CDM

PHASE I
EDWARDS UNDERGROUND WATER DISTRICT STORAGE-RELEASE RECHARGE FACILITY EVALUATION

AUGUST 29, 1985

Camp Dresser & McKee

Prepared for:

Edwards Underground
Water District
1615 North St. Marys
San Antonio, Texas 78210

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EDWARDS UNDERGROUND WATER DISTRICT STORAGE-RELEASE

RECHARGE FACILITY EVALUATION

1.0 INTRODUCTION

1.1 BACKGROUND

The Edwards Aquifer is one of the most productive aquifers in the southwestern U.S. (Figure 1.0-1). The aquifer serves as a water supply for more than a million people in and around the City of San Antonio, as well as other cities, and as a source of irrigation water for counties to the west of Bexar County. Much of the water consumed from the aquifer is withdrawn from wells; however, natural spring discharge from the aquifer serves as a municipal supply for towns such as Brackettville, and as a recreational focus for the cities of New Braunfels and San Marcos. This spring discharge also contributes to the flow in the Guadalupe and Blanco Rivers.

The Edwards Aquifer is recharged principally by leakage from streams flowing across the Balcones Fault Zone, a system of closely spaced faults that developed between the stable interior of Texas, characterized by the Edwards Plateau, and the Gulf Coastal Plain. Much of the recharge is derived from direct runoff associated with specific rainfall events on and upstream of the recharge area. In addition, some of the rainfall that infiltrates the rocks of the Edwards Plateau and Hill Country upstream of the recharge area is later discharged as spring discharge into the streams crossing the recharge area. The spring discharge serves to maintain flow in some of the streams long after rainfall/runoff events have ended, providing a continuous source of recharge during most years.

From 1934 through 1980, the average annual recharge to the Edwards Aquifer, from stream leakage and from direct infiltration, was estimated to be approximately 594,800 acre-feet (ac-ft), or an average of about 531 million gallons per day (mgd). The maximum annual recharge, recorded in 1958, was 1.711 million ac-ft, or an average of 1,527 mgd. The minimum annual recharge, recorded in 1956, was 43,700 ac-ft, or an average of only 39 mgd. In addition to surface recharge, it is estimated that about 24,000 ac-ft

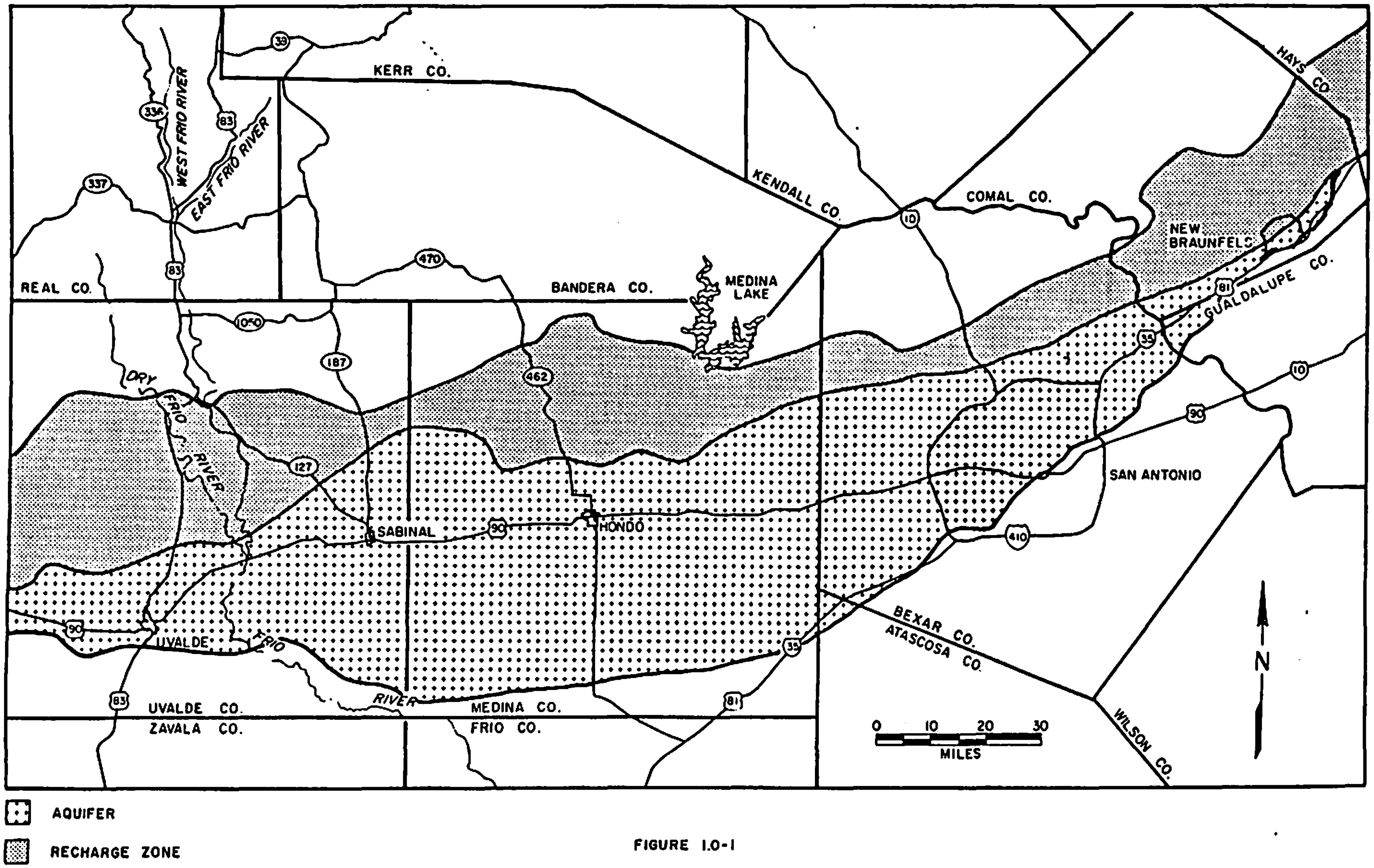


FIGURE 1.0-1

LOCATION OF EDWARDS AQUIFER & RECHARGE ZONE per year or 22 mgd is recharged by subsurface underflow from the Glen Rose Formation (Austin Geological Society, 1984; see Appendix A for list of references cited). About 66 percent of all the recharge to the Edwards Aquifer occurs to the west of Bexar County (Table 1.0-1).

The Edwards Aquifer is tilted and progressively downfaulted toward the coast (Figure 1.0-2). Water entering the aquifer becomes confined, or artesian, as it moves away from the recharge zone. Confined or artesian conditions occur when the entire thickness of the aquifer is fully saturated and relatively impermeable strata lie over and under the aquifer. Water in a well drilled into a confined or artesian aquifer rises in the well bore above the top of the aquifer and may flow onto the ground surface. The water level rise in the well bore occurs because the water level in the recharge area is topographically higher than the top of the aquifer at the well and perhaps even the ground surface. The geological formations that serve to confine the Edwards Aquifer are the overlying Del Rio Clay, Buda Limestone, and other geologically younger formations, and the underlying Glen Rose Formation, the upper part of which is marly and relatively impermeable.

In general, groundwater in the Edwards Aquifer moves eastward from the Kinney, Uvalde, and Medina counties into Bexar County and then northeastward towards Comal and Hays counties (Figure 1.0-3). Significant coastward movement is constrained by a lack of discharge points and lower permeability in the coastward parts of the aquifer. A "bad water-line" occurs toward the coast, where the mineral content of the water rises above 1,000-milligrams per liter (Maclay and Small, 1983), rendering the water less suitable or even unsuitable to drink. The majority of the natural discharge from the Edwards Aquifer occurs at six springs -- Las Moras, Leona River, San Antonio, Comal, San Marcos (Aquarena), and Hueco Springs (Texas Water Development Board Report 189, 1975 -- most of which are in Bexar, Comal, and Hays counties.

TABLE 1.0-1

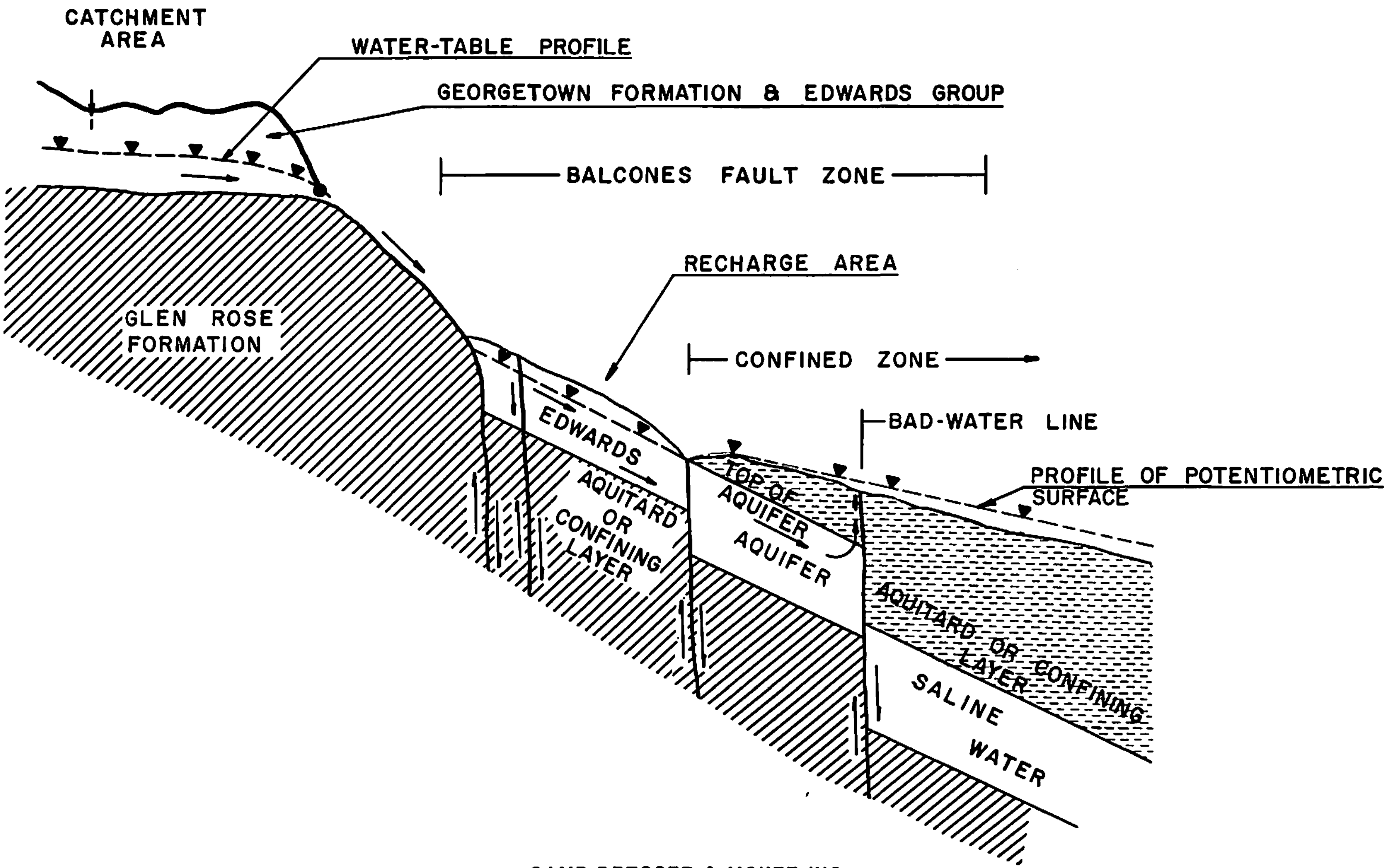
EDWARDS AQUIFER RECHARGE
BY RIVER IN 1980

