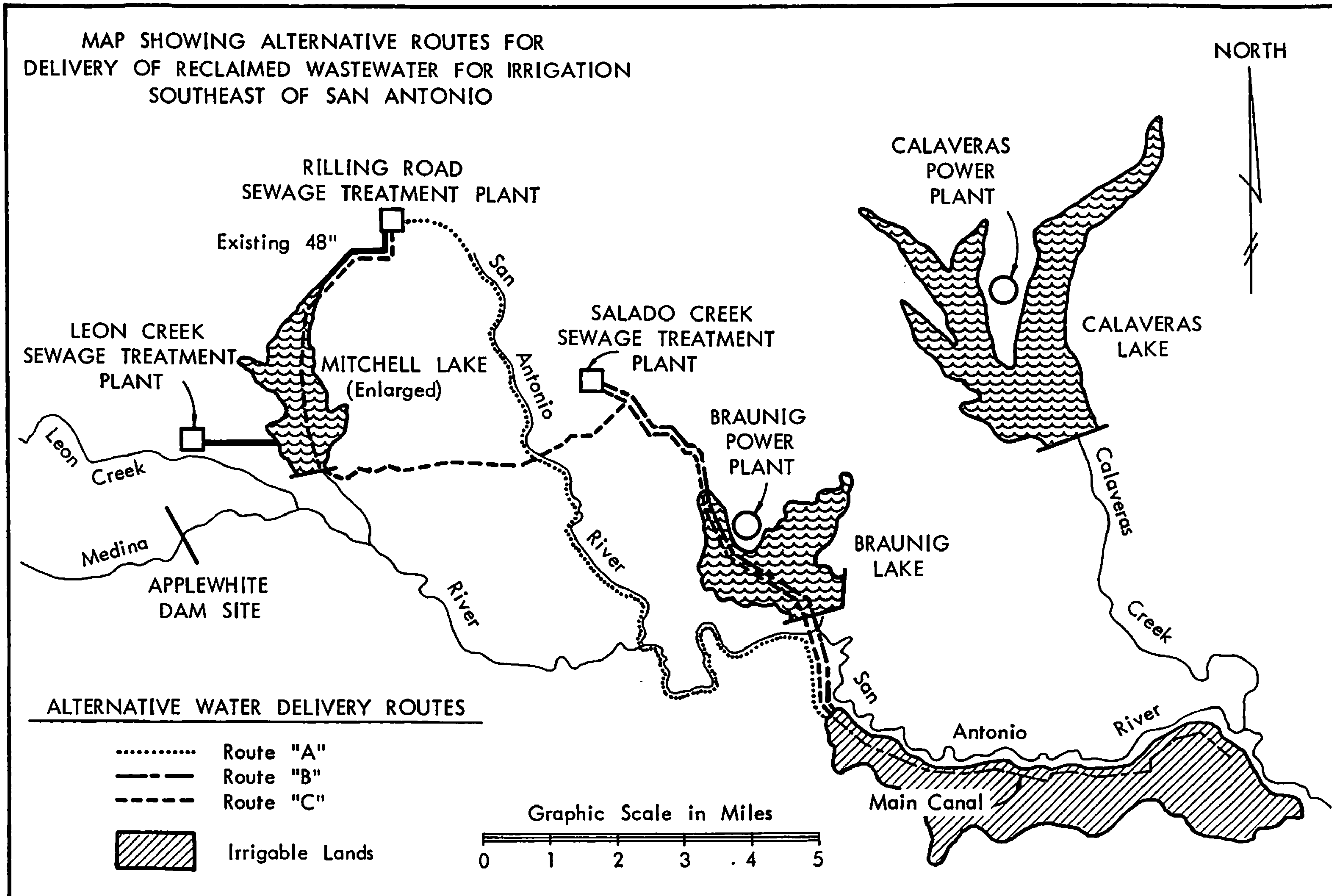

MAP SHOWING ALTERNATIVE ROUTES FOR
DELIVERY OF RECLAIMED WASTEWATER FOR IRRIGATION
SOUTHEAST OF SAN ANTONIO
NORTH
RILLING ROAD
SEWAGE TREATMENT PLANT
Existing 48"
LEON CREEK
SEWAGE TREATMENT
PLANT
MITCHELL LAKE
(Enlarged)
San Antonio River
SALADO CREEK
SEWAGE TREATMENT
PLANT
CALAVERAS
POWER
PLANT
CALAVERAS
LAKE
BRAUNIG
POWER
PLANT
BRAUNIG
LAKE
Leon Creek
Medina River
APPLEWHITE
DAM SITE
Calaveras Creek
San Antonio River
Main Canal
ALTERNATIVE WATER DELIVERY ROUTES
Route "A"
Route "B"
Route "C"
Irrigable Lands
Graphic Scale in Miles
0 1 2 3 4 5

FIGURE 7.2

Texas Water Rights Commission could presumably grant a permit allowing San Antonio to use the bed and banks of the river to transport *reclaimed* water belonging to the City, the Commission has generally held in the past that treated wastewaters should become public waters once they are released into a stream.

Thus, from the standpoint of protecting the City's ownership and right to re-use the water, it would be preferable to move it through City-owned transmission facilities to Lake Braunig and thence across the San Antonio River to the irrigation canal. If this is the case, there are again two alternatives, one involving only the irrigation water and the other with the irrigation supply being part of a much larger movement of reclaimed water through Lake Braunig as outlined in Section 6. The various possibilities shown on Figure 7.2 can be summarized as follows:

a. Release of water from the treatment plants into natural streams to flow down to a diversion pump station at the beginning of the irrigation system.

b. Delivery through an outfall line from the Salado Creek sewage treatment plant to Lake Braunig and subsequent transfer through a second pipe line under the San Antonio River into the western end of the main irrigation canal.

c. Inclusion of the irrigation supply as part of large-scale movement of reclaimed water through Lake Braunig and transfer of the irrigation requirements through a pipe line under the San Antonio River as in "b" above.

In each instance, the quantity of reclaimed water required for delivery into the main canal would be 9,200 acre-feet per year.

Until some time after 1985, feasibility of the southeast irrigation would depend on having a moderate volume (3,300 to 3,700 acre-feet) of regulating storage to furnish supplemental water in dry summer months. The amount needed would decrease with time, as output from the sewage treatment plants rises. Either Mitchell Lake or the proposed Applewhite Reservoir could supply the necessary backup storage while it is needed. They would fit best with alternative "a" above, although Mitchell Lake would also be directly applicable to condition "c". They could be used with any of the alternatives, provided there is diversion capacity available to take water from the river and transfer it into the upper end of the irrigation canal. Lake Braunig and Lake Calaveras should not be considered sources of the supplemental storage, since depletion of their contents would be in conflict with the primary power plant cooling function during the peak generating season. Likewise, use of Mitchell Lake as a power plant site would make it unavailable for support of irrigation.

8. COSTS AND BENEFITS

Cost of Irrigation Water Delivery West of San Antonio

Table 8.1 gives the estimated capital costs of constructing facilities to deliver reclaimed wastewater west of San Antonio for irrigation use in amounts ranging from 25,000 to 40,000 acre-feet per annum. The systems rated at 25,000, 30,000 and 35,000 acre-feet per year are to supply water to the Bexar-Medina-Atascosa main canal. The 40,000 acre-feet per year facility would be for service to lands along the Medina River in Bexar and Medina Counties but would not provide water for the Bexar-Medina-Atascosa District.

Table 8.2 outlines the annual cost of debt service, maintenance and operation for these facilities. Principal and interest payments were based on 30 equal annual payments with interest at 6%. Power costs assume a unit electricity rate of 1¢ per kilowatt-hour. Table 8.3 combines the annual cost figures with the estimated savings in withdrawals from the Edwards Underground Reservoir to show the resulting unit cost per thousand gallons of ground water conserved. For purposes of this evaluation, it is assumed that a gain of 1,700 acre-feet per year in yield at the Applewhite Reservoir, attributable to operating Lake Medina entirely for recharge, would save 1,700 acre-feet per year in pumpage from the Edwards limestone.

Cost of Irrigation Water Delivery Southeast of San Antonio

Table 8.4 summarizes the capital costs of facilities to deliver reclaimed water for irrigation southeast of San Antonio, along the south side of the San Antonio River in Bexar and Wilson Counties, showing three alternatives based on various basic delivery routes. Table 8.5 compares

Table 8.1

Estimated Capital Cost of Facilities To Supply Reclaimed Water for Irrigation West of San Antonio

- Amounts in $1,000 -

	25,000 Ac-Ft/Yr Delivered	30,000 Ac-Ft/Yr Delivered	35,000 Ac-Ft/Yr Delivered	40,000 Ac-Ft/Yr Delivered
Rilling Pump Station	$ 575.4	$ 658.5	$ 719.6	$ 798.6
Pipe Line Section No. 1	1,768.7	1,914.8	2,193.6	2,443.0
Lower Main Canal	1,516.6	1,547.8	1,583.3	1,624.0
Booster Station No. 1	254.6	294.6	336.5	368.9
Pipe Line Section No. 2	177.4	192.1	220.9	249.9
Upper Main Canal				
Before Big Sous Station	968.5	990.1	1,013.4	1,061.1
After Big Sous Station	1,898.4	2,082.0	2,182.1	2,050.7
Big Sous Pump Station	222.1	233.1	314.8	354.8
Big Sous Reservoir	1,867.7	1,918.6	1,994.4	2,074.2
Castroville Booster Station	405.5	475.9	784.6	-
Medina River Pipe Line	240.0	263.7	263.7	-
Booster Stations 2 and 3	-	-	-	301.1
Pipe Line Sections 3 and 4	-	-	-	80.3
Canal North of Castroville	-	-	-	1,944.4
Total	$ 9,894.9	$10,571.2	$11,606.9	$13,360.0

Notes: The 25,000, 30,000 and 35,000 Ac-Ft/Yr systems supply water only to the Medina Canal. The 40,000 Ac-Ft/Yr system is entirely for irrigation north and east of the Medina River.

Table 8.2

Estimated Annual Cost To Supply Reclaimed Water for Irrigation West of San Antonio

- Amounts in $1,000 -

	25,000 Ac-Ft/Yr Delivered	30,000 Ac-Ft/Yr Delivered	35,000 Ac-Ft/Yr Delivered	40,000 Ac-Ft/Yr Delivered
Principal and interest	$ 718.9	$ 768.0	$ 843.2	$ 970.6
Maintenance and operation of canals and pipe lines	32.8	35.0	36.9	47.3
Maintenance and operation of Big Sous Reservoir	18.7	19.2	19.9	20.7
Maintenance and operation of pump stations, exclusive of power	66.4	68.5	70.5	74.6
Power	264.0	312.1	357.2	352.1
Total	$1,100.8	$1,202.8	$1,327.7	$1,465.3

Notes: Principal and interest based on 30 equal payments at 6% interest.

Power costs based on 1¢ per kilowatt-hour.

Table 8.3

Comparative Unit Costs of Edwards Water Saved By Use of Reclaimed Water For Irrigation West of San Antonio

	25,000 Ac-Ft/Yr Delivered	30,000 Ac-Ft/Yr Delivered	35,000 Ac-Ft/Yr Delivered	40,000 Ac-Ft/Yr Delivered
Ac-Ft/Yr delivered to Bexar-Medina-Atascosa District	25,000	30,000	35,000	-
Ac-Ft/Yr delivered to other lands north and east of the Medina River	-	-	-	40,000
Annual cost to deliver reclaimed water in $1,000	$1,100.8	$1,202.8	$1,327.7	$1,465.3
Added recharge achieved at Lake Medina in Ac-Ft/Yr	14,000	14,000	14,000	-
Savings in Edwards Underground Reservoir pumpage for irrigation in Ac-Ft/Yr	-	-	-	40,000
Gain in Applewhite Reservoir yield in Ac-Ft/Yr	1,700	1,700	1,700	-
Total gain to Edwards Underground Reservoir in Ac-Ft/Yr	15,700	15,700	15,700	40,000
Unit cost of Edwards Underground water gained in ¢/1,000 gallons	21.5¢	23.5¢	26.0¢	11.2¢

Table 8.4

Estimated Capital Cost of Facilities To Supply Reclaimed Water for 4,000 Acres of Irrigation Southeast of San Antonio

	Alternative "a"	Alternative "b"	Alternative "c"
Diversion pump station on the San Antonio River	$ 247.6	$ ---	$ ---
36" Pipe line from Salado Creek sewage treatment plant to Lake Braunig	---	300.8	*(See notes)
24" Pipe line from Lake Braunig under the San Antonio River to the main irrigation canal	---	131.2	131.2
Main irrigation canal and primary laterals	991.7	991.7	991.7
Total	$1,239.3	$1,423.7	$1,122.9*

Notes: Alternative "a": Delivery via the San Antonio River to a diversion pump station at the upper end of the main irrigation canal.

Alternative "b": Delivery of the irrigation water by pipe line from the Salado Creek treatment plant to Lake Braunig and thence by pipe line under the San Antonio River to the upper end of the main irrigation canal.

*Alternative "c": Inclusion of the irrigation water with larger amounts of reclaimed water being routed through Lake Braunig and diversion of the irrigation requirements from Lake Braunig by pipe line under the San Antonio River to the main irrigation canal. In this case, the facilities to carry the water from the treatment plants to Lake Braunig would be the same as outlined in Table 8.8; their costs are not included in this table, and the total cost shown here is the incremental amount attributable to irrigation.

Table 8.5

Estimated Annual Cost To Supply Reclaimed Water for Irrigation Southeast of San Antonio

- Amounts in $1,000 -

	Alternative "a"	Alternative "b"
Principal and interest	$ 90.0	$103.4
Maintenance and operation of canals and pipe lines	24.3	26.5
Maintenance and operation of diversion pump station, exclusive of power	12.0	-
Power	9.4	
Total	$135.7	$129.9

Notes: Alternative "a": Delivery via the San Antonio River to a diversion pump station at the upper end of the main irrigation canal.