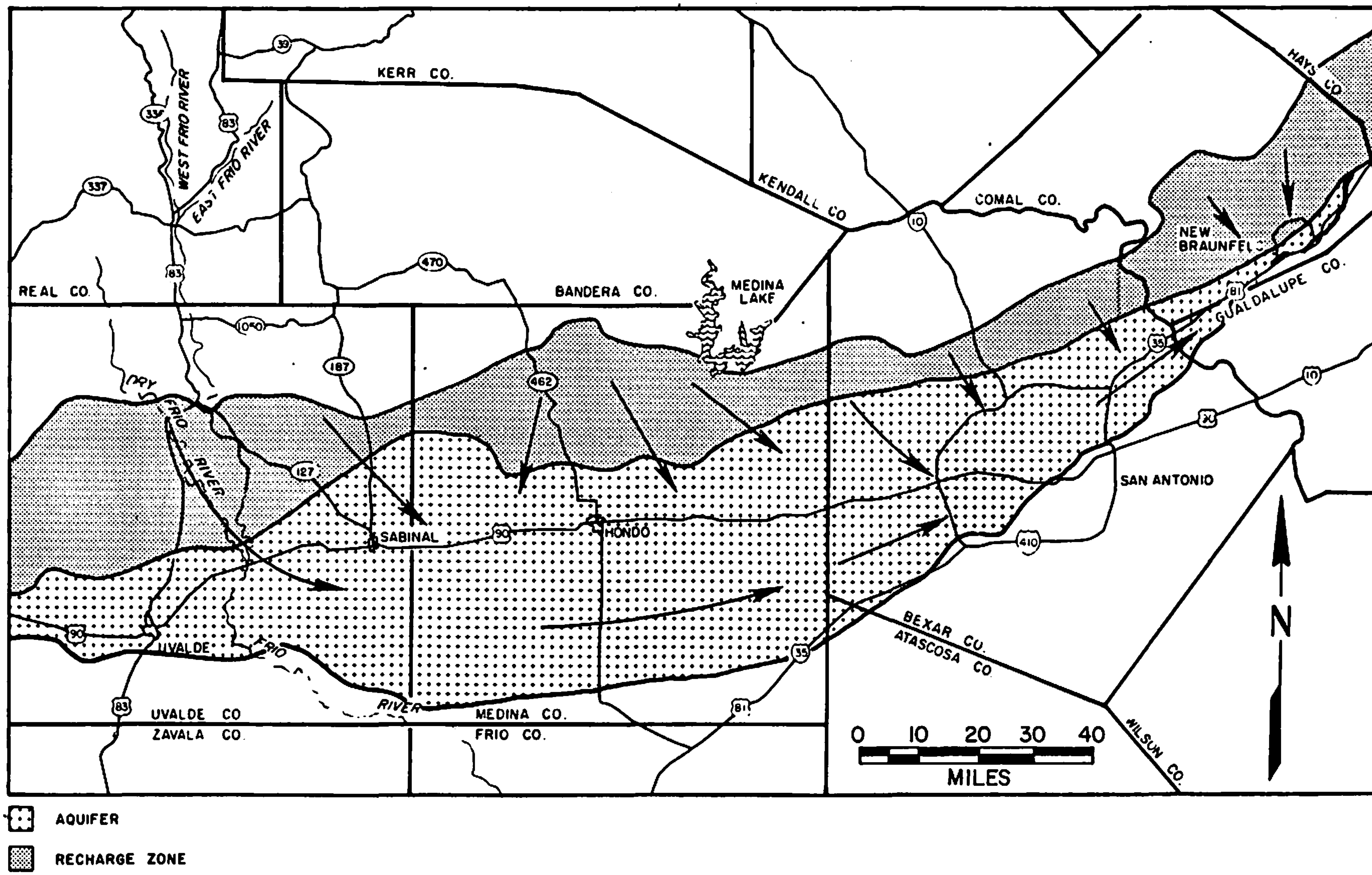
(Source: EUWD Bulletin 40)

River Basin	1980 Recharge (Ac-Ft)
Nueces-West Nueces River Basin	58,600
Frio-Dry Frio River Basin	85,600
Sabinal River Basin	42,600
Area Between Sabinal and Medina River Basins	25,300
Medina Lake	88,300
Area between Cibolo Creek and Medina River Basins	18,800
Cibolo-Dry Comal Creek Basin	55,400
Blanco River	31,800
TOTAL	406,400

DIAGRAMATIC CROSS-SECTION OF THE EDWARDS AQUIFER

FIGURE 1.0-2





LOCATION OF EDWARDS AQUIFER & RECHARGE ZONE

FIGURE 1.0-3

The Edwards Aquifer is different from most aquifers in Texas because it is composed of limestone and dolomite. Voids in the rock (porosity) and the interconnection between the voids (permeability) have developed by dissolution of the limestone, interbedded gypsum, and fossils, and because of other changes during and after the rocks were formed (Abbott, 1975; Maclay and Small, 1983). Locally, caverns have also developed.

The development of caverns and the extensive interconnection of other voids allows rapid movement of the groundwater through the freshwater portion of the aquifer. Water levels in the Edwards Aquifer respond very quickly to recharge events (rainfall and rainfall runoff), and water movement through the aquifer is unusually fast for an artesian aquifer. This means that in years when there is much less than normal rainfall (droughts) and stream flow is diminished, recharge to the aquifer is also diminished. Spring flow discharge from the aquifer, although reduced, continues until water levels in the aquifer fall below the spring orifices. At the same time, withdrawals for municipal and irrigation purposes are likely to increase, further depleting the aquifer and lowering water levels. For the purposes of this study, groundwater levels below 625 ft in elevation, measured in selected wells, were considered undesirable. At water levels below this elevation, storage in the aquifer is reduced, spring flow ceases at Comal Springs, and there is some concern that further declines in water levels (pressure heads) in the aquifer will induce upward movement of "bad water" into the fresh water portion of the aquifer.

In 1980, an estimated 491,100 ac-ft of groundwater was withdrawn from the Edwards Aquifer (Table 1.0-2). Of this amount, withdrawals for municipal supply in Bexar County represented about 46 percent, or 227,000 ac-ft, and municipal withdrawals in the six counties that are encompassed by the district represented about 52 percent, or 256,200 ac-ft. Total withdrawals of groundwater have been increasing and, with the continued growth in Bexar, Comal, and Hays counties, are likely to increase in the future. During years with normal or above normal rainfall, the Edwards aquifer has historically yielded sufficient water to meet all demands; however, during drought years, particularly during prolonged drought, groundwater supplies

TABLE 1.0-2

EDWARDS AQUIFER HISTORICAL PUMPAGE

(Source: EUWD Bulletin 40)

Year	Total Well Discharge (Ac-Ft)	Year	Total Well Discharge (Ac-Ft)
1940	120,100	1961	228,200
1941	136,800	1962	267,900
1942	144,600	1963	276,400
1943	149,100	1964	260,200
1944	147,300	1965	256,100
1945	153,300	1966	255,900
1946	155,000	1967	341,300
1947	167,000	1968	251,700
1948	168,700	1969	307,500
1949	179,400	1970	329,400
1950	193,800	1971	406,800
1951	209,700	1972	371,300
1952	215,400	1973	310,400
1953	229,800	1974	377,400
1954	246,200	1975	327,800
1955	261,000	1976	349,500
1956	321,100	1977	380,600
1957	237,300	1978	431,800
1959	234,500	1980	491,100
1960	227,100		

have been less than adequate. Coupled with the growth in the Edwards Underground Water District (EUWD or the District) and the anticipated increased demand for water, consideration of measures to increase the yield of the aquifer is prudent.

1.2 STORAGE-RECHARGE CONCEPTS

The U.S. Soil Conservation Service in cooperation with other local public entities has completed several flood detention structures and groundwater recharge structures in the Nueces, San Antonio, and Guadalupe River basins. These structures have increased recharge to the Edwards by an estimated 17,000 ac-ft per year, or an average of 15 mgd (Austin Geological Society, 1984). Some of these structures are located on the recharge zone and simply detain streamflow during a runoff event to allow time for the water to infiltrate through the stream bed before it flows across the recharge zone.

The U.S. Army Corps of Engineers (1964) and EUWD studied the potential for further recharge using larger structures. Conclusions drawn in this report issued by the Corps were that four reservoirs constructed upstream of the recharge zone on the Nueces, Frio, Sabinal, and Blanco rivers could effectively increase recharge to the aquifer by approximately 63,900 ac-ft per year, or an average of 57 mgd. These structures would store runoff from the Edwards Plateau and the Hill Country in excess of what the aquifer would accept through the downstream reaches. The stored water would then be released immediately after the runoff event at the maximum rate it could be recharged. Although increasing the average annual recharge to the aquifer, reservoirs operated in the manner proposed by the Corps increased storage in the aquifer when it is least needed, when rainfall has been sufficiently plentiful to allow runoff, and when demands on the water supply in the aquifer are the least. Because the aquifer responds so quickly to a recharge event, the increased amount of water would largely result only in increased spring flow. The water would then be unavailable during drought periods when it is needed the most.

Ideally, to counteract the effects of a prolonged drought on the aquifer, reservoirs such as those proposed by the Corps would retain water in storage in excess of natural recharge during a runoff event until it is needed most, i.e. when natural recharge is minimal, demands are at a maximum, and water levels in the aquifer are falling. The water in storage could then be released at some rate equal to or less than the maximum rate at which the downstream reaches on the fault zone can recharge the aquifer. The purpose of the releases would be to reduce or halt further water level declines in the aquifer. Releases from the reservoirs would continue until water levels in the aquifer began to rise either because of increased natural recharge or declines in demand, or until the reservoirs were empty. Subsequent wet periods would allow the reservoirs to refill.

The U.S. Army Corps of Engineers (1964) also considered this approach and concluded that it would not be effective. Although water could be stored until some critical period, evaporative losses from the reservoirs would diminish both the amount of water in the reservoir at the critical periods and the total recharge to the aquifer. The Corps approach provided for storage of all runoff in selected streams, not just the streamflow in excess of that which could be naturally recharged through the stream reaches on the recharge zone. This is why a net loss of recharge to the aquifer would occur.

Because of the anticipated growth in the District and particularly because of the lengthy drought that commenced in 1983 and continued into fall 1984, the EUWD decided to re-evaluate the potential of constructing a storage/release recharge facility on either the Frio River, near Concan, or the Dry Frio, near Reagan Wells. The intent of the study is to compare the two sites and assess the feasibility of capturing excess runoff, i.e. runoff in excess of what would naturally recharge the aquifer, for later release and additional recharge of Edwards. Although there may be a total loss of water to the aquifer/stream system due to evaporation, the aquifer itself should benefit from increased recharge, especially when natural recharge is at a minimum and stabilization of water levels is needed.