Alternative "b": Delivery of the irrigation water by pipe line from the Salado Creek treatment plant to Lake Braunig and thence by pipe line under the San Antonio River to the main irrigation canal.

Alternative "c": (Not shown): Inclusion of the irrigation water with larger amounts of reclaimed water being routed through Lake Braunig and diversion of the irrigation requirements from Lake Braunig by pipe line under the San Antonio River to the main irrigation canal. With proper allowance for sharing the cost of the larger facilities carrying reclaimed water to the power plant lakes, the annual costs of alternative "c" would be essentially the same as those of alternative "b."

the annual cost of alternatives "a" and "b". Alternative "c" is essentially similar to alternative "b" except for making joint use of facilities for large-scale movement of treated wastewater through the power plant lakes. The annual costs indicated for alternative "b" can therefore be considered as representative of the costs attributable to alternative "c" when allowance is made for a proper share of the costs of the larger facility. As in the previous tables, power costs were evaluated at 1¢ per kilowatt-hour, and debt service was based on 30 equal annual payments of principal and interest at 6% interest. In terms of over-all annual cost, alternative "b" (or "c") would be preferable and would involve annual expenses of approximately $130,000 for the 4,000 acres of irrigation under consideration here, or an average of $32.50 per year per acre served.

Cost of Tertiary Treatment

Table 8.6 shows estimated costs to provide lime clarification and multi-media filtration for various volumes of secondary effluent at the Rilling Road plants. These estimates are based on cost data published by the Federal Water Quality Administration (24), together with cost trend information from Engineering News-Record magazine. The four capacities indicated cover the range of potential requirements being considered for irrigation use west of San Antonio, with allowance for seepage and evaporation losses of about 20% of the delivery volumes.

Although the specific processes covered by Table 8.6 would not necessarily be the ones chosen as a result of a detailed design study, they do reflect the basic level of cost for significant betterment of the reclaimed wastewater. By comparison, the present over-all cost of sewerage

Table 8.6

Estimated Cost of Lime Clarification and Multi-Media Filtration

Irrigation Requirements (Ac-Ft/Yr)	Tertiary Facility Capacity (MGD)	Capital Cost	Unit Cost per 1,000 Gallons		
			Maintenance and Operation	Debt Service	Total
25,000	27	$3,800,000	5.6¢	2.8¢	8.4¢
30,000	32	$4,300,000	5.4¢	2.7¢	8.1¢
35,000	37	$4,800,000	5.2¢	2.6¢	7.8¢
40,000	43	$5,200,000	5.0¢	2.4¢	7.4¢

Note: Debt service requirements are based on equal annual payments to cover principal and interest on 30-year bonds at 6% interest.

service in San Antonio, including collection, treatment and administration, is approximately 11-1/3¢ per 1,000 gallons.

It is also of interest to compare the costs of Table 8.6 with those involved in delivering reclaimed wastewater for irrigation use. The cost to move the water westward for irrigation would range from 13.5¢ per 1,000 gallons for 25,000 acre-feet per year to 11.2¢ per 1,000 gallons for 40,000 acre-feet per year. To deliver water for the proposed irrigation use southeast of San Antonio (9,200 acre-feet per year) would cost approximately 4.5¢ per 1,000 gallons.

Cost To Raise Mitchell Lake

Table 8.7 is a breakdown of the cost of raising the water level at Mitchell Lake by 12 feet. The total for design and construction and for the necessary additional land is estimated to be $1,140,000. Principal and interest payments to amortize this amount in 30 years at 6% interest would be $114,700 per year. Not included in Table 8.5 is the cost to provide another means for disposal of excess activated sludge and digester supernatant liquor at the Rilling Road plants.

Table 8.7

Estimated Cost To Raise The Normal Water Level 12 Feet At Mitchell Lake

- Amounts in $1,000 -

Preparation of site	$ 25.0
Core trench excavation	40.0
Compacted embankment	215.1
Riprap	118.8
Riprap blanket	39.6
Mulching	10.0
Clearing	40.5
Spillway structure	408.1
Protection of Pleasanton Road	150.0
Contingencies and engineering	261.8
Land	270.0
Total	$1,578.9

Cost of Alternative Disposal of Waste Activated Sludge

In the latter part of 1969, Mr. John D. Holm, Sewage Treatment Plant Superintendent, made preliminary studies of the cost of five alternate methods for disposing of the excess activated sludge at the Rilling Road plants when treating 85 MGD of wastewater. The estimated capital cost of facilities for filter press dewatering and incineration, exclusive of the cost of thickeners, was $2,731,000. The estimated additional cost of an adequate centrifuge thickener installation is $450,000. It would also be necessary to provide for chlorination or other treatment of the digester supernatant before returning it from the digesters to the primary settling tanks. Over-all, the capital cost of the new facilities would now be approximately $3.5 million. Principal and interest on an investment of $3.5 million, based on 30 equal annual payments at 6% interest, would be $254,300 per year. The total added cost to dispose of waste activated sludge by incineration instead of by discharge to Mitchell Lake, and to process primary digester supernatant for return to the primary settling tanks, should be expected to be between $15 and $20 per million gallons of sewage treated.

Cost of Inter-Connecting Lakes Mitchell, Braunig and Calaveras

Table 8.8 reflects estimated costs of conduits to link Mitchell Lake, Lake Braunig and Lake Calaveras as shown in Figure 6.2, together with the necessary additional outfall lines to place the reclaimed water from

Table 8.8

Estimated Cost to Link Lakes Mitchell, Braunig and Calaveras

- Amounts in $1,000 -

Additional 48" conduit from Rilling Road sewage treatment plants to Mitchell Lake	$ 533.3
72" Conduit from Mitchell Lake to junction with 48" conduit from Salado Creek sewage treatment plant	1,968.9
48" Conduit from Salado Creek sewage treatment plant to junction with 72" conduit from Mitchell Lake	115.0
96" Conduit from junction of 72" and 48" lines to Braunig Lake	1,428.9
78" Conduit from Braunig Lake to Calaveras Lake	943.7
Total	$4,989.8

the Rilling Road and Salado Creek sewage treatment plants in Mitchell and Braunig Lakes, respectively. These facilities would allow combined operation of the lakes as reflected in the performance studies of Appendix C.

Benefits

The economic value of savings in pumpage from the Edwards Underground Reservoir can best be viewed in terms of the probable cost to obtain a supplemental supply of surface water in large quantity for the San Antonio area. The expense of delivering surface water from likely sources of supply has previously been investigated in detail (25). Debt service and maintenance and operation for filter plant facilities can be evaluated closely from comparable experience in other cities. With reasonable allowance for the cost of raw water at the source, it is estimated that the over-all unit cost to bring a significant volume of surface water to San Antonio and treat it for use in the municipal distribution system would be in the vicinity of 15¢ per 1,000 gallons.

Benefits attributable to recreational uses of the lakes are somewhat less clearly defined, although the need for water-oriented recreation is increasingly important in any large metropolitan area. The growing population, coupled with the trend toward higher average personal income and more leisure time, result in heavy demands for meaningful outdoor recreation of all kinds, and water activities are among the most popular. Table 8.9 indicates the expected magnitude of requirements for certain types of recreational activity in Bexar County during the years 1970, 1980 and 1990, based on criteria set forth in the Comprehensive Outdoor Recreation Plan of the Texas Parks and Wildlife Department (26). Emphasis in this table is on activities which would be appropriate for lakes and

Table 8.9

Partial Estimate of Potential Bexar County Demand for Water-Related Outdoor Recreation

- Thousands of Activity-Days -

	1970	1980	1990
Fresh water fishing	2,222	2,621	3,022
Picnics	1,155	1,362	1,571
Boating	743	877	1,011
Camping	399	470	542
Water skiing	292	345	398
Canoeing	36	43	50
Sailing	18	21	25

shoreline areas. To support water-related recreation on this scale, approximately 21,000 acres of water surface would be needed in 1970, increasing to 28,500 acres by 1990. At the present time, within 50 miles of San Antonio, there are some 9,600 acres of normal water surface area in major reservoirs that are available for public use, so the supply falls considerably short of the potential demand.

The monetary value of recreational benefits obviously depends in large degree on the assumed worth of a day's fishing or boating or the opportunity to spend a day in some other outdoor activity. In a city environment, the primary need is for ready availability of such opportunities for all citizens, allowing people to enjoy the out-of-doors without undue expense or travel. An advisory committee reporting to President Johnson in 1964 (27) suggested a range of from 50¢ to $1.50 per day for the types of recreation under discussion here, but did not set exact amounts for specific activities. Boating and fishing are the two main categories of recreational use applicable to the power plant cooling lakes. From the guidelines set out in Reference (26), each acre of lake surface may reasonably be considered to represent 90 activity-days of boating and 270 activity-days of fishing in the course of a year. Even at 50¢ per activity-day, potential recreational benefits from the reclamation and raising of Mitchell Lake (1,389 acres of surface area at elevation 536) would thus be valued at more than $250,000 per annum.

From the standpoint of benefits obtainable from re-use of the reclaimed water, power plant cooling is preferable to irrigation. In terms of ground water conservation, the cooling use is at least as effective as would be the long-range irrigation prospects west of San Antonio, and no Edwards Underground Reservoir water would be conserved by the proposed new irrigation southeast of San Antonio. The recreational benefits of the power plant lakes would not be available from irrigation. Where there is a choice between using the water for cooling and for irrigation, priority should be given to the cooling use.

9. CONCLUSIONS AND RECOMMENDATIONS

a. San Antonio's wastewater reclamation plants are currently producing approximately 100,000 acre-feet per year of water that can be re-used for some purposes, and the amount is expected to increase to 173,000 acre-feet per year by the end of the century.

b. The two most promising uses for reclaimed wastewater in the San Antonio area are irrigation and power plant cooling. At the present time, 16,200 acre-feet per year have been committed to existing obligations for irrigation in the vicinity of Mitchell Lake, and 72,000 acre-feet per year are covered by permits for diversions to Lake Braunig and Lake Calaveras.

c. Once the Braunig and Calaveras power plants are developed to full capacity, water requirements to replace evaporative losses and maintain suitable chemical concentrations in the cooling lakes will be more than the present diversion permits. The estimated peak requirements are 24,000 acre-feet per year at Lake Braunig and 69,800 acre-feet per year at Lake Calaveras. Their existing permits are for 12,000 acre-feet per year and 60,000 acre-feet per year, respectively.

d. In general, power plant cooling use offers greater over-all benefits than irrigation, especially in terms of ground water conservation and recreation. Where it is necessary to choose between the two, first preference should be given to the power plant needs.

e. The total of existing obligations and other potential uses will exceed the available supply of reclaimed wastewater for the next 20 years or longer. There probably will not be sufficient uncommitted wastewater for new large-scale irrigation until 1990 or after. The proposed irrigation operations west of San Antonio, which would require from 25,000 to 40,000 acre-feet per year, are thus long-term considerations rather than prospects for the near future. A lesser volume (9,200 acre-feet per year) of new irrigation southeast of San Antonio could be supplied now if backed by a moderate amount of regulating storage.

f. Eventual use of reclaimed wastewater to meet the irrigation requirements of Bexar-Medina-Atascosa Counties Water Improvement District No. 1 in lieu of the supply from Lake Medina would gain an average of 15,700 acre-feet per year in increased recharge and yield from the Medina River. The amount of reclaimed water needed would be in the range of 25,000 to 35,000 acre-feet per year, plus an estimated 20% additional to replace losses in the conveyance system. The corresponding unit expenditure per 1,000 gallons of increased recharge and yield would range from 21.5¢ to 26.0¢ at present-day cost levels. Operation of Lake Medina for recharge instead of irrigation would result in higher water levels in that reservoir part of the time; however, the recreational improvement would not be sufficient to offset the inherently high costs of delivering the reclaimed water to the Medina canal. Use of reclaimed wastewater for irrigation in the Bexar-Medina-Atascosa District does not appear to be economically justified.

g. Use of reclaimed wastewater for irrigation of other lands along the

Medina River in western Bexar and eastern Medina Counties would reduce the long-range ground water pumpage in that area by as much as 40,000 acre-feet per year for an estimated unit cost of 11.2¢ per 1,000 gallons of ground water conserved at today's cost levels. Use of the reclaimed water for large-scale irrigation of such lands would be economically justified on that basis.

h. Approximately 4,000 acres of land along the south bank of the San Antonio River in southeastern Bexar County and northwestern Wilson County could be supplied with reclaimed wastewater for irrigation. The supply would be dependable only if supported by some 3,300 to 3,700 acre-feet of regulating storage not already committed to other purposes. Mitchell Lake could serve this need if not otherwise utilized. The estimated cost of delivering the reclaimed water to this area is $32.50 per year per acre.

i. Sites for additional power plant cooling lakes near San Antonio are limited, and the only likely prospect appears to be at Mitchell Lake. It is feasible to raise Mitchell Lake 12 feet, which would provide enough surface area to support a generating plant of about 1,400 megawatts capacity. The estimated capital cost to raise the water surface 12 feet is $1.58 million. If Mitchell Lake is to be considered seriously as a power plant site, it must be available in the immediate future. After about 1978, a lake of that size may well be too small to accomodate the large generating units projected to be needed by that time.

j. Use of Mitchell Lake for something other than its present purpose would require construction of new facilities for disposal of waste activated sludge and primary digester supernatant at the Rilling Road plants. The estimated capital cost of providing such facilities is $3.5 million. The added unit cost of sewage treatment at the Rilling Road plants due to adoption of a new system for waste activated sludge and digester supernatant could be expected to be between $15 and $20 per million gallons treated, including debt service on the capital investment.

k. It is feasible to inter-connect Lakes Mitchell, Braunig and Calaveras so that most of the City's reclaimed wastewater could be passed through those lakes by gravity flow. The estimated capital cost of a system of gravity conduits linking the lakes to the Rilling Road and Salado Creek treatment plants and to one-another is $4.99 million. Such a system would retain definite ownership and control of the water until released from Lake Calaveras. It would noticeably improve the quality of water impounded in Lake Braunig, but peak chemical concentrations in Lake Calaveras would be increased unless and until the direct linkage made available significantly more inflow to that lake. This concept would necessitate a comprehensive engineering study to determine what effect this circulation would have on the cooling capabilities of Braunig and Calaveras Lakes as they are now designed to function.

l. It is recommended that the City Public Service Board seek to amend the water rights permits associated with Lake Braunig and Lake Calaveras so as to be able to divert 24,000 acre-feet per year from the San Antonio River to Lake Braunig and 69,800 acre-feet per year to Lake Calaveras.

m. The extent to which additional reclaimed wastewater can be utilized effectively for power plant cooling will be influenced by economic and operational considerations associated with the over-all power system. In the near future, it will be necessary for the City Public Service Board to start planning for the next phase of system development. It is recommended that, as part of that planning, attention be given to whether or not Mitchell Lake should be raised and used as a power plant cooling reservoir.

n. It is recommended that no additional irrigation be undertaken with reclaimed wastewater until the City Public Service Board has an opportunity to establish the long-range desirability of using Mitchell Lake as a power plant site.

o. If, after study of the various factors involved, it is determined that Mitchell Lake should not be used as a power plant site, consideration could be given to new irrigation with reclaimed wastewater southeast of San Antonio.

p. If it should be decided to use Mitchell Lake for power plant cooling, the prospect for any further irrigation with reclaimed wastewater would be quite marginal for the next 15 years or more, or until such time as there has been enough increase in the available supply to make the irrigation possible without need for supplemental withdrawals from storage in summer months.

APPENDIX A

LIST OF REFERENCES

APPENDIX A

LIST OF REFERENCES

(1) City of San Antonio: "Wastewater Treatment Annual Report," 1969 and preceding years.

(2) San Antonio City Water Board: Water Statistics," San Antonio, 1969.

(3) City Public Service Board of San Antonio: "28th Annual Report - Fiscal Year Ended January 31, 1970," and similar reports for earlier years.

(4) Black and Veatch, Consulting Engineers: "Water Requirements for Calaveras Lake Project, City Public Service Board, San Antonio, Texas," Kansas City, Missouri, March 1967.

(5) Texas Water Commission (now Texas Water Development Board): "Inventory of Texas Irrigation, 1958 and 1964," Austin, June 1965. Supplemental information is also available from maps and data on file at the Water Development Board offices.

(6) Letter from D. T. Graham, Chief, Engineering Division, Galveston District, Corps of Engineers, to David H. Brune, Manager, San Antonio River Authority, concerning estimated lockage water requirements for navigation of the San Antonio River, January 29, 1968.

(7) U. S. Geological Survey: "Water Resources Data for Texas, Part 1, Surface Water Records," published annually at Austin, Texas. Prior to 1961, the same material was published at Washington D.C., under the title "Surface Water Supply of the United States, Part 8, Western Gulf of Mexico Basins."

LIST OF REFERENCES, Continued

(8) Environmental Sciences Services Administration (formerly the U. S. Weather Bureau): "Climatological Data, Texas," published monthly, with annual summaries, at Asheville, North Carolina.

(9) Environmental Science Services Administration: "Hourly Rainfall Data," published monthly, with annual summaries, at Asheville, North Carolina.

(10) Texas Water Development Board: Report 64, "Monthly Reservoir Evaporation Rates for Texas, 1940 Through 1965," Austin, October 1967.

(11) Texas Board of Water Engineers: "Bulletin 5601 - Geology and Ground-water Resources of Medina County, Texas," Austin, August 1956.

(12) Robert L. Lowry, Consulting Engineer: "Hydrologic Report on Medina River Above the Applewhite Damsite," prepared for the San Antonio City Water Board, Austin, August 1953.

(13) William F. Guyton and Associates: "Leakage From Medina Lake, Medina County, Texas," prepared for the San Antonio City Water Board, Austin, March 1958.

(14) Texas Board of Water Engineers: "Bulletin 5912 - Inventory and Use of Sedimentation Data In Texas," Austin, January 1959.

(15) U. S. Department of Agriculture, Soil Conservation Service SCS-TP-127: "Rates of Sediment Production in the Western Gulf States," Fort Worth, March 1956.

(16) U. S. Geological Survey: "Water Resources Data for Texas, Part 2, Water Quality Records," published annually at Austin, Texas.

(17) Federal Water Pollution Control Administration (now the Federal Water Quality Administration): "Water Quality Criteria," Washington, April 1, 1968.

(18) Texas Water Quality Board: "Water Quality Requirements, Volume I, Inland Waters," Austin, June 1967.

(19) John C. Merrill, Jr., and others: "The Santee Recreation Project, Santee, California - Final Report," U. S. Department of the Interior, Federal Water Pollution Control Administration, Cincinnati, Ohio, 1967.

(20) Fred N. Pfeiffer and C. Thomas Koch: "A Plan for Improving the Water Quality of the San Antonio River by Reuse of Return Flow," San Antonio, January 1968.

(21) Texas Board of Water Engineers: "Ground Water Resources of Bexar County, Texas," prepared in cooperation with the U. S. Geological Survey, Austin, May 1947.

(22) Texas Board of Water Engineers: Bulletin 5601, "Geology and Ground Water Resources of Medina County, Texas," prepared in cooperation with the U. S. Geological Survey, Austin, August 1956.

(23) Texas Board of Water Engineers: Bulletin 5911, "Ground Water Geology of Bexar County, Texas," prepared in cooperation with the U. S. Geological Survey, Austin, October 1959.

(24) Robert Smith and Walter F. McMichael: "Cost and Performance Estimates for Tertiary Wastewater Treating Processes," Federal Water Quality Administration, Robert A. Taft Water Research Center, Cincinnati, June 1969.

LIST OF REFERENCES, Continued

(25) Turner, Collie and Braden, Inc.: "Preliminary Engineering Study of Alternative Conveyance Systems - Lake Austin to San Antonio and Cuero-Cibolo to San Antonio," Houston, March 1967.

(26) Texas Parks and Wildlife Department: "State of Texas Comprehensive Outdoor Recreation Plan," Austin, 1965.

(27) Ad Hoc Water Resource Council: "Policies, Standards, and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources, Supplement No. 1, Evaluation Standards for Primary Outdoor Recreation Benefits," report presented to President Lyndon B. Johnson, Washington, June 4, 1964.

APPENDIX B

HYDROLOGIC DATA

Table B-1

Sources of Runoff Data

Medina Lake

1/1937 - 5/1939	Records from the U. S. Geological Survey gaging station on the Guadalupe River near Spring Branch, multiplied by the drainage area factor .49.
6/1939 - 12/1952	Records from the U. S. Geological Survey gaging station on the Guadalupe River near Comfort, multiplied by the drainage area factor .76.
1/1953 - 12/1968	Records from the U. S. Geological Survey gaging station on the Medina River near Pipe Creek, multiplied by the drainage area factor 1.34.

Applewhite Reservoir Site With Medina Lake Used for Irrigation

1/1937 - 2/1937	Records from the U. S. Geological Survey gaging station on the Guadalupe River near Spring Branch, multiplied by the correlation factor .165, plus average historical seepage past Diversion Dam (1,333 acre-feet/month), plus Medina Lake historical spills.
3/1937 - 7/1939	Records from the U. S. Geological Survey gaging station on the Guadalupe River near Spring Branch multiplied by the correlation factor .30.
8/1939 - 12/1952	Records from the U. S. Geological Survey gaging station on the Medina River near San Antonio, multiplied by the correlation factor .75.
1/1953 - 12/1968	Records from the U. S. Geological Survey gaging station on the Medina River near San Antonio minus records from the U. S. Geological Survey gaging station on the Medina River near Riomedina, with the difference multiplied by the drainage area factor .613, plus records from the U. S. Geological Survey gaging station on the Medina River near Riomedina.

Applewhite Reservoir Site With Medina Lake Used for Recharge of Edwards Underground Reservoir

1/1937 - 7/1939	Records from the U. S. Geological Survey gaging station on the Guadalupe River near Spring Branch, multiplied by the correlation factor .165, plus spills from Lake

Medina based on a reservoir operation study with no demand.

8/1939 - 12/1952	Records from the U. S. Geological Survey gaging station on the Medina River near San Antonio, multiplied by the correlation factor .41, plus spills from Lake Medina based on a reservoir operation study with no demand.
1/1953 - 12/1968	Records from the U. S. Geological Survey gaging station on the Medina River near San Antonio, minus records from the U. S. Geological Survey gaging station on the Medina River near Riomedina, with the difference multiplied by the drainage area factor .637, plus spills from Lake Medina based on a reservoir operation study with no demand.

Table B-2

Runoff Data in Tens of Acre-Feet for Lake Medina

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	1,370	1,020	1,210	830	550	1,810	430	210	230	280	250	690	8,880
1938	1,470	860	690	1,200	1,120	480	270	160	180	140	160	170	6,900
1939	300	200	210	190	230	80	670	220	140	610	240	240	3,330
1940	240	350	440	1,390	1,130	840	650	390	210	430	780	2,100	8,950
1941	660	2,360	2,000	3,630	3,660	1,170	780	540	970	1,470	680	620	18,540
1942	570	470	430	2,110	2,980	780	450	330	420	1,190	650	590	10,970
1943	490	400	470	500	390	940	270	140	220	240	230	300	4,590
1944	410	480	870	520	5,210	1,660	450	480	570	650	410	910	12,620
1945	1,480	1,280	1,920	1,650	730	460	390	190	710	890	410	930	11,040
1946	570	590	650	570	1,040	590	210	110	300	1,260	1,940	880	8,710
1947	1,880	1,130	1,000	1,060	940	1,860	540	320	200	200	270	320	9,720
1948	300	370	360	370	310	260	320	110	140	190	170	200	3,100
1949	260	1,470	820	910	640	530	250	580	440	280	240	290	6,710
1950	330	330	280	390	430	270	140	80	140	130	140	170	2,830
1951	170	180	320	230	900	540	70	30	50	50	120	140	2,800
1952	140	140	180	380	620	500	110	20	1,730	190	170	550	4,730
1953	320	200	190	120	50	10	80	350	1,050	1,540	380	270	4,560
1954	200	160	150	120	600	150	50	10	10	10	10	10	1,480
1955	70	160	90	70	540	70	470	160	40	30	10	30	1,740

Table B-2, Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1956	40	50	50	30	50	10	0	170	40	30	70	10	550
1957	10	30	830	5,010	2,750	2,710	430	130	1,460	3,400	2,300	1,540	20,600
1958	3,480	3,710	5,130	2,080	1,850	6,580	1,630	630	3,940	4,150	3,820	1,820	38,820
1959	1,180	860	710	1,300	920	1,710	1,050	440	290	2,960	880	780	13,080
1960	920	860	1,020	860	630	280	900	3,980	1,090	1,470	1,620	2,450	16,080
1961	2,320	3,990	2,520	1,330	740	1,920	1,100	760	480	440	450	470	16,520
1962	400	300	300	430	250	210	50	30	10	990	240	300	3,510
1963	230	200	220	240	240	110	40	30	10	13	40	147	1,520
1964	201	442	630	415	228	94	27	375	5,253	1,340	871	590	10,466
1965	456	1,166	938	992	2,090	1,206	442	188	241	817	362	737	9,635
1966	603	509	523	710	858	523	389	2,291	1,903	911	576	456	10,252
1967	375	295	281	268	121	54	13	13	657	1,635	1,635	898	6,245
1968	3,645	2,747	2,948	2,023	3,712	1,675	1,434	563	509	429	402	469	20,556
Avg.	784	853	887	998	1,141	941	441	438	739	886	641	627	9,331

Table B-3

Runoff Data in Acre-Feet for Applewhite Reservoir Site With Medina Lake Used for Irrigation

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	6,648	4,763	5,394	3,941	2,948	7,207	2,366	1,189	1,134	1,658	2,084	3,638	42,970
1938	6,304	4,216	3,661	5,181	4,868	2,729	1,833	996	960	1,196	1,756	1,902	35,602
1939	2,354	2,013	2,018	1,793	1,857	1,323	2,450	1,396	1,211	1,649	2,131	2,961	23,156
1940	2,366	2,866	2,448	3,136	3,051	4,307	3,594	1,469	1,215	2,780	4,333	4,822	36,387
1941	3,174	9,918	3,826	6,916	6,195	3,454	2,532	1,859	1,887	2,391	2,808	3,244	48,204
1942	2,895	3,379	2,858	4,284	4,502	2,569	6,759	2,187	21,088	15,999	4,833	3,916	75,269
1943	4,453	3,703	3,576	3,173	3,133	3,225	3,168	1,986	2,798	2,657	3,624	3,281	38,777
1944	4,019	3,375	3,408	2,984	3,789	2,647	2,422	3,564	2,756	3,055	3,267	5,027	40,313
1945	6,704	6,614	4,929	4,607	3,739	4,569	2,893	2,625	2,732	3,301	3,185	3,629	49,527
1946	4,301	3,539	3,871	4,275	4,235	4,770	2,897	21,633	22,486	6,926	4,981	4,834	88,748
1947	4,925	3,949	4,088	3,455	3,477	3,266	2,963	2,560	2,260	2,784	3,640	4,043	41,410
1948	3,658	3,895	3,379	3,193	2,194	2,552	2,598	1,632	722	1,168	902	730	26,623
1949	1,086	4,051	2,247	7,240	3,022	10,597	2,336	1,473	1,395	7,301	1,823	4,041	46,612
1950	4,096	2,973	2,789	3,476	3,104	3,301	1,250	2,366	2,189	1,386	1,599	1,542	30,071
1951	508	1,587	1,189	541	4,633	2,302	321	303	1,328	351	332	381	13,776
1952	430	1,427	775	586	1,739	1,362	205	162	1,494	933	962	1,745	11,820
1953	1,773	635	1,555	768	0	0	28	1,312	13,647	1,435	1,831	2,097	25,081
1954	2,015	466	503	1,357	2,250	299	240	269	0	366	6	0	7,771
1955	780	2,571	1,491	405	2,108	423	275	1,376	514	298	322	613	11,176