1.3 SCOPE OF WORK

There are six critical issues that must be addressed in assessing the feasibility of constructing a storage/release recharge facility on either the Frio or the Dry Frio River. These issues are:

1. Hydrology

   - How much excess runoff (i.e., runoff in excess of that which is naturally recharged to the aquifer) can the river basins above the potential sites yield?
   - Is there enough excess runoff available in the river basins upstream of the potential sites to fill the reservoirs?
   - Because of evaporative losses, will there be an acceptable amount of water in either of the potential reservoirs when it is needed, i.e. when there has been little or no inflow into the reservoir for some time?
   - How long will the water in such a reservoir last, i.e. over how many days, weeks, or months can releases be made from a reservoir?
   - After a release, will the reservoirs refill in time to be of use the next time they are needed?

2. Water rights

   - Is there sufficient water available in either the Frio or the Dry Frio rivers for appropriation, or, at the least, can the water rights conflict, as well as conflicts related to freshwater inflows to the bays and estuaries, be resolved?
   - Does the water which currently flows across the recharge zone reach the diversion or storage sites of the downstream water rights holders in the season in which those rights can be exercised beneficially?

3. Reservoir sites

   - Is there a suitable site on the Frio or the Dry Frio River for construction of a dam and reservoir?
     - What are the foundation conditions?
     - Will the sites leak excessively or can the leakage be controlled?
     - What is the fate of water that is lost through leakage from the reservoir? Does it ultimately recharge the Edwards? Will there be seepage return flows when the reservoir water levels are lowered?
     - Will leakage, coupled with evaporated losses, drain the reservoir so that there will be insufficient water remaining in storage in the reservoir for release when needed?

- Would additional releases to satisfy water rights or storage only of flows that are significantly greater than are naturally recharged affect the feasibility of the project?
- What are the effects of evaporation from the reservoir or seepage return flows on the quality of water available for recharge?
- What flood control measures will be necessary?
- What kind of dam should be built, and are there sufficient quantities of suitable local materials available to construct a dam?
- What are the land and other socioeconomic conflicts at each site?
- What are the estimated capital and operating costs of the reservoir, and are they acceptable?
- What are the overall benefits and costs of constructing a storage/release recharge reservoir at either site, considering the operating requirements?

4. Long-term recharge rates

- What are the currently estimated rates of recharge to the Edwards Aquifer along the Frio and Dry Frio reaches crossing the recharge zone?
- Can these recharge rates be sustained for the foreseeable future or will the recharge zone tend to clog over time because the flows in the rivers are now more controlled?

5. Does the water recharged artificially reach the potential users when it is needed.

6. Permit requirements

- What are the requirements for obtaining a permit from the Texas Water Rights Commission to construct the facility?
- What opposition is likely to be encountered?

After discussions with the EUWD, Camp Dresser & McKee Inc. (CDM) proposed a three-phased study program consisting of fifteen separate tasks. The tasks and phases were organized in order of priority, and each successive phase would be addressed only if at the end of the preceding phase, the project is still deemed feasible. Only sites on the Frio and the Dry Frio would be considered at this time; alternate sites would be addressed if no sites on these two rivers appeared feasible.

On October 2, 1984, CDM entered into an agreement with the EUWD to perform the first phase of the study and to provide the following professional services:

Task 1 - Conduct Initial Project Conference

Conduct an initial project conference with the District to refine the objectives of the project and to obtain all pertinent information.

Task 2 - Review Available Information

Review all available published and unpublished information relevant to the project.

Task 3 - Review Hydrologic Data

Examine available hydrologic data to determine basin yield, and the quantity, frequency, and characteristics of stormwater runoff that might be available for storage. Stream gage records for the Dry Frio near Reagan Wells (20 years of record) and the Frio near Concan (58 years of record) will be examined in particular and compared to develop records for both sites that correspond to the same period. Standard statistical methods will be used.

Task 4 - Evaluate Edwards Aquifer Water Levels

Water level records for selected observation wells near the City of San Antonio will be compiled and examined to ascertain short-term seasonal changes and long-term trends that have occurred. The water levels will be matched to occurrence of recorded droughts to ascertain when artificial recharge would have been desirable. For the purposes of this study, it will be assumed that once the water level in a selected index well reached a predetermined level, water available in a storage reservoir would be released.

Task 5 - Evaluate Potential Reservoir Sites

Through use of topographic, soils, and geologic maps, potential dam sites on the Dry Frio and the Frio Rivers will be examined. Stage-area-volume relationships will be determined for the most viable sites. No field work will be performed to assess foundation conditions or the availability of borrow material. Leakage estimates will not be made, nor will the fate of leakage water be considered at this time.

Task 6 - Preliminary Evaluation of Feasibility

Based on the information derived from the previous tasks, CDM will perform a preliminary evaluation of the feasibility of constructing a storage/ release reservoir on either the Dry Frio River or the Frio River to augment natural recharge to the Edwards Aquifer. Analysis of storage/yield relationships will be conducted for one or both sites by assuming that a reservoir was constructed on both rivers at the beginning of the common period of record and ascertaining, considering historical inflows and evaporative losses, whether significant amounts of water could be captured and stored for release and recharge during drought conditions. Maximum recharge rates determined by the U.S. Geological Survey (1983) will be used as the release rates. Computer models previously developed by CDM for the Texas Department of Water Resources (TDWR) will be used to simulate reservoir behavior. A brief, concise report to the EUWD will be prepared to present the preliminary evaluation of feasibility.

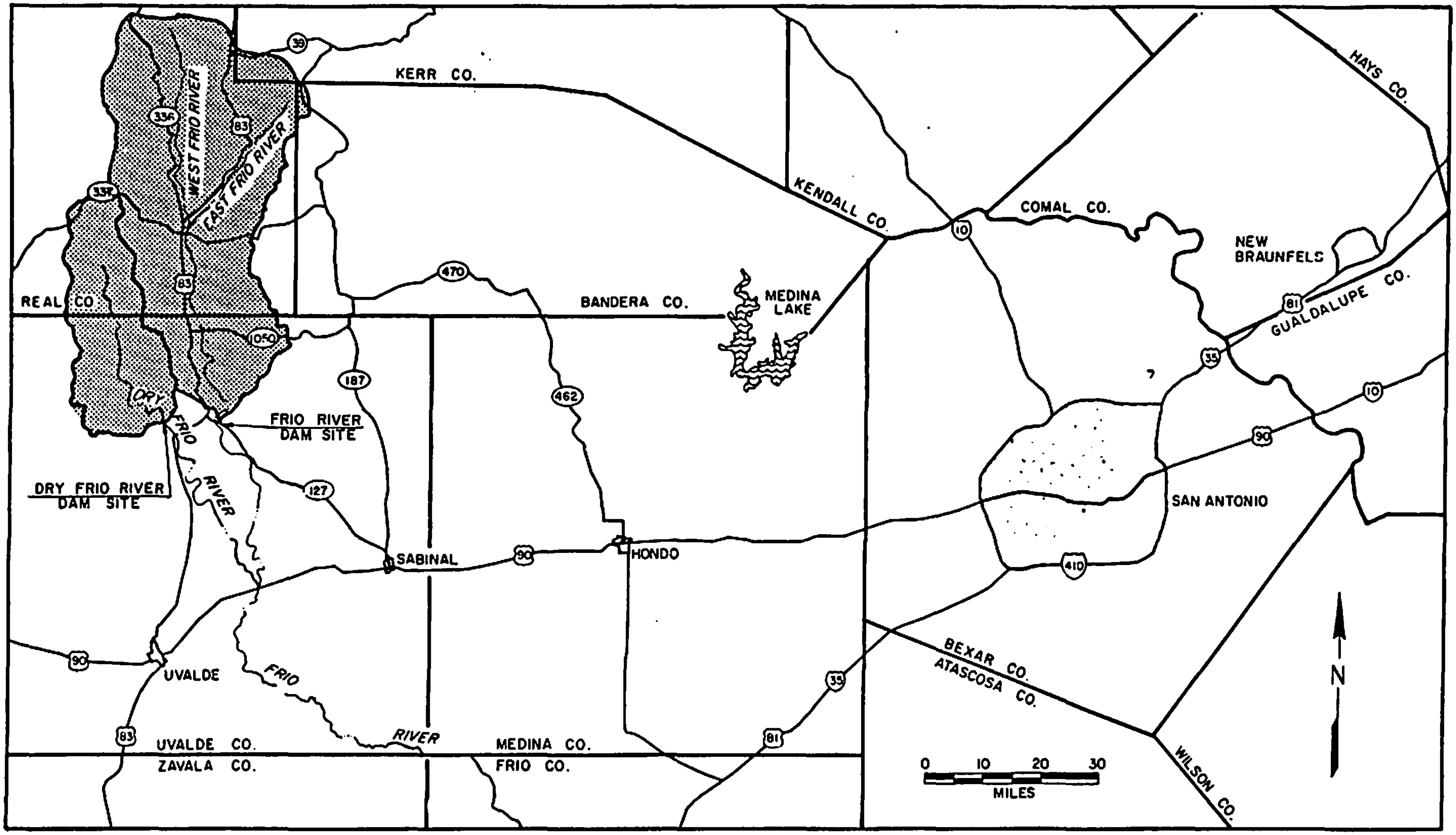
2.0 SITE DESCRIPTION

The two potential reservoir sites examined in this feasibility study are located in Uvalde County less than five miles apart (Figure 2.0-1). The site on the Frio River is approximately one mile north of where State Highway 127 crosses the Frio River at Concan, Texas (also known as the first crossing). The site on the Dry Frio River is just below the confluence of the Dry Frio and Fish Creek. Both sites are just upstream of where the Frio and the Dry Frio rivers exit from the Texas Hill Country and cross the Balcones Fault Zone, the recharge area for the Edwards Aquifer. For the most part the two sites are similar -- meteorology and basic hydrology are the same at both sites. The geology at the two sites differs slightly; only the current land use at the two sites differs significantly.

The average annual temperature in Uvalde County is 69°F (TDWR, 1983). Although mild, the seasonal variations can be harsh, as shown in Figure 2.0-2 in which the average monthly high and low temperatures for Uvalde have been plotted. The highest official temperature recorded in Uvalde County was 114°F; the lowest recorded was 7°F.

The average annual rainfall in Uvalde County is 23.23 inches (TDWR, 1983) and occurs predominantly as a result of four different meteorological mechanisms. Spring and fall rains are generated by passage of frontal systems. Lines of thunderstorms develop along and in advance of the frontal boundaries. Rainfall is usually widespread and rainfall accumulations can be significant because of the abundance of moisture-laden air flowing in from the Gulf of Mexico. Winter rains are generated by the same mechanism but the storms are usually less violent. Extended periods of rainfall during the winter months also occur because of overrunning of cold air masses behind frontal systems by warmer moist air from the Gulf of Mexico or from the Pacific Ocean.