Table B-3, Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1956	822	545	383	252	662	247	264	1,096	1,096	2,873	323	758	9,321
1957	218	930	962	22,266	13,351	11,698	1,371	473	5,637	4,780	3,436	2,947	68,069
1958	7,493	10,302	3,798	3,150	19,984	13,188	5,236	1,792	26,176	37,772	32,348	11,184	172,423
1959	6,049	5,059	4,059	4,506	3,912	2,048	3,159	2,008	1,511	9,046	3,266	3,123	47,746
1960	3,002	3,403	4,422	2,589	2,294	2,315	2,936	1,244	696	4,651	2,667	1,887	32,106
1961	1,951	28,740	13,124	4,043	2,772	3,379	7,727	1,843	2,944	7,817	4,400	4,314	83,054
1962	4,486	3,346	2,295	4,258	3,084	2,717	1,095	1,014	600	803	1,782	2,225	27,705
1963	2,117	2,499	2,046	1,818	1,485	1,245	917	473	617	5,492	1,928	2,289	22,926
1964	2,747	2,830	4,543	2,118	1,963	4,698	857	632	1,989	4,262	9,190	2,932	38,761
1965	2,664	8,920	4,078	4,016	18,130	5,322	2,420	1,352	1,435	2,451	2,769	6,658	60,215
1966	3,212	3,164	2,792	3,761	3,724	2,150	1,567	1,505	2,460	1,752	2,253	2,650	30,990
1967	2,696	2,659	2,766	2,198	1,422	1,334	1,401	191	15,901	3,316	4,514	3,787	42,185
1968	38,986	7,493	6,168	4,965	9,409	4,048	5,083	2,269	2,861	2,988	3,658	4,333	92,261
Avg.	4,342	4,557	3,295	3,789	4,470	3,603	2,349	2,070	4,554	4,551	3,655	3,173	44,408

Table B-4

Runoff Data in Acre-Feet for Applewhite Reservoir Site With Medina Lake Used for Recharge of Edwards Underground Reservoir

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	7,957	5,181	5,394	3,941	2,948	7,207	2,366	1,189	1,134	1,658	2,084	3,638	44,697
1938	6,304	4,216	3,661	5,181	4,868	2,729	1,833	996	960	1,196	1,756	1,902	35,602
1939	2,354	2,013	2,018	1,793	1,857	1,323	2,450	1,396	1,211	1,649	2,131	2,961	23,156
1940	2,366	2,866	2,448	3,136	3,051	4,307	3,594	1,469	1,215	2,780	4,333	4,822	36,387
1941	3,174	9,918	3,826	6,916	6,195	3,454	2,532	1,859	1,887	2,391	2,808	3,244	48,204
1942	2,895	3,379	2,858	4,284	4,502	2,569	6,759	2,187	21,088	15,999	4,833	3,916	75,269
1943	4,453	3,703	3,576	3,173	3,133	3,225	3,168	1,986	2,798	2,657	3,624	3,281	38,777
1944	4,019	3,375	3,408	2,984	3,789	2,647	2,422	3,564	2,756	3,055	3,267	5,027	40,313
1945	6,704	6,614	4,929	4,607	3,739	4,569	2,893	2,625	2,732	3,301	3,185	3,629	49,527
1946	4,301	3,539	3,871	4,275	4,235	4,770	2,897	21,633	22,486	6,926	4,981	4,834	88,748
1947	4,925	3,949	4,088	3,455	3,477	3,266	2,963	2,560	2,260	2,784	3,640	4,043	41,410
1948	3,658	3,895	3,379	3,193	2,194	2,552	2,598	2,105	1,080	1,882	2,123	2,063	30,722
1949	2,419	4,051	2,247	7,240	3,022	10,597	2,336	1,473	1,395	7,434	2,648	4,166	49,028
1950	4,096	2,973	3,313	3,476	3,104	3,807	2,167	2,839	2,547	2,100	2,820	2,875	36,117
1951	1,841	2,920	2,522	1,684	4,633	2,302	1,238	776	1,686	1,065	1,553	1,714	23,934
1952	1,763	2,760	2,108	1,729	1,739	1,362	1,122	635	1,494	933	1,836	2,239	19,720
1953	1,821	1,783	2,857	1,911	0	0	28	1,312	13,647	1,435	1,831	2,097	28,722
1954	2,015	1,799	1,836	1,732	2,250	299	240	269	0	366	6	0	10,812
1955	780	2,571	1,491	405	2,108	423	275	1,376	514	298	322	613	11,176

Table B-4, Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1956	822	545	383	252	662	247	264	1,096	1,096	2,873	323	758	9,321
1957	218	930	962	22,266	13,351	11,698	1,371	473	5,637	4,780	3,436	2,947	68,069
1958	7,493	10,302	3,798	3,150	19,984	52,413	6,583	1,792	35,163	40,259	33,794	12,453	227,184
1959	7,358	5,059	4,059	4,506	3,912	2,205	3,159	2,008	1,511	12,387	3,266	3,123	52,553
1960	3,002	3,403	4,422	2,589	2,294	2,315	2,936	8,192	696	7,842	6,787	15,916	60,394
1961	13,646	30,302	15,631	4,043	2,772	7,359	9,231	1,843	2,944	7,817	4,400	4,314	104,302
1962	4,486	3,346	2,295	4,258	3,084	2,717	1,095	1,014	600	803	1,782	2,225	27,705
1963	2,117	2,499	2,046	1,818	1,485	1,245	917	473	617	5,492	1,928	2,289	22,926
1964	2,747	2,830	4,543	2,118	1,963	4,698	917	632	1,989	4,262	9,190	2,932	38,821
1965	2,664	8,920	4,078	4,016	18,130	5,322	2,420	1,352	1,435	2,451	2,769	6,658	60,215
1966	3,212	3,164	2,792	3,761	3,724	2,150	1,567	1,505	2,460	1,752	2,253	2,650	30,990
1967	2,696	2,659	2,766	2,198	1,422	1,334	1,401	664	16,156	3,316	4,514	3,787	42,913
1968	38,986	7,493	6,168	4,965	9,409	4,048	5,083	2,269	2,861	2,988	3,658	4,333	92,261
Avg.	4,915	4,780	3,555	3,908	4,470	4,974	2,526	2,361	4,877	4,904	3,996	3,795	49,061

Table B-5

Sources of Evaporation Data

Lake Medina

1/1937 - 12/1939	Records of the Weather Bureau evaporation pan at Dilley multiplied by .78, minus Weather Bureau records of rainfall at Dilley multiplied by .90, with the difference multiplied by .90.
1/1940 - 12/1965	Based on data published by Report 64 of the Texas Water Development Board, using .43 of the values indicated for quadrangle H-8 plus .57 of the values indicated for quadrangle H-9.
1/1966 - 12/1968	Records of the Weather Bureau evaporation pan at Dilley multiplied by .78, minus Weather Bureau records of rainfall at Dilley multiplied by .90, with the difference multiplied by .60; plus records of the Weather Bureau evaporation pan at Canyon Dam multiplied by .78, minus Weather Bureau records of rainfall multiplied by .90, with the difference multiplied by .40.

Applewhite Reservoir Site

1/1937 - 12/1939	Records of the Weather Bureau evaporation pan at Beeville multiplied by .94, minus Weather Bureau records of rainfall at Beeville multiplied by .94, with the difference multiplied by 1.18.
1/1940 - 12/1965	Based on data published in Report 64 of the Texas Water Development Board, using .84 of the values indicated for quadrangle H-9 plus .16 of the values indicated for quadrangle I-9.
1/1966 - 12/1968	Records of the Weather Bureau evaporation pan at Canyon Dam multiplied by .78, minus Weather Bureau records of rainfall at Canyon Dam multiplied by .94, with the difference multiplied by 1.11.

Table B-6

Net Evaporation Data for Lake Medina

- Values in Feet -

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	0.06	0.20	0.19	0.43	0.44	0.53	0.40	0.66	0.22	0.32	0.21	-0.52	3.14
1938	0.01	0.12	0.26	0.11	0.21	0.54	0.60	0.57	0.48	0.42	0.27	0.05	3.64
1939	0.09	0.19	0.35	0.53	0.33	0.39	0.46	0.49	0.43	0.22	0.08	0.13	3.69
1940	0.11	0.05	0.24	0.18	0.17	0.04	0.58	0.71	0.65	0.25	0.01	-0.07	2.92
1941	0.00	-0.16	-0.13	-0.11	0.09	0.10	0.52	0.65	0.22	0.19	0.25	0.12	1.74
1942	0.18	0.12	0.30	-0.08	0.15	0.46	0.13	0.50	0.05	0.02	0.27	0.17	2.27
1943	0.15	0.27	0.27	0.38	0.30	0.35	0.48	0.86	0.14	0.39	0.18	0.04	3.81
1944	-0.07	-0.01	0.09	0.39	-0.06	0.44	0.81	0.35	0.49	0.42	0.02	-0.05	2.82
1945	-0.07	-0.02	0.05	0.19	0.49	0.45	0.67	0.74	0.46	0.17	0.30	0.14	3.57
1946	-0.02	0.09	0.25	0.16	0.08	0.31	0.74	0.45	-0.08	0.14	0.14	0.04	2.30
1947	-0.07	0.22	0.22	0.29	0.25	0.42	0.79	0.47	0.80	0.58	0.23	0.13	4.33
1948	0.18	-0.03	0.29	0.33	0.43	0.45	0.58	0.70	0.38	0.26	0.32	0.22	4.11
1949	-0.04	-0.11	0.14	-0.21	0.35	0.21	0.59	0.50	0.50	0.02	0.35	-0.01	2.29
1950	0.10	0.09	0.38	0.19	0.24	0.36	0.63	0.67	0.48	0.52	0.39	0.29	4.34
1951	0.22	0.01	0.12	0.30	-0.08	0.41	0.80	0.88	0.57	0.58	0.30	0.27	4.38
1952	0.21	0.14	0.14	0.15	0.18	0.49	0.68	0.96	0.14	0.59	0.07	0.08	3.83
1953	0.28	0.15	0.22	0.37	0.51	0.75	0.90	0.53	0.31	0.08	0.26	0.12	4.48
1954	0.16	0.37	0.42	0.28	0.41	0.57	0.79	0.88	0.80	0.36	0.32	0.33	5.69
1955	0.11	0.08	0.29	0.51	0.27	0.59	0.70	0.66	0.57	0.65	0.29	0.23	4.95

Table B-6, Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1956	0.14	0.16	0.38	0.39	0.53	0.82	0.88	0.80	0.73	0.49	0.34	0.21	5.87
1957	0.23	0.08	0.13	-0.36	-0.25	0.33	0.88	0.96	0.14	0.06	-0.08	0.12	2.24
1958	-0.17	-0.11	0.09	0.18	0.07	0.24	0.63	0.72	-0.13	-0.19	0.17	0.13	1.63
1959	0.13	-0.04	0.31	0.10	0.18	0.22	0.52	0.51	0.46	-0.09	0.15	0.09	2.54
1960	0.05	0.11	0.09	0.26	0.35	0.54	0.41	0.30	0.57	-0.14	0.13	-0.15	2.52
1961	0.03	-0.07	0.23	0.31	0.48	0.00	0.15	0.56	0.49	0.15	0.11	0.08	2.52
1962	0.13	0.23	0.26	0.05	0.46	0.32	0.81	0.77	0.36	0.40	0.11	0.02	3.92
1963	0.14	0.00	0.31	0.17	0.25	0.46	0.73	0.76	0.44	0.35	0.13	0.09	3.83
1964	-0.01	0.07	0.14	0.23	0.25	0.41	0.78	0.63	0.16	0.31	0.16	0.10	3.23
1965	0.14	-0.24	0.13	0.15	-0.16	0.43	0.78	0.71	0.61	0.16	0.20	-0.16	2.75
1966	0.04	0.05	0.30	0.17	0.02	0.50	0.73	0.41	0.20	0.34	0.35	0.19	3.30
1967	0.21	0.18	0.34	0.35	0.42	0.78	0.69	0.50	-0.48	0.15	-0.08	0.07	3.13
1968	-0.51	0.04	0.18	0.10	0.20	0.23	0.51	0.67	-0.05	0.27	0.06	0.03	1.73
Avg.	0.07	0.07	0.22	0.20	0.24	0.41	0.64	0.64	0.35	0.26	0.19	0.08	3.37

Table B-7

Net Evaporation Data for Applewhite Reservoir Site

- Values in Feet -

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1937	0.06	0.19	0.12	0.50	0.56	0.46	0.52	0.44	0.54	0.37	0.21	-0.54	3.43
1938	0.13	0.13	0.33	0.21	0.37	0.61	0.82	0.51	0.21	0.38	0.21	-0.05	3.86
1939	0.07	0.31	0.40	0.60	0.55	0.39	0.40	0.56	0.17	0.43	0.22	0.10	4.20
1940	0.08	0.04	0.24	0.22	0.25	-0.03	0.54	0.71	0.60	0.21	-0.04	-0.07	2.75
1941	0.01	-0.09	-0.08	-0.13	0.04	0.05	0.50	0.67	0.21	0.19	0.24	0.12	1.73
1942	0.17	0.13	0.30	-0.04	0.14	0.41	-0.05	0.44	-0.04	-0.02	0.24	0.19	1.87
1943	0.13	0.26	0.23	0.35	0.26	0.39	0.42	0.80	0.14	0.47	0.15	0.05	3.65
1944	-0.12	-0.01	0.04	0.36	-0.05	0.47	0.77	0.43	0.48	0.41	-0.04	-0.10	2.64
1945	-0.03	-0.05	0.09	0.21	0.51	0.42	0.55	0.65	0.49	0.11	0.28	0.13	3.36
1946	-0.06	0.06	0.20	0.16	0.09	0.25	0.72	0.34	-0.17	0.12	0.09	0.00	1.80
1947	-0.07	0.19	0.19	0.26	0.14	0.55	0.73	0.45	0.72	0.54	0.23	0.08	4.01
1948	0.15	-0.06	0.25	0.36	0.42	0.52	0.57	0.60	0.40	0.24	0.28	0.22	3.95
1949	-0.06	-0.05	0.17	-0.26	0.37	0.18	0.56	0.54	0.56	0.00	0.32	-0.01	2.32
1950	0.14	0.12	0.35	0.15	0.26	0.37	0.57	0.70	0.48	0.48	0.38	0.28	4.28
1951	0.27	0.03	0.20	0.36	0.10	0.34	0.78	0.88	0.36	0.39	0.21	0.22	4.14
1952	0.22	0.14	0.17	0.17	0.27	0.50	0.59	0.94	0.05	0.58	0.05	-0.01	3.67
1953	0.29	0.14	0.24	0.25	0.42	0.69	0.83	0.46	0.31	0.11	0.24	0.12	4.10
1954	0.15	0.33	0.37	0.24	0.38	0.56	0.78	0.82	0.73	0.38	0.31	0.33	5.38
1955	0.12	0.05	0.30	0.49	0.32	0.58	0.75	0.66	0.57	0.62	0.30	0.23	4.99

Table B-7, Continued

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1956	0.16	0.17	0.37	0.38	0.46	0.73	0.84	0.71	0.68	0.47	0.30	0.18	5.45
1957	0.25	0.07	0.09	-0.25	-0.15	0.32	0.85	0.87	0.04	0.12	-0.09	0.13	2.25
1958	-0.15	-0.13	0.11	0.16	-0.03	0.34	0.62	0.72	-0.13	-0.19	0.16	0.13	1.61
1959	0.15	-0.08	0.31	0.12	0.18	0.20	0.51	0.45	0.47	-0.02	0.17	0.09	2.55
1960	0.08	0.09	0.09	0.22	0.34	0.41	0.43	0.23	0.56	-0.19	0.12	-0.12	2.26
1961	0.04	-0.04	0.23	0.28	0.46	-0.03	0.15	0.60	0.44	0.21	0.02	0.09	2.50
1962	0.12	0.20	0.24	0.01	0.43	0.22	0.77	0.77	0.28	0.37	0.07	0.00	3.48
1963	0.15	-0.01	0.30	0.17	0.30	0.44	0.71	0.77	0.49	0.36	0.12	0.09	3.89
1964	-0.02	0.05	0.13	0.24	0.25	0.42	0.80	0.62	0.26	0.35	0.18	0.11	3.39
1965	0.10	-0.26	0.14	0.14	-0.28	0.40	0.77	0.67	0.59	0.15	0.23	-0.16	2.49
1966	0.03	0.01	0.32	0.19	0.14	0.59	0.81	0.38	0.17	0.41	0.41	0.16	3.62
1967	0.24	0.19	0.28	0.45	0.28	0.84	0.68	0.62	-0.47	0.17	-0.13	0.06	3.21
1968	-0.79	0.08	0.18	0.12	0.17	0.30	0.50	0.76	0.07	0.32	0.02	-0.01	1.72
Avg.	0.06	0.07	0.22	0.21	0.25	0.40	0.62	0.62	0.32	0.27	0.17	0.06	3.27

Table B-8

Medina Lake
Area and Capcity Data

Elevation (Ft)	Area (Ac)	Capacity (Ac-Ft)
920	0	0
930	25	115
940	54	500
950	128	1,200
960	226	3,050
970	459	5,720
980	670	12,220
990	896	19,120
1,000	1,261	30,140
1,010	1,622	44;330
1,020	2,077	62,580
1,030	2,597	85,860
1,040	3,205	114,520
1,050	3,874	149,950
1,060	4,624	192,000
1,070	5,417	242,430
*1,072	5,575	254,000

*Top of conservation storage.

Table B-9

Applewhite Reservoir Site Area and Capacity Data

Elevation (Ft)	Area (Ac)	Capacity (Ac-Ft)
465	0	0
470	15	28
475	43	170
480	73	460
485	123	940
490	200	1,734
495	325	3,046
500	450	4,984
505	580	7,559
510	713	10,788
515	858	14,706
520	1,028	19,411
525	1,293	25,143
530	1,738	32,642
535	2,358	42,822
540	3,162	56,494
545	4,217	74,821
550	5,570	99,172
555	7,130	130,854
560	8,836	170,715

Table B-10

Mitchell Lake
Area and Capacity Data

Elevation (Ft)	Area (Ac)	Capacity (Ac-Ft)
508	0	0
510	1	75
512	71	239
513	257	562
514	389	1,470
516	518	2,616
518	628	3,943
520	699	5,406
522	764	5,952
524	848	7,021
526	926	8,795
528	1,013	10,734
530	1,097	12,844
532	1,189	15,130
534	1,286	17,606
536	1,389	20,282

Table B-11

Big Sous Reservoir
Area and Capacity Data

Elevation (Ft)	Area (Ac)	Capacity (Ac-Ft)
820	2	1
830	15	72
840	40	329
850	84	935
860	134	2,020
870	213	3,716
880	320	6,367
890	430	10,112
900	550	15,012
910	677	21,133
920	842	28,683
930	1,043	38,087

APPENDIX C

RESERVOIR OPERATION STUDIES

Table C-1

Summary of Medina Lake Operation Study With 35,000 Ac-Ft/Yr of Irrigation Demand

- Values in Acre-Feet -

	Evapo-rative Loss	Ground-water Recharge	Diversion Dam Seepage	Irri-gation Use	Runoff	Spills	Contents At End Of Year
Start							254,000
1937	17,298	83,328	16,000	35,000	88,800	713	190,461
1938	16,040	60,718	16,000	35,000	69,000	0	131,703
1939	10,882	42,478	16,000	35,000	33,300	0	60,643
1940	5,467	47,171	16,000	35,000	89,500	0	46,505
1941	6,491	56,925	16,000	35,000	185,400	0	117,489
1942	8,051	52,343	16,000	35,000	109,700	0	115,795
1943	10,919	41,888	16,000	35,000	45,900	0	57,888
1944	7,588	49,296	16,000	35,000	126,200	0	76,204
1945	9,881	54,800	16,000	35,000	110,400	0	70,923
1946	4,918	48,040	16,000	35,000	87,100	0	54,065
1947	9,595	50,477	16,000	35,000	97,200	0	40,193
1948	4,104	28,098	9,334	21,359	31,000	0	8,298
1949	1,852	29,156	13,393	20,997	67,100	0	10,000
1950	3,254	19,554	6,866	2,191	28,300	0	6,435
1951	3,135	20,539	2,668	3,975	28,000	0	4,118
1952	2,915	24,581	6,552	7,370	47,300	0	10,000
1953	3,421	26,996	6,833	5,405	45,600	0	12,945
1954	3,972	17,249	2,667	2,634	14,800	0	1,223
1955	3,189	13,556	0	0	17,400	0	1,878
1956	1,229	5,312	0	0	5,500	0	837
1957	4,965	49,698	12,001	30,120	206,000	0	110,053
1958	9,550	100,016	16,000	35,000	388,200	83,687	254,000
1959	13,970	87,735	16,000	35,000	130,800	1,111	230,984
1960	13,049	84,913	16,000	35,000	160,800	0	242,822
1961	14,023	91,486	16,000	35,000	165,200	37,794	213,719
1962	16,835	57,442	16,000	35,000	35,100	0	123,542
1963	9,867	41,293	16,000	35,000	15,200	0	36,582
1964	3,835	40,439	15,914	24,958	104,660	0	56,096
1965	6,110	50,235	16,000	35,000	96,350	0	45,101
1966	5,538	44,403	16,000	35,000	102,520	0	46,680
1967	3,899	41,515	13,718	23,034	62,450	0	26,964
1968	7,042	57,765	16,000	35,000	205,560	0	116,717
Avg.	7,590	47,482	12,811	26,313	93,760	3,853	

Table C-2

Summary of Medina Lake Operation Study Without Irrigation Demands

- Values in Acre-Feet -

	Evaporative Loss	Groundwater Recharge	Diversion Dam Seepage	Runoff	Spills	Contents At End of Year
Start						254,000
1937	17,736	91,170	16,000	88,800	2,440	215,454
1938	18,270	73,903	16,000	69,000	0	176,281
1939	14,896	50,398	16,000	33,300	0	128,287
1940	10,510	57,643	16,000	89,500	0	133,634
1941	9,394	80,114	16,000	185,400	0	213,526
1942	11,970	78,306	16,000	109,700	0	216,950
1943	18,312	63,580	16,000	45,900	0	164,958
1944	13,717	68,874	16,000	126,200	0	192,567
1945	17,826	78,958	16,000	110,400	0	190,183
1946	10,630	67,337	16,000	87,100	0	183,316
1947	20,789	72,488	16,000	97,200	0	171,239
1948	16,271	50,063	16,000	31,000	0	119,905
1949	8,065	52,428	16,000	67,100	0	110,512
1950	12,333	42,087	16,000	28,300	0	68,392
1951	8,486	40,796	16,000	28,000	0	31,110
1952	4,269	40,090	16,000	47,300	0	18,051
1953	3,555	32,098	10,581	45,600	0	17,417
1954	3,963	20,767	5,523	14,800	0	1,964
1955	2,520	14,906	0	17,400	0	1,938
1956	1,331	5,095	0	5,500	0	1,012
1957	5,833	51,018	12,001	206,000	0	138,160
1958	9,653	108,259	16,000	388,200	138,448	254,000
1959	14,445	96,400	16,000	130,800	5,918	252,037
1960	14,128	100,421	16,000	160,800	28,288	254,000
1961	14,321	98,216	16,000	165,200	58,880	231,783
1962	18,989	65,490	16,000	35,100	0	166,404
1963	14,338	48,165	16,000	15,200	0	103,101
1964	9,599	52,371	16,000	104,660	0	129,791
1965	10,883	64,483	16,000	96,350	0	134,775
1966	12,643	57,617	16,000	102,520	0	151,035
1967	11,628	55,939	16,000	62,450	0	129,918
1968	10,052	87,220	16,000	205,560	0	222,206
Avg.	11,604	61,459	14,379	93,760	7,311	

Table C-3

Summary of Applewhite Reservoir Operation Study Based on Constant Demand With 35,000 Ac-Ft/Yr of Irrigation Demand At Lake Medina

- Values in Acre-Feet -

	Evaporative Loss	Demand	Inflow	Spills	Contents At End Of Year
Start					40,000
1937	7,422	12,700	42,970	22,848	40,000
1938	8,287	12,700	35,602	16,718	37,897
1939	8,895	12,700	23,156	0	39,458
1940	5,956	12,700	36,387	17,189	40,000
1941	3,778	12,700	48,204	31,726	40,000
1942	4,089	12,700	75,269	58,480	40,000
1943	7,978	12,700	38,777	18,099	40,000
1944	5,770	12,700	40,313	21,843	40,000
1945	7,344	12,700	49,527	29,483	40,000
1946	3,935	12,700	88,748	72,113	40,000
1947	8,766	12,700	41,410	19,944	40,000
1948	8,502	12,700	26,623	9,228	36,193
1949	5,074	12,700	46,612	25,031	40,000
1950	9,220	12,700	30,071	10,351	37,800
1951	8,190	12,700	13,776	0	30,686
1952	5,261	12,700	11,820	0	24,545
1953	4,966	12,700	25,081	0	31,960
1954	7,741	12,700	7,771	0	19,290
1955	4,845	12,700	11,176	0	12,921
1956	3,302	12,700	9,321	0	6,240
1957	4,508	12,700	68,069	17,101	40,000
1958	3,519	12,700	172,423	156,204	40,000
1959	5,575	12,700	47,746	29,471	40,000
1960	4,925	12,700	32,106	14,481	40,000
1961	5,466	12,700	83,054	64,888	40,000
1962	7,348	12,700	27,705	11,169	36,488
1963	7,917	12,700	22,926	0	38,797
1964	7,240	12,700	38,761	17,618	40,000
1965	5,369	12,700	60,215	42,146	40,000
1966	7,855	12,700	30,990	10,435	40,000
1967	6,820	12,700	42,185	22,665	40,000
1968	3,761	12,700	92,261	75,800	40,000
Avg.	6,238	12,700	44,408	25,470	

Minimum content: 4,980 Ac-Ft at end of March 1957.

Table C-4

Summary of Applewhite Reservoir Operation Study Based on Constant Demand With No Irrigation Demand At Lake Medina

- Values in Acre-Feet -

	Evaporative Loss	Demand	Inflow	Spills	Contents At End Of Year
Start					40,000
1937	7,420	14,800	44,697	22,477	40,000
1938	8,252	14,800	35,602	15,668	36,882
1939	8,425	14,800	23,156	0	36,813
1940	5,924	14,800	36,387	12,476	40,000
1941	3,775	14,800	48,204	29,629	40,000
1942	4,089	14,800	75,269	56,380	40,000
1943	7,976	14,800	38,777	16,001	40,000
1944	5,770	14,800	40,313	19,743	40,000
1945	7,344	14,800	49,527	27,383	40,000
1946	3,935	14,800	88,748	70,013	40,000
1947	8,766	14,800	41,410	17,844	40,000
1948	8,584	14,800	30,722	8,003	39,335
1949	5,040	14,800	49,028	28,523	40,000
1950	9,355	14,800	36,117	11,962	40,000
1951	8,631	14,800	23,934	5,660	34,843
1952	6,943	14,800	19,720	0	32,820
1953	7,114	14,800	28,722	0	39,628
1954	10,249	14,800	10,812	82	25,309
1955	5,778	14,800	11,176	0	15,907
1956	3,683	14,800	9,321	0	6,745
1957	4,504	14,800	68,069	15,510	40,000
1958	3,519	14,800	227,184	208,865	40,000
1959	5,573	14,800	52,553	32,180	40,000
1960	4,932	14,800	60,394	40,662	40,000
1961	5,466	14,800	104,302	84,036	40,000
1962	7,310	14,800	27,705	10,119	35,476
1963	7,449	14,800	22,926	0	36,153
1964	7,211	14,800	38,821	12,963	40,000
1965	5,326	14,800	60,215	40,089	40,000
1966	7,778	14,800	30,990	8,978	39,434
1967	6,774	14,800	42,913	20,773	40,000
1968	3,761	14,800	92,261	73,700	40,000
Avg.	6,458	14,800	49,061	27,803	

Minimum Content: 4,954 Ac-Ft at end of March 1957.