Summer rains are largely the result of convective storms. Differential heating of the ground induces the formation of convective thermals that can pump warm moist air high into the atmosphere where the air cools and water

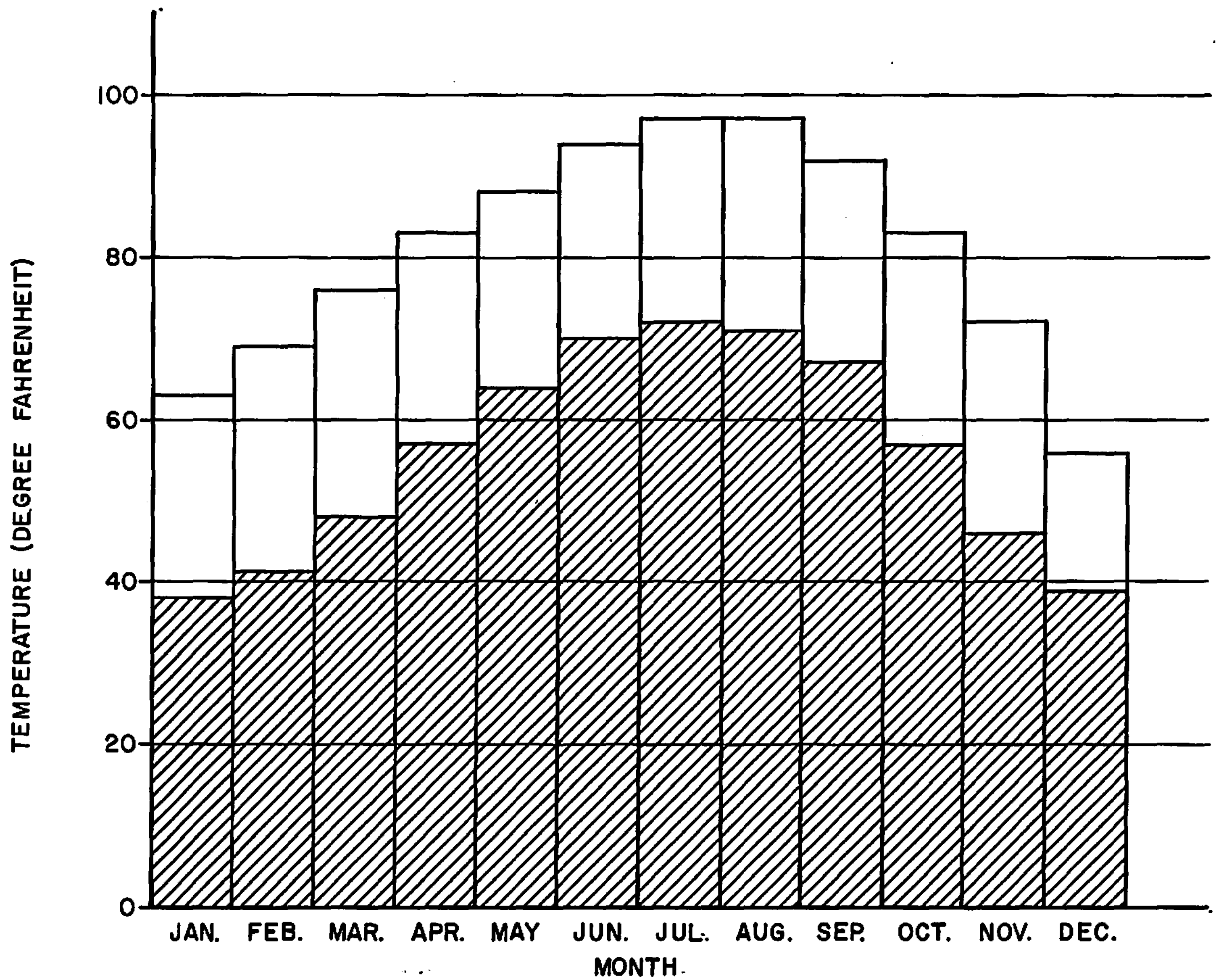


PROJECT LOCATION MAP

FIGURE 2.0-1

FIGURE 2.0-2

AVERAGE MONTHLY HIGH & LOW TEMPERATURES



vapor condenses to form precipitation. Typically, these storms can be very intense, but small in areal extent with rainfall rates varying significantly over short distances. Because of the small areal extent and rapid movement, the accumulation of rainfall from individual storms is seldom great.

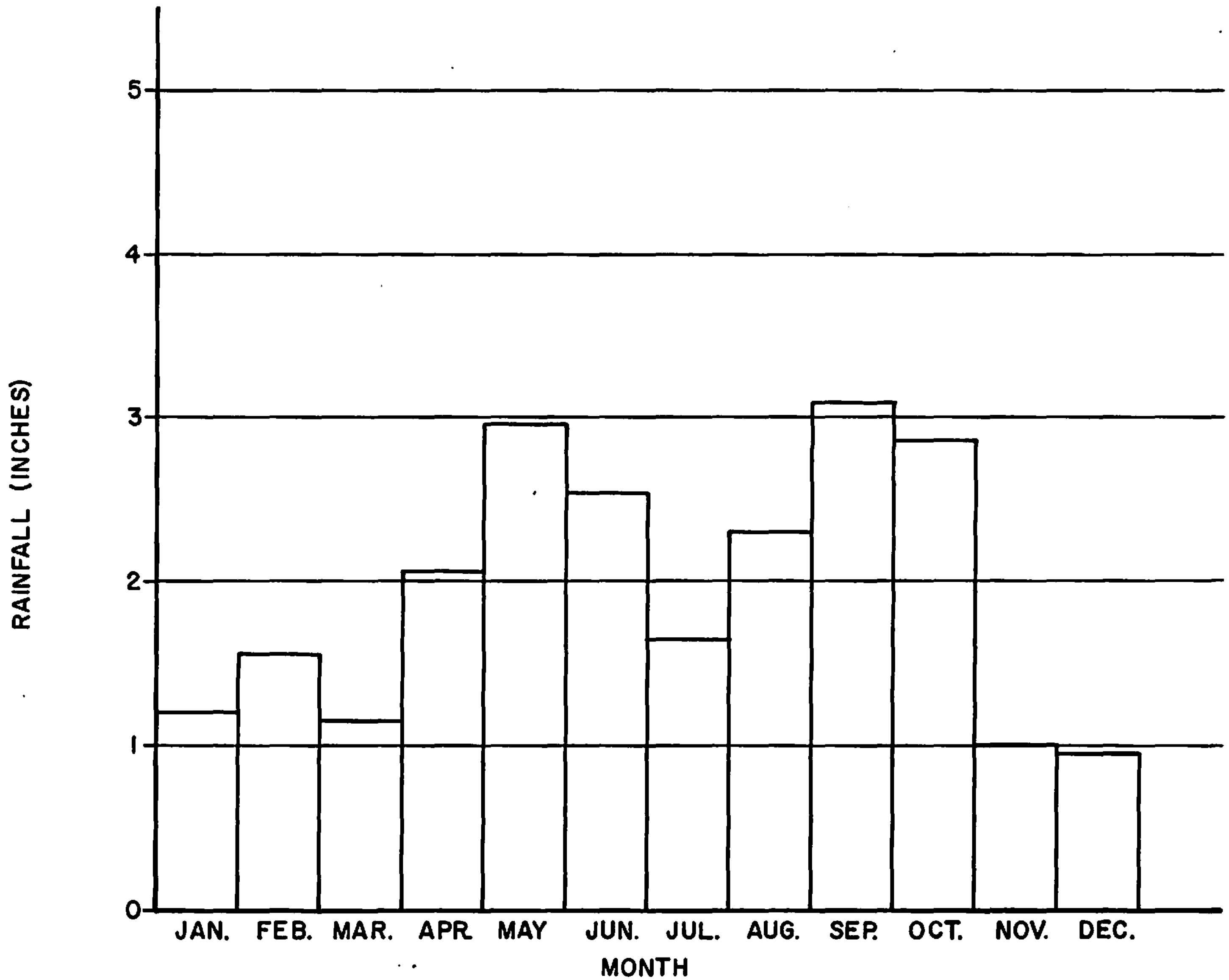
The greatest potential for significant rainfall is from the remnants of hurricanes and other tropical storms that move ashore from the Gulf of Mexico. These storms tend to be massive and usually result in several days of torrential rainfall. Tropical Storm Amelia, which caused record-breaking amounts of rainfall (11.6 in./24 hr) in Bandera and Kerr Counties and flooding on the Medina River in August 1978, is an example of such a storm. These storms normally occur only in the months from June through October.

The average annual distribution of rainfall by month is shown in Figure 2.0-3. Considerable seasonal as well as annual variation in rainfall amounts occurs. Such storms as Tropical Storm Amelia can add substantially to the monthly and annual total accumulations of rainfall. Similarly, there can be lengthy dry spells, during which none of the precipitation mechanisms described above produces much rainfall. For example, from January through August 1984, only 10.4 inches of rainfall were recorded at Sabinal, Texas; the normal total accumulation of rainfall in Sabinal for this period is 15.5 inches. During this same period, there was even less precipitation at Uvalde, Texas. The small amount of rainfall received at Sabinal was less than for the same period of the worst year (1956) of the worst drought recorded (1950's) in the area. The 1950's drought, however, was not characterized by significantly below normal amounts of rainfall in any one year, as occurred in the first part of 1984, but rather by five consecutive years of below normal rainfall.

Of the approximately 23 inches of average annual rainfall that occurs in the area of the two potential reservoir sites, only about 4.18 inches, or 18 percent runs off the land, either in the form of direct runoff or

FIGURE 2.0-3

AVERAGE MONTHLY PRECIPITATION



springflow discharge. Almost 19 inches, or 82 percent of the average annual rainfall, is lost to evaporation, consumed by plants, or infiltrates into the deep layers of the underlying rocks. Within the recharge zone, however, the average annual runoff is only 0.62 inches. Stream leakage and recharge to the Edwards Aquifer accounts for the difference in the recorded runoff.