Table C-5

Summary of Applewhite Reservoir Operation Study
Based on Variable Demand
With 35,000 Ac-Ft/Yr of Irrigation Demand At Lake Medina

- Values in Acre-Feet -

	Evapo-rative Loss	Demand	Inflow	Spills	Contents At End Of Year
Start					40,000
1937	7,338	27,000	42,970	13,270	35,362
1938	7,919	27,000	35,602	5,807	30,238
1939	5,687	24,032	23,156	0	23,675
1940	3,827	26,258	36,387	0	29,977
1941	3,619	27,000	48,204	10,373	37,189
1942	4,023	27,000	75,269	41,435	40,000
1943	7,895	27,000	38,777	4,222	39,660
1944	5,624	27,000	40,313	7,349	40,000
1945	7,263	27,000	49,527	15,264	40,000
1946	3,935	27,000	88,748	57,813	40,000
1947	8,516	27,000	41,410	7,095	38,799
1948	7,911	27,000	26,623	2,402	28,109
1949	4,862	27,000	46,612	2,859	40,000
1950	8,706	27,000	30,071	3,201	31,164
1951	5,178	23,289	13,776	0	16,473
1952	2,933	12,734	11,820	0	12,626
1953	3,372	11,203	25,081	0	23,132
1954	5,122	15,797	7,771	0	9,984
1955	3,630	8,908	11,176	0	8,622
1956	2,809	8,908	9,321	0	6,226
1957	4,364	20,972	68,069	8,959	40,000
1958	3,509	27,000	172,423	141,914	40,000
1959	5,473	27,000	47,746	15,273	40,000
1960	4,766	27,000	32,106	3,511	36,829
1961	5,413	27,000	83,054	47,470	40,000
1962	7,062	27,000	27,705	4,143	29,500
1963	4,961	23,289	22,926	0	24,176
1964	4,661	25,516	38,761	0	32,760
1965	5,133	27,000	60,215	21,850	38,992
1966	7,302	27,000	30,990	2,889	32,791
1967	5,117	26,258	42,185	3,601	40,000
1968	3,738	27,000	92,261	61,523	40,000
Avg.	5,365	23,974	44,408	15,069	

Minimum Content: 4,916 Ac-Ft at end of July 1956.

Table C-6

Summary of Applewhite Reservoir Operation Study Based On Variable Demand With No Irrigation Demand At Lake Medina

- Values in Acre-Feet -

	Evaporative Loss	Demand	Inflow	Spills	Contents At End Of Year
Start					40,000
1937	7,331	28,300	44,697	14,349	34,717
1938	7,872	28,300	35,602	4,633	29,514
1939	5,524	23,629	23,156	0	23,517
1940	3,707	26,744	36,387	0	29,453
1941	3,602	28,300	48,204	9,193	36,562
1942	3,996	28,300	75,269	39,535	40,000
1943	7,869	28,300	38,777	3,574	39,034
1944	5,592	28,300	40,313	5,455	40,000
1945	7,233	28,300	49,527	14,500	39,494
1946	3,935	28,300	88,748	56,007	40,000
1947	8,465	28,300	41,410	6,555	38,090
1948	7,957	28,300	30,722	1,268	31,287
1949	4,914	28,300	49,028	7,101	40,000
1950	8,961	28,300	36,117	3,583	35,273
1951	6,953	28,300	23,934	0	23,954
1952	4,208	20,515	19,720	0	18,951
1953	4,072	19,691	28,722	0	23,910
1954	5,556	18,133	10,812	0	11,033
1955	3,768	9,341	11,176	0	9,100
1956	2,863	9,341	9,321	0	6,217
1957	4,357	21,984	68,069	7,945	40,000
1958	3,507	28,300	227,184	195,377	40,000
1959	5,463	28,300	52,553	18,790	40,000
1960	4,837	28,300	60,394	27,257	40,000
1961	5,415	28,300	104,302	70,587	40,000
1962	7,007	28,300	27,705	3,712	28,686
1963	4,768	23,629	22,926	0	23,215
1964	4,510	25,966	38,821	0	31,560
1965	5,121	28,300	60,215	19,992	38,362
1966	7,249	28,300	30,990	1,721	32,082
1967	4,898	27,522	42,913	2,575	40,000
1968	3,731	28,300	92,261	60,230	40,000
Avg.	5,476	25,650	49,061	17,936	

Minimum Content: 5,088 Ac-Ft at end of August 1956.

Table C-7

Lake Braunig Chemical Quality Study for Drouth Conditions

	River Diversions (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS Coming In	Going Out	In The Lake	mg/l of TDS
1980							
Start						36.0	1,000
Jan	1.0	.5	.5	.7	.7	36.0	1,000
Feb	1.0	.5	.5	.7	.7	36.0	1,000
Mar	2.5	.8	1.7	1.7	2.3	35.4	983
Apr	2.5	.9	1.6	1.7	2.1	35.0	972
May	2.5	1.0	1.5	1.7	2.0	34.7	964
Jun	2.0	1.4	.6	1.3	.8	35.2	978
Jul	2.3	1.7	.6	1.6	.8	36.0	1,000
Aug	2.1	1.5	.6	1.4	.8	36.6	1,017
Sep	2.6	1.4	1.2	1.7	1.7	36.6	1,017
Oct	2.5	1.0	1.5	1.7	2.1	36.2	1,006
Nov	2.0	.8	1.2	1.4	1.6	36.0	1,000
Dec	1.0	.5	.5	.7	.7	36.0	1,000
Total	24.0	12.0	12.0	16.3	16.3		
1985							
Start						36.0	1,000
Jan	.8	.4	.4	.5	.5	36.0	1,000
Feb	.8	.4	.4	.5	.5	36.0	1,000
Mar	2.2	.7	1.5	1.5	2.0	35.5	987
Apr	2.2	.8	1.4	1.5	1.9	35.1	976
May	2.3	.9	1.4	1.6	1.9	34.8	968
Jun	1.9	1.3	.6	1.3	.8	35.3	982
Jul	2.1	1.5	.6	1.4	.8	35.9	998
Aug	1.9	1.3	.6	1.3	.8	36.4	1,012
Sep	2.3	1.3	1.0	1.6	1.4	36.6	1,018
Oct	2.2	.9	1.3	1.5	1.8	36.3	1,009
Nov	1.7	.7	1.0	1.1	1.4	36.0	1,000
Dec	1.0	.5	.5	.7	.7	36.0	1,000
Total	21.4	10.7	10.7	14.5	14.5		

Notes:
(1) Concentration of total dissolved solids in river diversions assumed to be 500 milligrams per liter.
(2) Lake capacity 26,500 acre-feet.
(3) Evaporative losses are the sum of natural and induced evaporation (see Tables 3.3 and 3.12 in the text).

Table C-8

Lake Calaveras Chemical Quality Study for Drouth Conditions

	River Diversions (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS Coming In	Going Out	In The Lake	mg/l of TDS
1980							
Start						85.8	1,000
Jan	2.6	1.3	1.3	1.8	1.8	85.8	1,000
Feb	6.3	1.2	5.1	4.3	6.8	83.3	971
Mar	6.9	2.1	4.8	4.7	6.3	81.7	953
Apr	6.7	2.2	4.5	4.5	5.8	80.4	937
May	6.3	2.5	3.8	4.3	4.8	79.9	932
Jun	4.8	3.7	1.1	3.3	1.4	81.8	954
Jul	3.3	4.3	.0	2.2	.0	84.0	995
Aug	4.2	4.0	.0	2.9	.0	86.9	1,026
Sep	6.7	3.5	2.4	4.5	3.3	88.1	1,027
Oct	6.7	2.6	4.1	4.5	5.7	86.9	1,013
Nov	4.1	1.9	2.2	2.8	3.0	86.7	1,011
Dec	3.0	1.5	1.5	2.0	2.1	86.6	1,010
Total	61.6	30.8	30.8	41.8	41.0		
1985							
Start						85.8	1,000
Jan	3.0	1.5	1.5	2.0	2.0	85.8	1,000
Feb	6.3	1.4	4.9	4.3	6.5	83.6	975
Mar	6.9	2.4	4.5	4.7	5.9	82.4	961
Apr	6.7	2.5	4.2	4.5	5.4	81.5	950
May	6.9	2.8	4.1	4.7	5.3	80.9	943
Jun	5.9	4.1	1.8	4.0	2.3	82.6	963
Jul	4.4	4.8	.0	3.0	.0	85.6	1,004
Aug	5.4	4.5	.5	3.7	.7	88.6	1,033
Sep	6.7	3.9	2.8	4.5	3.9	89.2	1,040
Oct	6.9	3.0	3.9	4.7	5.5	88.4	1,031
Nov	6.7	2.2	4.5	4.5	6.2	86.7	1,011
Dec	4.0	1.8	2.2	2.7	3.0	86.4	1,007
Total	69.8	34.9	34.9	47.3	46.7		

Notes:
(1) Concentration of total dissolved solids in river diversions assumed to be 500 milligrams per liter.
(2) Lake capacity: 63,200 acre-feet; slight drawdown experienced in July and August of 1980 and July of 1985.
(3) Evaporative losses are the sum of natural and induced evaporation (see Tables 3.4 and 3.12 in the text).

Table C-9

Mitchell Lake Chemical Quality Study for Drouth Conditions

	Inflow From Rilling (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS Coming In	Going Out	In The Lake	mg/l of TDS
1980							
Start						16.3	592
Jan	7.4	.4	7.0	5.0	5.5	15.8	574
Feb	6.9	.4	6.5	4.7	5.0	15.5	563
Mar	6.7	.8	5.9	4.6	4.5	15.6	566
Apr	6.3	.8	5.5	4.3	4.2	15.7	570
May	6.1	.9	5.2	4.1	4.0	15.8	574
Jun	4.4	1.4	3.0	3.0	2.4	16.4	595
Jul	3.4	1.6	1.8	2.3	1.5	17.2	624
Aug	4.0	1.5	2.5	2.7	2.2	17.7	643
Sep	6.4	1.3	5.1	4.3	4.4	17.6	639
Oct	6.5	1.0	5.5	4.4	4.7	17.3	628
Nov	6.7	.7	6.0	4.6	5.0	16.9	613
Dec	7.0	.5	6.5	4.7	5.3	16.3	592
Total	71.8	11.3	60.5	48.7	48.7		
1985							
Start						17.2	624
Jan	7.4	.6	6.8	5.0	5.6	16.6	603
Feb	6.9	.6	6.3	4.7	5.1	16.2	588
Mar	6.7	1.0	5.7	4.6	4.6	16.2	588
Apr	6.3	1.0	5.3	4.3	4.2	16.3	592
May	6.1	1.2	4.9	4.1	4.0	16.4	595
Jun	4.4	1.7	2.7	3.0	2.2	17.2	624
Jul	3.4	2.0	1.4	2.3	1.2	18.3	664
Aug	4.0	2.0	2.0	2.7	1.8	19.2	697
Sep	6.4	1.6	4.8	4.3	4.5	19.0	690
Oct	6.5	1.3	5.2	4.4	4.8	18.6	675
Nov	6.7	.9	5.8	4.6	5.2	18.0	653
Dec	7.0	.7	6.3	4.7	5.5	17.2	624
Total	71.8	14.6	57.2	48.7	48.7		

Notes:
(1) Concentration of total dissolved solids in Rilling plant flows assumed to be 500 milligrams per liter.
(2) Enlarged lake capacity: 20,300 acre-feet.
(3) Evaporative losses are the sum of natural and induced evaporation (see Tables 3.5 and 3.13 in the text).
(4) Ten percent of local irrigation flow assumed to pass through the lake.

Table C-10

Lake Braunig Chemical Quality Study for Drouth Conditions With Mitchell Lake Used for Power Plant Cooling

	River Diversions (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS			mg/l of TDS
				Coming In	Going Out	In The Lake	
1980							
Start						36.0	1,000
Jan	1.1	.5	.6	.8	.8	36.0	1,000
Feb	2.5	.5	2.0	1.9	2.7	35.2	979
Mar	2.5	.8	1.7	1.8	2.2	34.8	968
Apr	2.5	.9	1.6	1.8	2.1	34.5	959
May	2.5	1.0	1.5	1.8	1.9	34.4	957
Jun	2.0	1.4	.6	1.5	.8	35.1	976
Jul	2.3	1.7	.6	1.7	.8	36.0	1,000
Aug	2.1	1.5	.6	1.6	.8	36.8	1,023
Sep	2.5	1.4	1.1	2.0	1.5	37.3	1,037
Oct	2.5	1.0	1.5	2.0	2.1	37.2	1,034
Nov	2.5	.8	1.7	2.0	2.4	36.8	1,023
Dec	2.3	.5	1.8	1.8	2.5	36.1	1,004
Total	27.3	12.0	15.3	20.7	20.6		
1985							
Start						36.0	1,000
Jan	.9	.4	.5	.7	.7	36.0	1,000
Feb	.9	.4	.5	.7	.7	36.0	1,000
Mar	2.5	.7	1.8	1.9	2.4	35.5	987
Apr	2.5	.8	1.7	1.9	2.3	35.1	976
May	2.5	.9	1.6	1.9	2.1	34.9	971
Jun	1.9	1.3	.6	1.4	.8	35.5	987
Jul	2.1	1.5	.6	1.5	.8	36.2	1,007
Aug	1.9	1.3	.6	1.4	.8	36.8	1,023
Sep	2.5	1.3	1.2	2.1	1.7	37.2	1,034
Oct	2.5	.9	1.6	2.0	2.2	37.0	1,029
Nov	2.5	.7	1.8	2.0	2.5	36.5	1,015
Dec	2.2	.5	1.7	1.7	2.3	35.9	998
Total	24.9	10.7	14.2	19.2	19.3		

Notes:
(1) Concentrations of total dissolved solids in river diversions based on monthly averages of water coming from upstream, including releases from Mitchell Lake as in Table C-9.
(2) Lake capacity: 26,500 acre-feet.
(3) Evaporative losses are the sum of natural and induced evaporation (see Tables 3.3 and 3.13 of the text).

Table C-11

Lake Calaveras Chemical Quality Study for Drouth Conditions With Mitchell Lake Used for Power Plant Cooling

	River Diversions (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS Coming In	1,000 Tons of TDS Going Out	1,000 Tons of TDS In The Lake	mg/l of TDS
1980							
Start						85.8	1,000
Jan	4.5	1.0	3.5	3.4	4.7	84.5	985
Feb	6.3	1.0	5.3	4.7	7.0	82.2	958
Mar	6.4	1.8	4.6	4.7	5.9	81.0	944
Apr	6.0	1.9	4.1	4.4	5.2	80.2	935
May	5.6	2.2	3.4	4.1	4.3	80.0	933
Jun	3.4	3.3	.1	2.5	.1	82.4	961
Jul	1.7	3.9	.0	1.2	.0	83.6	1,010
Aug	2.7	3.5	.0	2.1	.0	85.7	1,049
Sep	5.5	3.1	.0	4.4	.0	90.1	1,061
Oct	5.7	2.3	2.8	4.5	4.0	90.6	1,056
Nov	6.2	1.6	4.6	4.9	6.5	89.0	1,038
Dec	6.9	1.2	5.7	5.3	7.9	86.4	1,007
Total	60.9	26.8	34.1	46.2	45.6		
1985							
Start						85.8	1,000
Jan	7.6	1.3	6.3	5.9	8.4	83.3	971
Feb	6.9	1.3	5.6	5.2	7.3	81.2	947
Mar	7.4	2.1	5.3	5.5	6.8	79.9	932
Apr	6.8	2.2	4.6	5.1	5.8	79.2	923
May	6.5	2.6	3.9	4.8	4.9	79.1	922
Jun	4.2	3.7	.5	3.1	.6	81.6	951
Jul	2.4	4.4	.0	1.7	.0	83.3	1,003
Aug	3.4	4.0	.0	2.6	.0	85.9	1,045
Sep	6.2	3.5	.1	5.1	.1	90.9	1,060
Oct	6.5	2.7	3.8	5.3	5.5	90.7	1,058
Nov	7.2	1.9	5.3	5.8	7.5	89.0	1,038
Dec	7.6	1.5	6.1	6.0	8.5	86.5	1,009
Total	72.7	31.2	41.5	56.1	55.4		

Notes:
(1) Concentrations of total dissolved solids in river diversions based on monthly averages of water coming from upstream, including releases from Mitchell Lake as in Table C-9.
(2) Lake capacity: 63,200 acre-feet; slight drawdown of storage experienced in July, August and September of 1980 and in July and August of 1985.
(3) Evaporative losses are the sum of natural and induced evaporation (see Table 3.13 of the text).

Table C-12

Lake Braunig Chemical Quality Study for Drouth Conditions as of 1985
Operating as a Combined System with Lakes Mitchell and Calaveras

	From Mitchell Lake (1,000 AF)	From Salado Cr. Plant (1,000 AF)	Evaporative Losses (1,000 AF)	Outflow To Lake Calaveras (1,000 AF)	Total Dissolved Solids (1,000 Tons) Coming In	Going Out	In The Lake	Total Dissolved Solids (mg/l)
Start							24.2	673
Jan	6.8	2.9	.4	9.3	7.6	8.4	23.4	651
Feb	6.3	2.7	.4	8.6	6.9	7.5	22.8	634
Mar	5.6	2.9	.7	7.8	6.4	6.7	22.5	626
Apr	5.2	2.8	.8	7.2	6.1	6.1	22.5	626
May	4.6	3.0	.9	6.7	5.7	5.7	22.5	626
Jun	2.4	2.5	1.3	3.6	3.7	3.1	23.1	642
Jul	1.1	2.2	1.5	1.8	2.5	1.6	24.0	667
Aug	1.8	2.3	1.3	2.8	3.2	2.6	24.6	684
Sep	4.7	2.7	1.3	6.1	6.2	5.7	25.1	698
Oct	5.1	2.6	.9	6.8	6.5	6.5	25.1	698
Nov	5.7	2.7	.7	7.7	6.9	7.3	24.7	687
Dec	6.3	2.7	.5	8.5	7.3	7.8	24.2	673
Total	55.6	32.0	10.7	76.9	69.0	69.0		

Notes: (1) Quantities coming from Mitchell Lake are taken from Table C-9, with allowance for the fact that approximately 1/10 of the local irrigation around Mitchell Lake would be with water diverted directly from the lake.
(2) Evaporative losses are the sum of natural and induced evaporation.

Table C-13

Lake Calaveras Chemical Quality Study for Drouth Conditions as of 1985 Operating as a Combined System with Lakes Mitchell and Braunig

	From Lake Braunig (1,000 AF)	Evaporation Losses (1,000 AF)	Outflow (1,000 Ac-Ft)	1,000 Tons of TDS			mg/l of TDS
				Coming In	Going Out	In The Lake	
Start						96.1	1,120
Jan	9.3	1.3	8.0	8.4	12.2	92.3	1,076
Feb	8.6	1.3	7.3	7.5	10.9	88.9	1,037
Mar	7.8	2.1	5.7	6.7	8.2	87.4	1,019
Apr	7.2	2.2	5.0	6.1	7.0	86.5	1,009
May	6.7	2.6	4.1	5.7	5.6	86.6	1,010
Jun	3.6	3.7	.0	3.1	.0	89.7	1,048
Jul	1.8	4.4	.0	1.6	.0	91.3	1,112
Aug	2.8	4.0	.0	2.6	.0	93.9	1,169
Sep	6.1	3.5	.0	5.7	.0	99.6	1,186
Oct	6.8	2.7	2.8	6.5	4.5	101.6	1,185
Nov	7.7	1.9	5.8	7.3	9.3	99.6	1,186
Dec	8.5	1.5	7.0	7.8	11.3	96.1	1,120
Total	76.9	31.2	45.7	69.0	69.0		

Notes: (1) Quantities coming from Lake Braunig are based on Table C-12.

(2) Evaporative losses are the sum of natural and induced evaporation.

APPENDIX D

WATER QUALITY DATA

Table D-1	Chemical Quality Records For The San Antonio River Near Elmendorf As Published by the U. S. Geological Survey
Table D-2	Dissolved Oxygen Measurements At Various Points in Braunig Lake: 1969
Table D-3	Chemical Quality Observations At Braunig Lake: 1969
Table D-4	Bacteriological Observations At Lake Braunig: 1969 and 1970

Table D-1

Chemical Quality Records For The San Antonio River Near Elmendorf As Published by the U.S. Geological Survey

LOCATION.--Lat 29°14'15", long 98°21'43", at gaging station 2,000 feet downstream from Braunig Plant Lake, and 2.2 miles southwest of Elmendorf, Bexar County.
DRAINAGE AREA.--1,743 square miles.
RECORDS AVAILABLE.--Chemical analyses: October 1966 to September 1967.
Water temperatures: October 1966 to September 1967.
EXTREMES, 1966-67.--Dissolved solids: Maximum, 562 ppm Mar. 1-24; minimum, 261 ppm Sept. 16-17, 21-24.
Hardness: Maximum, 298 ppm Nov. 1-30; minimum, 190 ppm Sept. 16-17, 21-24.
Specific conductance: Maximum daily, 1,050 micromhos Dec. 23; minimum daily, 392 micromhos Sept. 23.
Water temperatures: Maximum, 85°F on several days during June to August; minimum, 53°F Jan. 9.

Chemical analyses, in parts per million, water year October 1966 to September 1967

Date of collection	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Strontium (Sr)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids (calculated): Parts per million	Tons per acre-foot	Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Noncarbonate	Sodium adsorption ratio	Specific conductance (micromhos at 25°C)	pH	Detergents (MBAS)	Nitrite (NO_2)
Oct. 1-4, 1966.	181	8.8	81	17		67	6.2	256	74	77	0.5	25	--	482	0.66	236	272	62	1.8	809	8.2	0.01	0.02
Oct. 5-9.......	224	13	76	15		58	6.7	243	72	72	.6	18	--	450	.61	272	251	52	1.6	766	7.8	.01	--
Oct. 10-31.....	155	21	84	18		73	7.7	278	80	88	.8	23	--	532	.72	223	284	56	1.9	898	7.5	.01	--
Nov. 1-30......	153	17	88	19		73	6.9	284	81	84	.7	25	--	535	.73	221	298	65	1.8	903	7.9	--	--
Dec. 1-31......	171	19	83	20		73	7.2	282	80	84	.6	28	--	534	.73	247	290	58	1.9	927	7.5	--	--
Jan. 1-31, 1967	168	16	85	20		75	7.0	282	81	85	.2	28	--	536	.73	243	294	64	1.9	903	7.6	.16	.05
Feb. 1-28......	146	18	82	20		77	7.4	275	84	88	.5	29	--	541	.74	213	287	62	2.0	902	7.6	--	--
Mar. 1-24......	124	18	80	21		82	7.3	282	86	95	1.0	33	--	562	.76	188	286	55	2.1	933	7.5	--	--
Mar. 25........	444	16	75	17		49	5.5	260	78	61	.8	1.0	--	431	.59	517	257	44	1.3	720	7.8	--	--
Mar. 26-27.....	332	14	71	14		52	6.3	220	76	63	.7	16	--	421	.57	377	234	54	1.5	708	7.9	--	--
Mar. 28-31.....	204	17	72	16		69	7.4	248	79	77	.9	21	--	481	.65	265	246	42	1.9	810	7.3	--	--
Apr. 1-30......	150	18	79	19		75	6.9	A259	82	82	.7	22	4.9	518	.70	210	275	62	2.0	886	8.4	.16	.00
May 1-8, 10-20.	133	18	77	18		79	7.0	265	79	91	.8	20	4.9	525	.71	189	266	49	2.1	888	7.9	--	--
May 9..........	191	16	74	17		67	5.9	251	66	73	.5	27	1.8	471	.64	243	254	49	1.8	789	8.2	--	--
May 21-23, 30..	162	15	76	18		59	5.9	242	74	70	.5	16	3.0	456	.62	199	264	65	1.6	773	7.8	--	--
May 24-29, 31..	94.6	19	80	18		78	7.1	259	77	89	.8	17	5.9	519	.71	133	274	61	2.1	876	7.8	--	--
June 1-30......	88.6	19	78	18		80	7.9	269	75	94	1.9	20	--	526	.72	126	268	48	2.1	884	8.2	--	--
July 1, 4-13, 16-31........	144	18	76	17		71	6.9	264	71	84	1.8	18	--	494	.67	192	260	43	1.9	822	7.7	.13	.02
July 2-3, 14-15	550	12	75	9.8		34	6.1	236	50	42	.6	5.5	--	351	.48	521	228	34	1.0	593	7.5	--	--
Aug. 1-18......	88.1	16	78	18		79	7.4	273	76	92	1.8	16	--	518	.70	123	268	45	2.1	881	8.2	--	--
Aug. 19-21.....	313	12	68	13		42	5.9	319	61	50	.6	7.4	--	368	.50	311	223	44	1.2	629	8.1	--	--
Aug. 22-31.....	204	14	73	14		59	6.6	244	64	68	1.1	15	--	435	.59	240	240	40	1.7	733	7.9	--	--
Sept. 1-2, 9-15, 25-30........	358	16	74	17		73	8.7	236	77	85	1.3	12	5.7	486	.66	470	254	61	2.0	810	7.6	--	--
Sept. 3-8......	595	13	70	11		39	8.1	214	55	47	.6	6.7	1.5	357	.49	574	220	44	1.1	593	7.5	--	--
Sept. 16-17, 21-24.........	4206	9.9	66	6.2		18	5.5	206	33	20	.4	.2	.60	261	.35	2960	190	21	.6	440	7.5	--	--
Sept. 18-20....	320	15	72	13		53	6.2	222	68	59	.7	12	1.9	410	.56	354	233	51	1.5	685	8.1	--	--
Weighted average.......	--	15	75	14		54	6.7	244	63	62	0.7	14	--	427	0.58	273	246	45	1.5	721	7.6	--	--
Time-weighted average.......	236	17	80	18		72	7.2	265	77	83	0.9	22	--	509	--	--	273	55	1.9	859	7.7	--	--
Tons per day...	--	9.4	48	9.1		35	4.3	156	40	40	0.5	9.2	--	--	--	--	--	--	--	--	--	--	--

A Includes 10 ppm carbonate (CO_3).