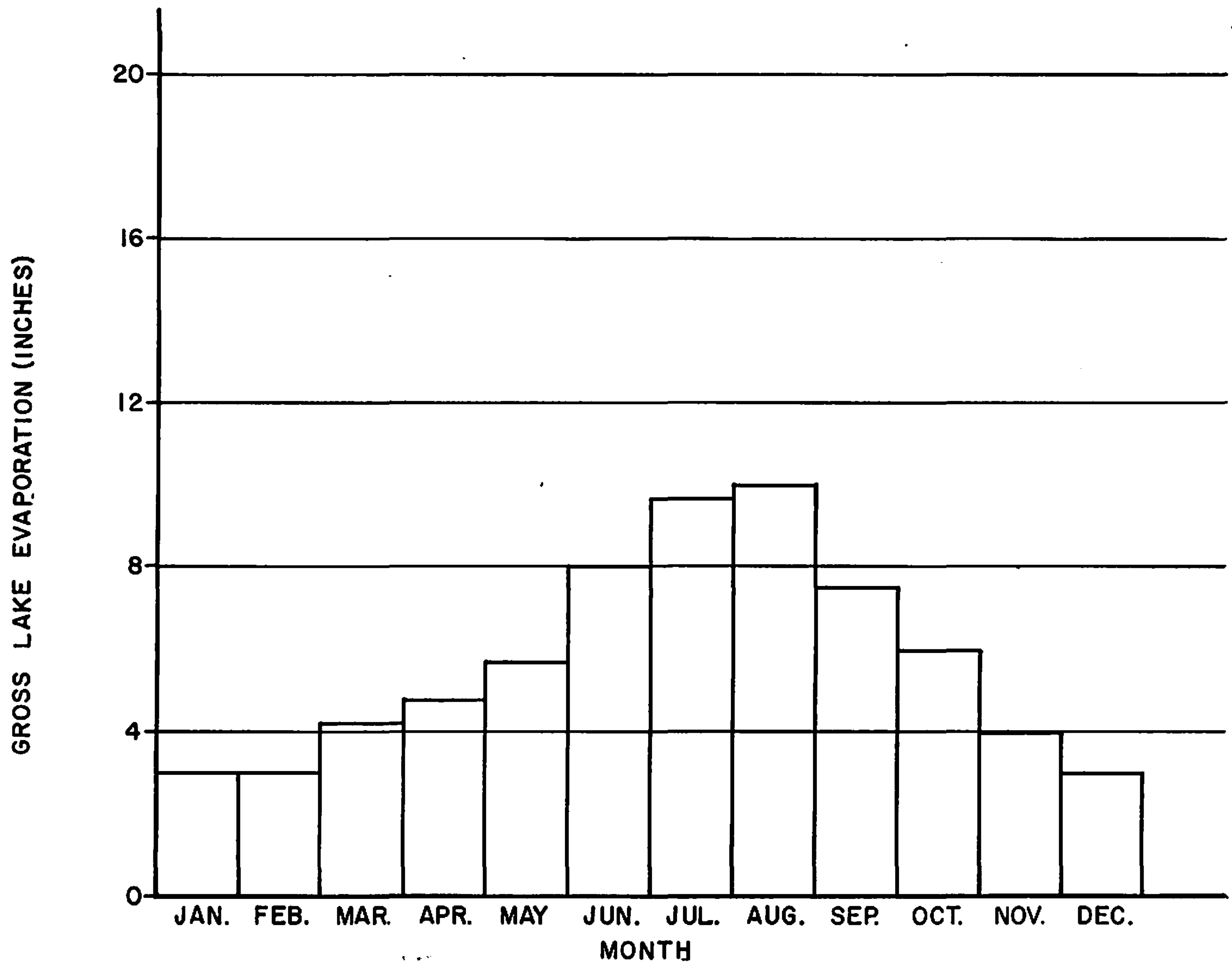
As indicated above, evaporative losses in the area of the potential reservoirs can be very large. The average annual gross lake evaporation, the total amount of evaporation that would take place from a lake surface, for Uvalde County is 69 inches (of water). The average monthly rate of evaporation, which parallels the average monthly temperature for Uvalde County, is shown in Figure 2.0-4. Net evaporation, used for the reservoir operations analyses described later, is equivalent to gross lake evaporation less the effective rainfall.

The geology and physiography of the two sites differ only slightly. The Frio River site is characterized by a flat alluvial valley floor, about one-quarter to two-and-a-half miles wide, and by steep valley walls. Typically, topographic relief in the area is on the order of 300 to 400 feet. The alluvial valley floor consists of limestone, dolomite, and chert gravel and sand, silt, and clay. The alluvium is predominantly a Quaternary terrace deposit through which the Frio has cut downward to the underlying bedrock. Modern-day alluvium, consisting mostly of eroded terrace material is scattered along the river channel.

Rocks exposed in the river channel and on the valley walls belong to the Glen Rose Formation and to the Salmon Peak and the Devils River Formations, which in this area are undivided (Barnes et al, 1974). The Glen Rose Formation consists of alternating beds of fossiliferous limestone, dolomite, and marl, a soft, chalky limestone. The limestone is yellowish-gray to light gray and very fine-grained. The dolomite beds are also yellowish brown and fine-grained, and can be distinguished from the limestone beds by their "sugary" texture. The Glen Rose is Cretaceous age and is the oldest

FIGURE 2.0-4

AVERAGE MONTHLY GROSS LAKE EVAPORATION



geologic unit exposed in the area of the reservoir site. The part of the Glen Rose that is exposed is the upper part, which tends to be less fossiliferous, thinner bedded, more dolomitic, and less permeable than the lower part.

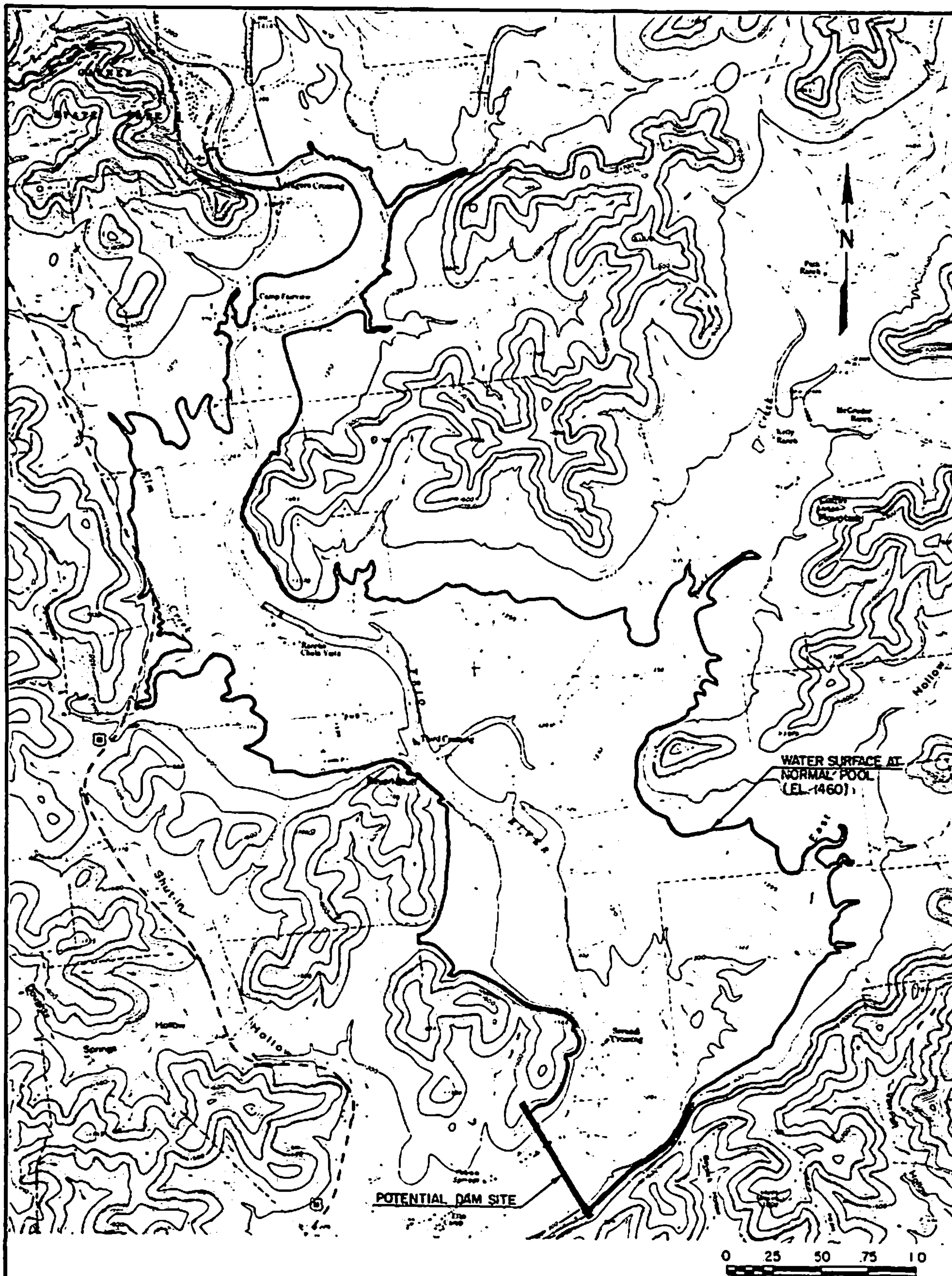
The overlaying rocks of the undivided Salmon Peak and the Devils River Formations, also Cretaceous age, consist of light gray, fossiliferous, hard, nodular, cherty limestone. This geologic unit, although called by different names is equivalent to the Edwards Formation and the rocks comprising the Edwards Aquifer.

At the Dry Frio site, the terrace gravels are not as wide, and the valley is narrower. The rocks exposed in the river channel and along the valley walls are the same, but there is much less upper Glen Rose exposed at the Dry Frio River site. Topographic relief at the Dry Frio site is approximately the same as at the Frio site.

Except on the alluvial valley terrace deposits, soil at both sites are thin and stoney or absent. Most of the valley walls consist of thin, patchy soils, colluvium (eroded material moving down slope), or rock. Ground cover on the valley walls consists of sparse grasses, weeds, and dense juniper (cedar). The valley walls can be used only for grazing sheep and goats. Soils on the alluvial terraces are locally fertile and deep enough to be farmed; corn and cotton are the principal crops. Farmland is not extensive at either site, however; and most of the flat land is used for rangeland, home sites, or recreation. Bald cypress, pecans, and oaks are abundant along the river channels.

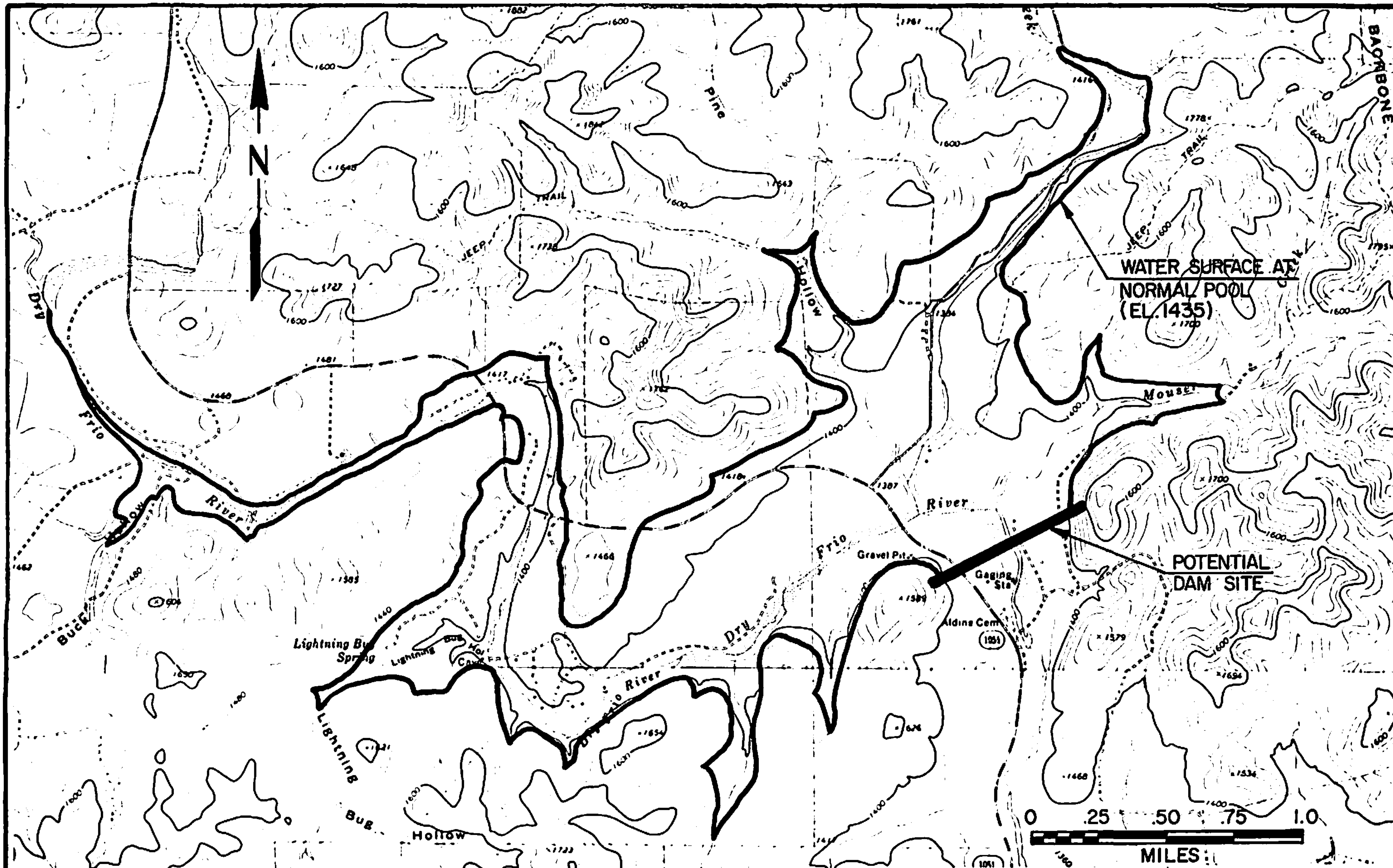
Development along the Frio River is much more extensive than along the Dry Frio River. Although both rivers are scenic, the Frio River is more popular. Garner State Park lies near where the upper end of the Frio River reservoir would occur. Between the potential dam site and the park, there are numerous recreational resorts with cabins and/or provisions for trailers or tents. Construction of first and second homes has increased and a significant amount of the valley has been subdivided into lots for new housing. Figure 2.0-5 shows the limits of inundation due to the conservation pool of the potential Frio River site.

Development in the Dry Frio River Valley is sparse. Between the possible dam site and the upper end of the potential reservoir at Reagan Wells there are few residences and no recreational resorts. Reagan Wells is a small community with only one paved road through it. A Baptist encampment is located in Reagan Wells. Figure 2.0-6 shows the limits of inundation due to the conservation pool of the potential Dry Frio River site.



POTENTIAL FRIO RIVER SITE

FIGURE 2.0-5



POTENTIAL DRY FRIO RIVER SITE

FIGURE 2.0-6

3.0 HYDROLOGIC EVALUATION

A hydrologic analysis of the two potential reservoir sites on the Frio and the Dry Frio rivers was performed to provide a basis for evaluating the feasibility of constructing a storage/release facility to artificially recharge the Edwards Aquifer. Typically, historic records with or without adjustment are used in such an analysis as a means of projecting future inflow conditions and evaporative losses. Information required to perform the analysis includes:

- Historic streamflow records for gages at or near the potential reservoir sites.
- Historic measurements of net evaporation in the area, i.e. gross evaporation from a lake, less rainfall.
- Stage (elevation of the water surface), surface area, and storage volume relationships for the potential reservoir sites.
- Projected reservoir demands.
- Anticipated reservoir operating rules.

The above information was assembled and developed as described in the following sections. Behavior of the reservoirs was simulated using a digital computer program RESOP II (Browder, 1978).

3.1 STREAMFLOW RECORDS

The two potential reservoir sites are located at or near streamflow gaging stations operated by the U.S. Geological Survey (USGS). The reservoir site on the Frio River is approximately 2.5 miles upstream of Gage No. 08195000, "Frio River at Concan, Texas." The period of record for this gage is from October 1923 through September 1984. (USGS gage records are reported for water years that correspond to the federal fiscal years that commence on October 1 and end on September 30.) The reservoir site on the Dry Frio is near Gage No. 08196000, "Dry Frio River near Reagan Wells, Texas." The period of record for this gage begins in September 1952 and continues through September 1984. Thus, there are 62 calendar years of record for the gage on the Frio River and 33 calendar years of record for the gage on the Dry Frio River.

To provide a common basis of comparison between the two potential reservoir sites, the record for the Dry Frio gage was extended to correspond to the same period of record as the Frio River gage. Because net evaporation data are only available starting in January 1940, as will be discussed in Section 3.2, the period of record for the Dry Frio River gage was extended back only to January 1940.

Three different methods were tested for extending the streamflow record for the Dry Frio River:

- Ratio of mean annual flows
- Monthly correlation analysis
- Monthly stochastic analysis

The ratio of the mean annual flows method involves the multiplication of the monthly flow of the Frio River for the period January 1940 to August 1952 by the ratio of the average annual flows of the Dry Frio River and the Frio River for the period of common record, i.e. September 1952 through September 1984.

The monthly correlation analysis method uses correlation constants computed for each month in the common period of record as shown in Equation 1 and the monthly values for the Frio River during the missing period to compute the monthly flows for the Dry Frio River:

$$QDF_{i,j} = a_j + b_j QF_{i,j} \qquad (1)$$

where: $QDF_{i,j}$ = Monthly flow in the Dry Frio River for year i and month j;

a_j = Regression constant for month j;

b_j = Regression coefficient for month j; and

$QF_{i,j}$ = Monthly flow in the Frio River for year i, and month j.

The monthly stochastic analysis is similar to the monthly correlation analysis except that a random component is added (Equation 2).

$$QDF_{i,j} = a_j + b_j QF_{i,j} + tS_j \qquad (2)$$

where: $QDF_{i,j}$, a_j, b_j, and $QF_{i,j}$ are defined as above;

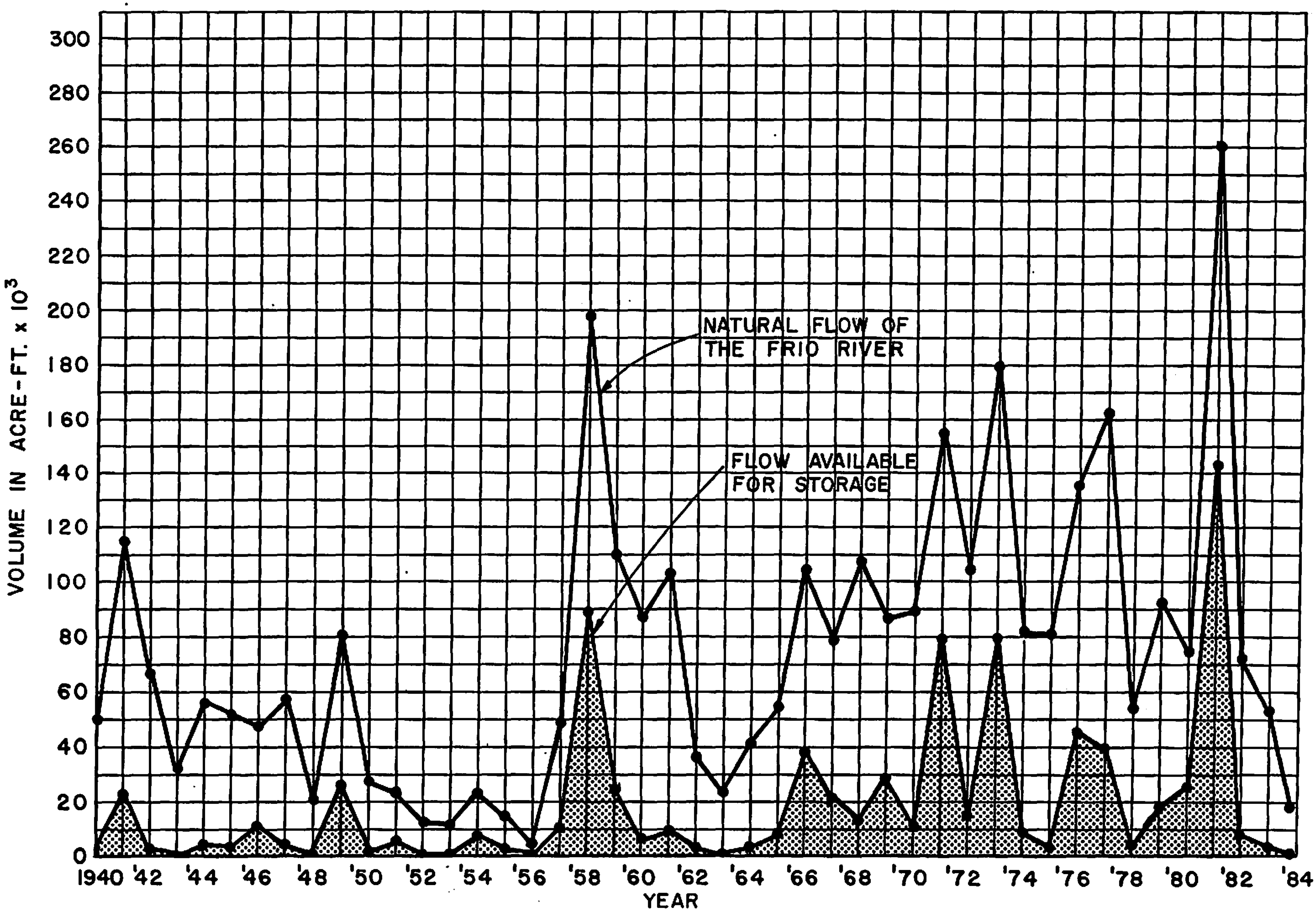
t = a random number with zero mean and unit standard deviation; and

S = the standard error of estimate for QDF in month j.

The method that best preserved the annual means was the ratio of mean annual flows; therefore, this method was selected to extend the record for the gage on the Dry Frio River. The streamflow records for the two sites are presented in Appendix B. Figures 3.1-1 and 3.1-2 are time-history plots of the annual flows at the two sites; further discussion of these figures is presented in Section 3.4.

3.2 NET EVAPORATION RECORD

The net evaporation is the lake surface evaporation less the amount of effective rainfall that occurs on the lake. Net evaporation data from the area are the same for the two sites because of their close proximity and similar physical settings. The net evaporation data were obtained from the Texas Natural Resources Information System (TNRIS). The data are currently available only for the period 1940 to 1981. Net evaporation data for the period January 1982 through September 1984 were computed using recorded pan evaporation rates and rainfall amounts at the National Weather Service Station in Uvalde. Although the streamflow record for the Frio River gage was longer than the net evaporation record, it was decided not to extend the net evaporation record, but to use only the period from 1940 to 1984 for the feasibility analysis. Despite using less than the maximum possible record for simulation of reservoir behavior, the length of record used is still more than forty years. The net evaporation data are contained in Appendix C. A plot of the net evaporation for the two sites is shown in Figure 3.2-1.