Table D-2

Dissolved Oxygen Measurements At Various Points In Braunig Lake: 1969

- Values in Milligrams per Liter -

Point	Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
2	1'	7.6	7.8	5.5	3.3	5.0	7.8	6.1	3.8	5.8	10.4	10.8	9.7	10.4
2	5'	7.1	7.2	4.9	3.0	5.0	7.6	5.4	3.7	5.7	10.2	10.8	9.7	9.7
3	1'	5.7	7.5	5.9	3.7	4.7	7.2	6.4	4.6	6.2	8.6	10.4	9.5	9.1
3	5'	4.8	6.3	5.8	3.3	4.8	7.1	6.3	4.7	5.9	8.6	10.4	9.5	9.0
4	1'	5.3	8.7	5.9	4.3	4.8	7.7	6.0	5.3	6.0	11.1	11.2	8.7	10.0
4	5'	5.2	6.5	5.3	4.0	5.0	7.7	5.8	5.3	6.0	11.0	10.8	8.7	9.9
4a	1'	6.4	8.3	6.1	5.4	4.7	8.3	6.6	5.9	6.3	10.0	11.0	8.6	10.4
4a	5'	5.6	4.0	5.3	5.2	4.7	8.0	6.4	6.1	6.3	10.0	10.8	8.5	10.2
5	1'	8.2	7.8	6.6	6.0	5.8	7.7	7.1	6.0	6.5	9.0	10.4	9.3	10.6
5	5'	7.6	7.2	6.4	5.9	5.6	7.4	6.9	6.0	6.5	9.0	10.4	9.3	10.3
5a	1'	7.3	7.5	6.8	6.6	6.0	8.0	7.8	6.6	5.7	9.4	10.4	7.7	11.2
5a	5'	5.6	7.2	5.7	6.5	5.8	7.5	7.5	6.5	5.5	9.0	10.4	7.7	10.6

Table D-3

Chemical Quality Observations At Braunig Lake: 1969

- All Samples Taken at Point 3a -

Dates / Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
Time (AM)													
Start	0830	0830	0800	0740	0750	1000	0800	0810	0800	0800	1000	0855	0810
Finish	0930		0845	0815	0820	1030	0830	0830	0830	1130	1030	0915	0840
Air Temperature (°C)													
Start	28.6	28.0	26.2	21.0	25.0	29.0	24.0	11.5	10.0	19.0	8.0	12.7	12.2
Finish	31.0		31.8	22.0	25.0	29.0	24.3	10.5	12.2	28.0	9.0	15.0	12.7
Water Temperature (°C)													
1'	33.5	33.5	31.8	29.0	30.0	31.0	27.3	24.0	21.2	22.0	17.0	17.0	16.0
10'	31.1	31.2	29.9	29.0	30.0	29.0	27.0	23.5	21.2	21.2	17.0	16.9	15.9
20'	29.7	30.9	29.3	28.5	29.0	29.0	27.0	23.5	21.0	21.2	17.0	16.9	15.6
30'	28.1	30.0	28.6	28.2	28.5	28.9	27.0	23.5	21.0	21.2	17.0	17.0	15.6
40'	27.5*	29.1	26.2	27.0	27.0	27.2	26.1	23.5	21.0	21.2	17.0	16.8	15.5
50'		27.2	26.2	27.8	28.2	27.2	26.1	23.2	21.0	22.0	17.0	16.9	15.6

*Measurements taken at 38' instead of 40' on 8/16.

Continued on the next page ....

Table D-3, Continued

Dates / Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
Dissolved Oxygen (mg/l)													
1'	8.0	7.8	5.4	4.5	5.7	7.6	6.6	4.8	6.4	8.9	8.0	9.8	10.7
10'	5.6	4.5	4.9	4.7	5.6	7.0	6.1	5.0	6.2	7.4	8.2	9.4	9.2
20'	1.1	1.0	2.3	3.7	3.9	5.2	5.0		6.5	6.7	8.2	9.8	9.2
30'	.0	.0	.5	1.3	2.0	2.5	4.6	4.9	6.2	5.6	8.6	9.7	8.6
40'	0*	.0	.0	.0	.0	.0	.4	4.8	4.4	6.8	8.4	9.3	7.2
50'		.0	.0	1.6	.4	.0	.9	2.8	4.7	3.7	8.4	7.6	6.8
pH Values													
1'	8.4	8.5	8.5	8.2	8.2	8.8	8.3		7.8	8.3	8.1	8.1	8.4
10'	8.4	8.4	8.6	8.5	8.4	8.7	8.4		8.0	8.2	8.1	8.2	8.3
20'	7.9	8.3	8.4	8.5	8.2	8.7	8.3		8.1	8.2	8.1	8.2	8.4
30'	7.7	7.8	8.2	8.3	8.1	8.4	8.3		8.0	8.3	8.2	8.2	8.4
40'	7.8*	8.0	8.0	8.5	7.9	8.0	8.0		8.0	8.2	8.2	8.3	8.4
50'		7.9	8.0	8.7	8.0	8.2	8.1		8.0	8.3	8.2	8.3	8.4
5-Day BOD (mg/l)													
1'	10.5	9.4	13.7	7.5	11.6	12.8	13.5	11.5	9.8	7.6	12.3	8.4	13.9
Suspended Solids (mg/l)													
1'	16.0	8.5	7.0	10.5	5.5	8.5	9.0	7.5	10.5	16.5	9.0	8.5	8.5

*Measurements taken at 38' instead of 40' on 8/16

Continued on the next page ....

Table D-3, Continued

Dates / Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
Chlorides (mg/l)													
1'	143	144	143	140	146	149	142	142	138	140	138	142	144
10'	136	144	141	142	146	144	144	142	144	144	142	144	144
20'	127	138	146	140	144	143	146	144	142	144	144	146	146
30'	124	139	139	140	146	145	144	140	142	144	144	144	146
40'	133*	138	139	138	140	144	144	140	144	144	142	142	144
50'		135	139	140	142	156	144	142	142	142	144	146	146
Ammonia Nitrogen (mg/l)													
1'	2.1	1.4	1.7	1.2	1.0	1.4	.4	1.0	.8	1.0	.7	.8	1.0
10'	1.0	1.7	1.5	1.2	1.1	1.0	.4	.8	.8	1.0	.7	.7	.9
20'	1.3	1.2	1.7	1.5	1.0	.7	.4	.9	.7	1.1	.8	.8	.8
30'	2.6	2.2	1.9	1.6	1.1	1.4	.4	.9	.7	1.0	1.1	.7	1.1
40'	2.0*	2.2	2.5	2.1	1.8	1.8	1.3	1.0	.8	.9	.9	.8	1.1
50'		2.7	3.4	2.0	1.7	1.4	.7	1.6	.9	1.9	.8	.8	1.0
Nitrite Nitrogen (mg/l)													
1'				.017	.013	.007	.03	.14	.015	.01	.04	.02	.03
10'				.015	.013	.005	.04	.14	.010	.01	.04	.02	.03
20'				.019	.048	.015	.09	.14	.010	.02	.04	.02	.03
30'				.017	.050	.015	.09	.14	.015	.03	.04	.02	.03
40'				.012	.015	.007	.04	.14	.030	.04	.04	.02	.03
50'				.013	.019	.014	.06	.12	.015	.04	.04	.03	.03

*Measurements taken at 38' instead of 40' on 8/16

Continued on the next page ...

Table D-3, Continued

Dates / Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
Nitrate Nitrogen (mg/l)													
1'	.0	.0	.0	.0	.0	.04	.1	.0	.25	.0	.20	.2	.1
10'	.0			.0	.0	.0	.1	.0	.50	.0	.19	.2	.0
20'	.0			.0	.0	.0	.6	.0	.65	.0	.25	.1	.1
30'	.0			.0	.0	.06	.1	.0	.70	.0	.22	.2	.2
40'	.0*			.0	.0	.0	.1	.0	.70	.1	.21	.2	.2
50'				.0	.0	.0	.2	.0	.60	.1	.21	.2	.2
Orthophosphate (mg/l)													
1'	.2	.3	.4	.6	.5	.5	.5	.6	.5	.29	.2	.1	.2
10'	.4	.4	.5	.7	.6	.5	.6	.7	.5	.29	.2	.1	.2
20'	.9	.6	.6	.8	.6	.5	.6	.7	.5	.30	.3	.1	.1
30'	1.2	1.0	.9	.8	.7	.6	.6	.7	.5	.36	.4	.2	.2
40'	1.2*	1.1	1.3	1.2	1.1	1.2	1.1	.7	.5	.40	.3	.2	.2
50'		1.4	1.0	1.1	1.0	.9	.7	.8	.5	.46	.3	.2	.2
Total Phosphate (mg/l)													
1'				3.6	1.8	1.8	1.8	1.7	.6	.50	.6	.4	1.8
10'				2.6	1.8	1.8	1.8	1.7	.7	.54	.7	.5	.9
20'				2.8	1.8	2.0	1.8	1.7	.6	.60	.6	.6	.7
30'				2.6	2.0	2.0	1.7	1.7	.6	.65	.7	.7	.7
40'				4.0	2.4	2.4	2.4	1.8	.6	.65	.8	.6	.6
50'				3.6	2.4	2.0	2.2	2.0	.7	.65	.6	.6	.6

*Measurements taken at 38' instead of 40' on 8/16

Continued on the next page ....

Table D-3, Continued

Dates / Depth	8/16	8/23	9/6	9/13	9/20	9/27	10/11	10/18	11/1	11/8	11/28	12/6	12/13
Total Alkalinity as $CaCO_3$ (mg/l)													
1'	112	118	120	119	142	140	148	154	152	158	160	155	144
10'	115	115	131	147	144	145	142	154	154	158	156	159	158
20'	139	122	134	141	146	142	142	146	154	156	160	156	162
30'	153	132	140	153	144	143	154	154	152	158	162	159	164
40'	156*	143	160	161	160	161	160	151	158	158	160	159	160
50'		142	158	155	144	140	146	156	156	158	160	161	160
Sulfate (mg/l)													
1'	110	132	108	121	109	110	110	102	110	102	98	102	102
10'	110			112	100	102	110	110	132	94	94	102	102
20'	108			131	100	102	114	114	127	94	94	102	102
30'	104			136	100	94	102	106	123	94	106	102	105
40'	104*			136	97	97	98	138	110	94	118	102	102
50'				142	93	102	110	127	136	94	127	98	102

*Measurements taken at 38' instead of 40' on 8/16

Table D-4

Bacteriological Observations At Lake Braunig: 1969 and 1970

- Most Probable Number (MPN) of Coliform Bacteria per 100 Milliliters -

Date	Point 2	Point 3	Point 3a	Point 4	Point 4a	Point 5	Point 5a
9/6/69			5				
9/13/69			13		2		
9/20/69			70		23		
9/27/69			23		33		
10/11/69			130		33		
10/18/69			109		22		
11/1/69			1,609		172		
11/8/69			221		49		
11/28/69			23		23		
12/6/69			94		79		
12/13/69			23		221		
1/26/70	11	4	7	7	5	14	2
1/26/70*	2	2	2	2	2	2	2

*All values are total coliform bacteria except the last line (1/26/70), which is fecal coliform bacteria.

BRAUNIG LAKE

MAP OF SAMPLING POINT LOCATIONS

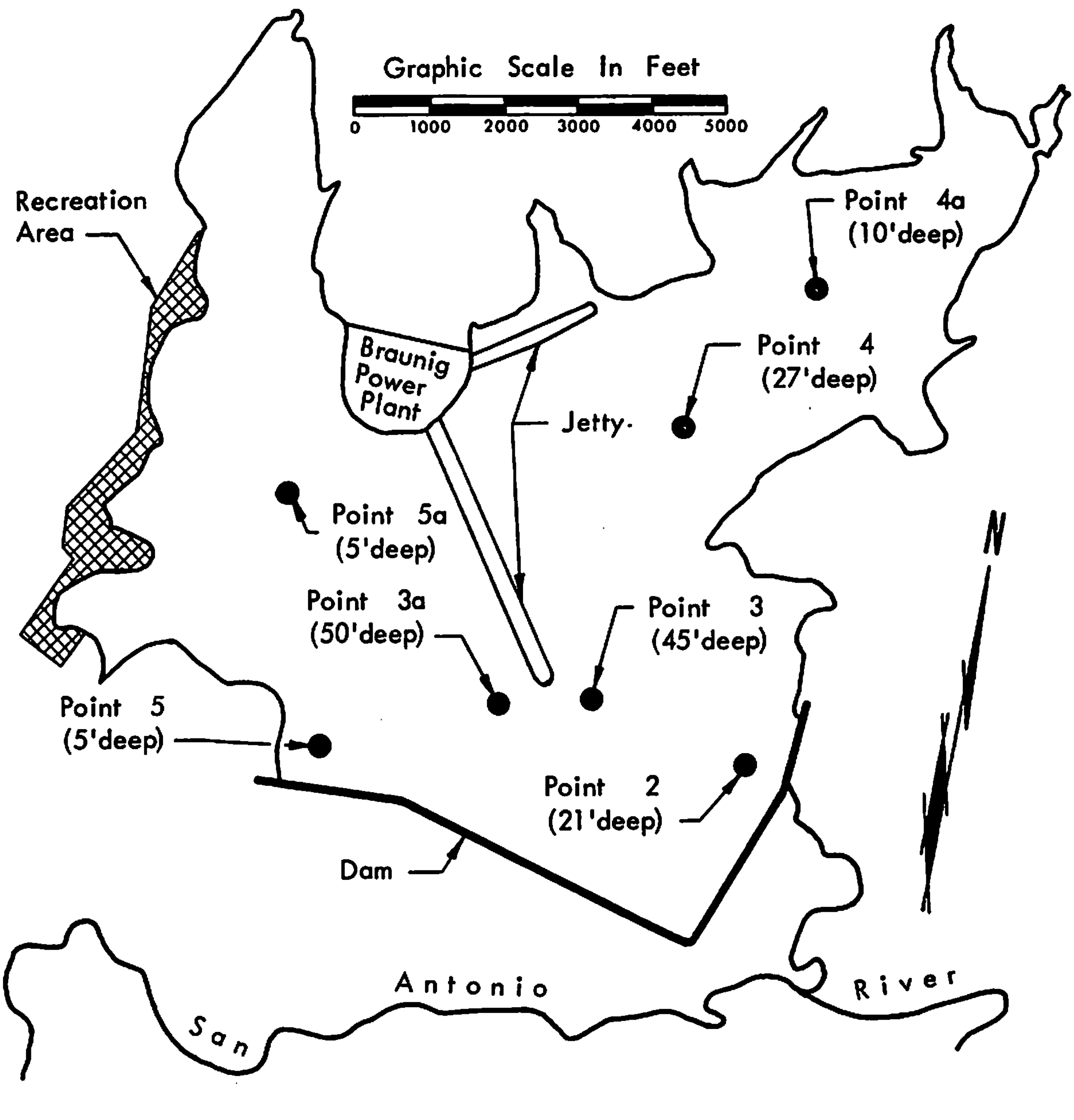


FIGURE D-1