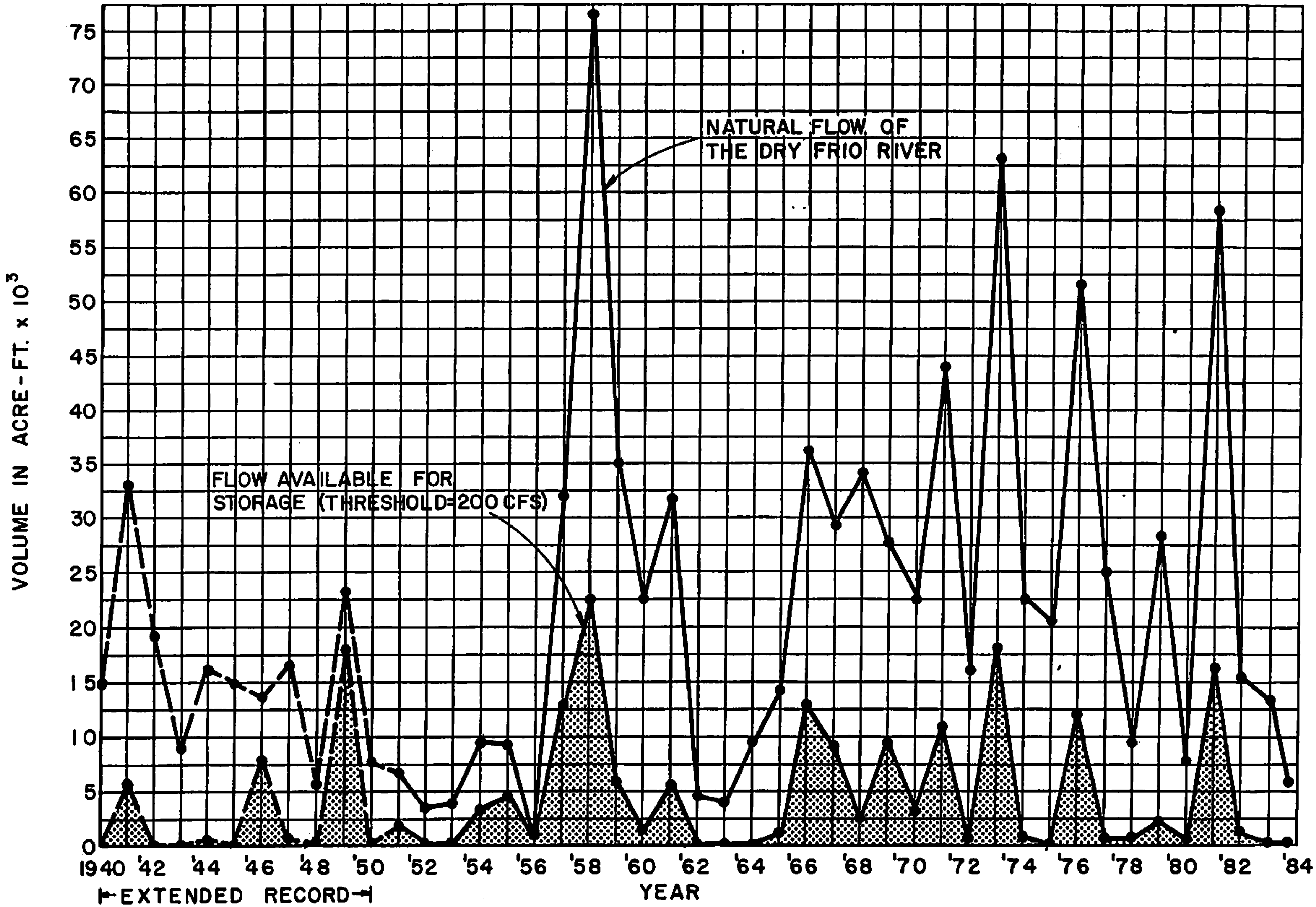


ANNUAL FLOW FRIO RIVER AT CONCAN, TEXAS

FIGURE 3.1-1

SOURCE: TDWR R-239

CAMP DRESSER & MCKEE INC.

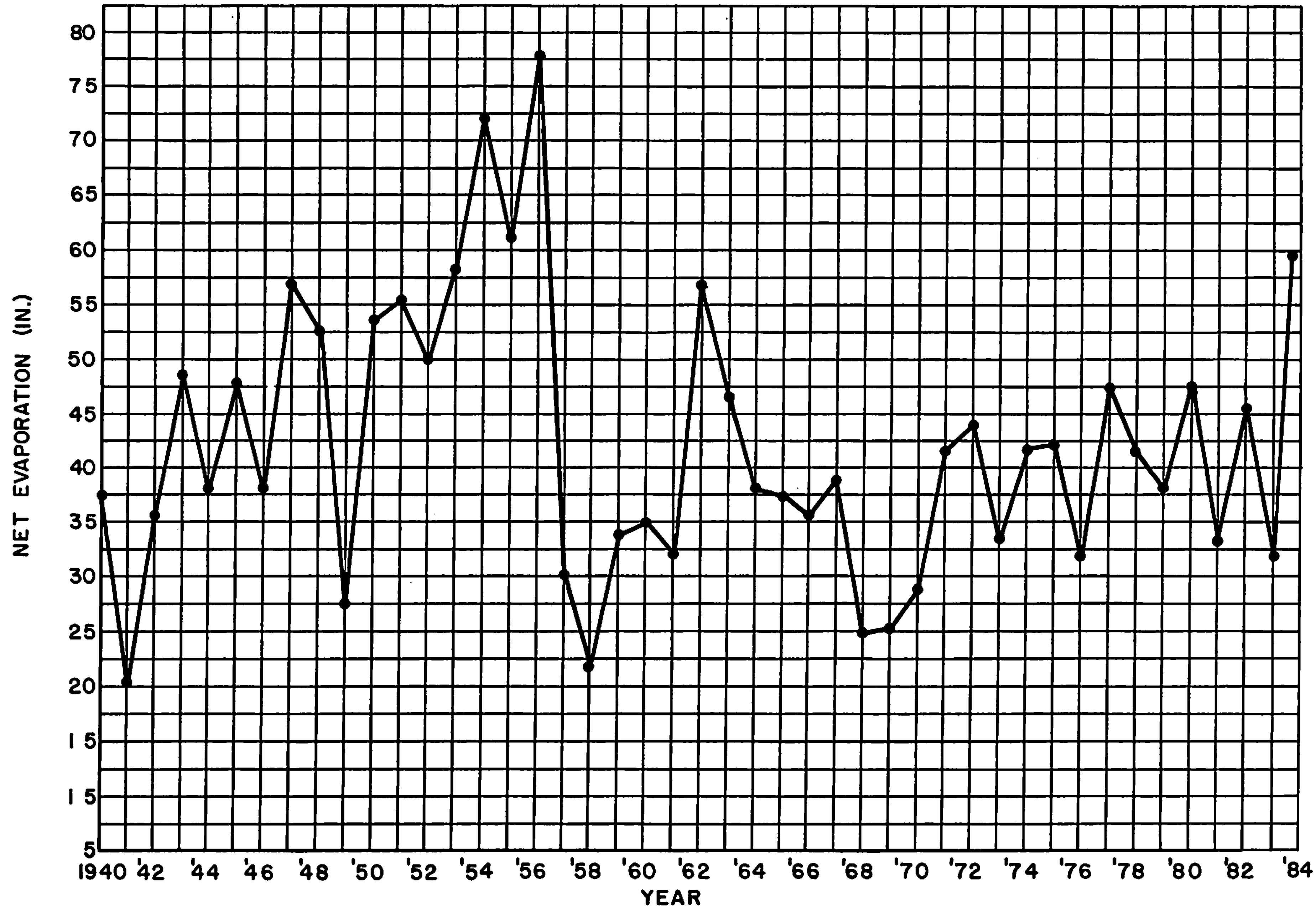


ANNUAL FLOW DRY FRIO RIVER NEAR REAGAN WELLS, TEXAS

FIGURE 3.1-2

SOURCE: TDWR R-239

CAMP DRESSER & MCKEE INC.



NET ANNUAL RESERVOIR EVAPORATION RATES
FIGURE 3.2-1
(SOURCE TDWR R-64)

CAMP DRESSER & MCKEE INC.

3.3 STORAGE - AREA RELATIONSHIP

Storage-area relationships were developed for the proposed reservoir sites. The site on the Frio River is essentially the same as the Concan site evaluated by the U.S. Army Corps of Engineers (1964) and the U.S. Bureau of Reclamation (USBR; 1983). The storage-area relationships used in the computer simulations for the two sites on the Frio and the Dry Frio rivers are shown in Tables 3.3-1 and 3.3-2.

3.4 RESERVOIR OPERATING RULES

Reservoir operating rules are a set of predetermined guidelines established to manage a reservoir. Usually, operating rules are developed with the objective of maximizing power production, water supply, flood control benefits, or recreation. In the case of the storage/release reservoirs being considered in this feasibility study, the objectives are:

- To maintain the natural amount of recharge.
- To store streamflow in excess of natural recharge for later release and recharge during drought periods.

To accomplish these objectives, the operating rules for simulating behavior of the reservoirs are as follows:

- All inflows to the reservoir less than the maximum recharge rate of the river will be released so that natural recharge to the aquifer will not be diminished. The quantity of streamflows in excess of the maximum recharge rate will be stored.
- Water stored in the reservoir will not be released until the water level in the Edwards Aquifer, as indicated in selected observation wells, drops to a given elevation.
- When releases from the reservoir are called for to maintain the water level in the aquifer, the rate of release will be at a rate such that the levels in the aquifer should stabilize a a predetermined elevation.
- Releases will continue until the water level in the selected observation well rises above the critical elevation or until the reservoir can no longer meet the demand. (It should be noted that when

TABLE 3.3-1

ELEVATION - STORAGE - AREA DATA
PROPOSED EDWARDS RESERVOIR
ON THE FRIO RIVER

Elevation (ft abv. msl)	Storage (Ac-Ft)	Area (Ac)
1,240	0	0
1,250	1,250	25
1,260	2,500	90
1,265	3,500	140
1,270	4,500	200
1,275	6,000	270
1,280	7,600	370
1,285	11,000	470
1,290	14,000	580
1,295	14,000	580
1,300	23,000	840
1,310	33,000	1,140
1,320	45,000	1,480
1,330	62,000	1,920
1,340	83,000	2,450
1,350	110,000	3,000
1,360	146,000	3,620

TABLE 3.3-2

ELEVATION - STORAGE - AREA DATA
PROPOSED EDWARDS RESERVOIR
ON THE DRY FRIO RIVER

Elevation (ft abv. msl)	Storage (Ac-Ft)	Area (Ac)
1,360	0	0
1,370	1,200	145
1,375	2,500	210
1,380	3,700	290
1,385	6,500	390
1,390	8,000	500
1,395	12,000	610
1,400	16,000	730
1,405	20,000	840
1,410	26,000	970
1,420	37,500	1,230
1,430	52,500	1,510
1,440	68,000	1,870
1,450	89,000	2,310
1,460	113,500	2,780
1,470	144,000	3,270
1,480	180,800	3,780

artificial recharge begins, the water level in the selected observation wells should stabilize near the critical elevation. Therefore, when the historical record shows a rise in the groundwater level, it was assumed that releases from the reservoir would be stopped.)

The USGS (1983) has estimated that the maximum recharge rate for the Frio River is 200 cubic feet per second (cfs). Hence, this is the streamflow above which water is retained to fill the reservoir. The maximum rate of recharge estimated by the USGS for the Dry Frio is higher, approximately 400 cfs. Only flows in excess of 400 cfs would be retained by a reservoir on the Dry Frio. Because the Dry Frio River basin is much smaller than the Frio, however, a storage threshold of 200 cfs was also examined. Figures 3.1-1 and 3.1-2 graphically depict the flows that would go into storage and the flows that would continue to naturally recharge the aquifer. Appendix D contains the streamflow records adjusted for the storage threshold value. It is interesting to note the large number of months in which no water could be stored in the reservoirs.

Release rates of 200, 300 and 400 cfs were simulated from both reservoirs, to combat drought conditions tested. The release rate of 200 cfs is approximately half the recorded average municipal water use in the six counties of the district for 1980, but is the estimated rate of maximum natural recharge of the Frio River. The rate of 400 cfs is slightly greater than the average municipal water use for the six counties in the district for 1980 (and is the estimated maximum rate of natural recharge for the Dry Frio River), and would contribute significantly toward halting declines in the water level in the Edwards Aquifer. A release rate greater than 200 cfs from the Frio River site, however, would require transfer of some of the releases to the Dry Frio River, or other means of augmenting natural recharge from the Frio River.

As the levels in the aquifer decline, the releases from the storage-recharge facility would begin. At first small releases combined with natural recharge from the other major river basins, Nueces, Sabinal and Medina Lake, would be adequate to halt the decline in water levels. If the drought were severe, though, measured either in the total deficit of rainfall or the duration of the deficit, the releases from the storage-recharge facility would begin to become the major source of water for the aquifer. By analyzing the reservoirs at the three release rates, the ability of the reservoir to supply a portion or all of the required recharge can be assessed.

3.5 RESERVOIR DEMAND

The demands placed on most reservoirs show monthly or annual variations, and perhaps slow annual growth. The demand (releases) from a storage/release facility on either the Frio River or the Dry Frio River will be aperiodic, occurring only once or twice over a number of years. The majority of the time, there will be no demand on the reservoirs. Releases will be made on a regular basis only to balance stream inflows less than the storage threshold. Leakage and evaporation will be the only normal losses from the system. Releases for recharge during a drought, though, will constitute a major drain on the reservoir, perhaps entirely depleting the water in storage.

To assess the effectiveness of the storage/release structures, the duration over which releases would be required was determined from a plot of aquifer water levels measured in Well No. 68-37-203 and Well No. 68-37-204. These wells are located on Fort Sam Houston in Bexar County. Well No. 68-37-204 was measured by the USGS on a weekly basis from November 1932 to June 1963. Measurement of Well No. 68-37-203 began in February 1962; this well is currently being measured on a daily basis. A plot of the water level measurements from these two wells, converted to elevation above mean sea level, is presented in Appendix E. Figure 3.5-1 contains the same information in a considerably reduced format.

For the period of record used in simulating reservoir operations (1940-1984), the water level in the aquifer dropped below the critical elevation (625 feet) four times in the two index wells; Well No's. 68-37-204 and 68-27-203. The first two times were from May through August and again in

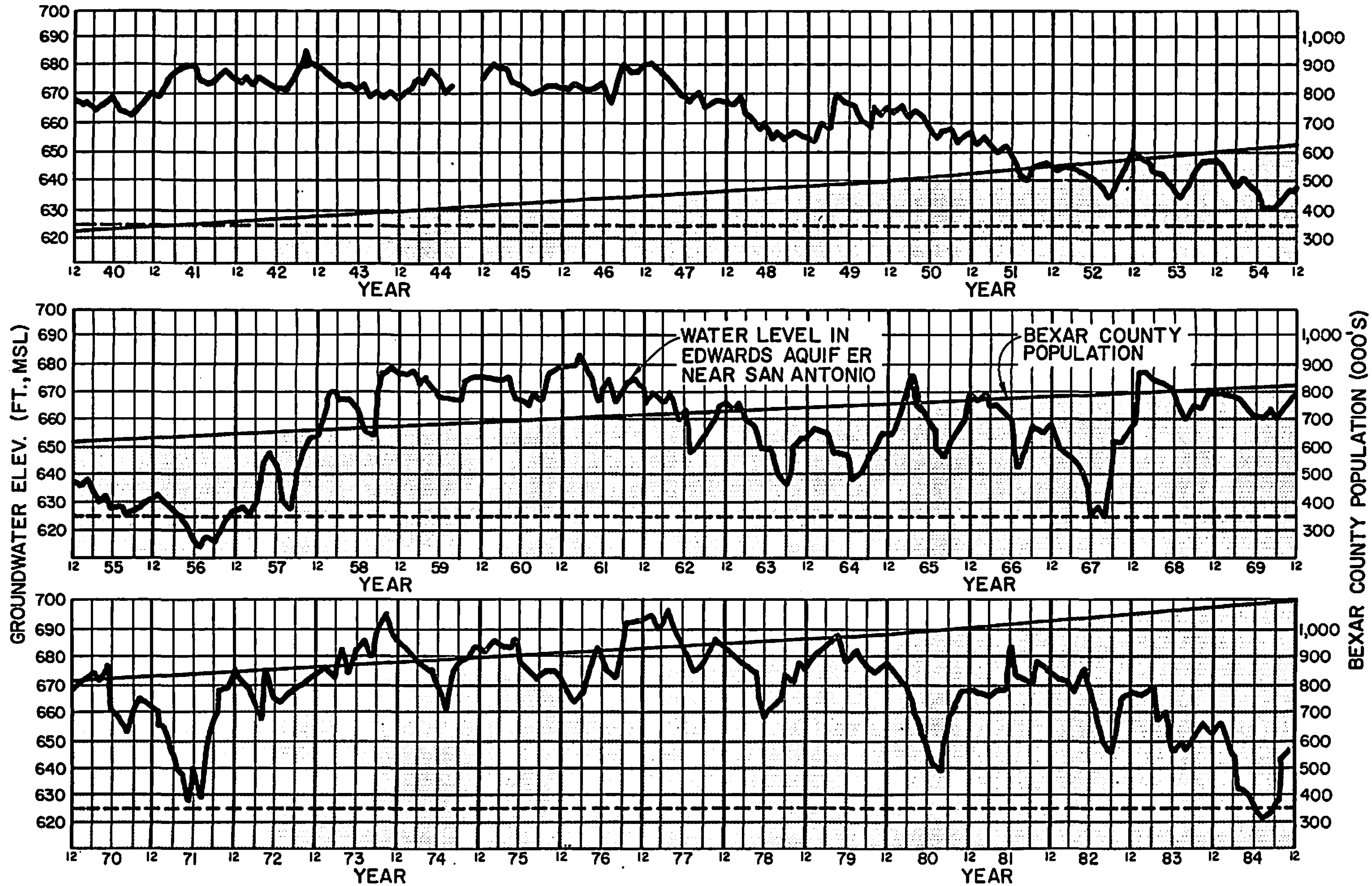


FIGURE 3.5-1

WATER LEVEL ELEVATIONS - EDWARDS AQUIF ER IN BEXAR CO.

October of 1956. The third time was a two week period in August 1967 and the fourth was for almost two months during the summer of 1984. During the remaining part of the 45-year period, there would have been no demand on the reservoir.

These drops in aquifer water level elevation would require that recharge from the potential reservoir be released from May through August and October of 1956, two weeks in August of 1967 and portions of June and August and all of July of 1984. The time during which releases were made would be shorter than the total time the water levels in the index wells were below the critical elevation; once recharge was begun, water levels in the aquifer should stabilize at or near the critical elevation -- 625 ft. Thus, if the historical record shows increases in elevation even though the water level remains below 625 ft. elevation, then with the recharge project it was assumed that the water level would move above the 625 ft. elevation and artificial recharge would cease. Whether the water recharged reached potential users was not considered.

3.6 RESERVOIR OPERATIONS ASSESSMENT

Reservoir operations analysis is essentially an accounting procedure to track the mass balance of the reservoir system. Inputs to the reservoir are streamflow and direct precipitation. Outputs from the reservoir are spills in excess of conservation storage, leakage, evaporation, and releases from or drafts on the water in storage. When inputs exceed outputs, storage in the reservoir is increased and the reservoir water level rises up to the maximum normal pool level. (For the purposes of this discussion, the benefits of flood control are ignored.) When outputs exceed inputs, storage in the reservoir must decrease and the water level falls.

As described previously, in simulating the behavior of a reservoir, historic streamflow records are used as though they are representative of the types and the pattern of flows that can be expected in the future after the reservoir is built. The longer the period of record used, the greater the assurance that the streamflows are indeed representative of the flows that can be expected.

Historical streamflow data are used to simulate reservior operation. For the purpose of the simulation, the reservoir is assumed to be built at the beginning of the period of record (1940). Typically, the practice in Texas is to assume that the reservoir is full at the beginning of the simulation period and no consideration is given to filling the reservoir. To be theoretically rigorous, though, the amount of water (mass) in storage at the beginning of the reservoir simulation period should be approximately the same as the amount of water in storage at the end of the simulation period. If the reservoir is assumed to be full at the beginning of the simulation period, and is less than full at the end of the simulation period, the quantity of water removed from storage has been effectively used to supplement streamflows and to create an artificially high reservoir yield. The larger the reservoir volume relative to the average annual inflows, the more significant this artificial supplement is. Similarly, if the reservoir is assumed to be empty at the beginning of the simulation period, yet contains some water in storage at the end of the simulation period, then some of the inflow that would otherwise be available to meet water demands has been used simply to increase storage.

Thus, to perform a reservoir operations analysis, the volumes in storage at the beginning and end of the simulation period should be approximately equal. To compute this storage volume, an initial storage volume is assumed and the storage at the end of the simulation period is determined. This end storage volume is then used as the initial storage volume, and additional iterations made until reasonable correspondence between the beginning and ending storage volumes is achieved. Usually, only two or three iterations are needed.

The information and assumptions described in the previous sections provided the input to the reservoir simulation model RESOP II. This model is the same model used by TDWR. Slight modifications to the model were necessary however, to simulate the effects of periodic releases from reservoirs on the Frio and Dry Frio Rivers and to assess the effect of different amounts of water in storage in the reservoir at the start of the simulation period.

4.0 DISCUSSION

The data and the procedures described in Section 3.0 were used to simulate the behavior of the potential storage/release reservoirs on the Frio and the Dry Frio Rivers. Ten reservior simulations were performed. Six reservoir simulations were performed for the potential storage/release reservoir on the Frio River. The simulations with recharge release rates of 200, 300 and 400 cfs were performed using a storage threshold of 200 cfs each with and without considering the effects of weather modification. Four simulations were made for the potential storage/ release reservoir on the Dry Frio using a storage threshold of 200 and 400 cfs and also with and without weather modification.

Based on historical water level records for the Edwards Aquifer and current demands for groundwater from the aquifer, the release from the storage-recharge reservoir would be required for a period of 154 days or five months. Examination of the capacity curves for the two potential reservoir sites reveals that only if a reservoir on the Frio River were completely full at the beginning of the release period, could it yield a release rate of 400 cfs for five months. For a release rate of 200 cfs the reservoir would have to be at least half full. Although a reservoir on the Frio could fill to these levels, it is unlikely that it would be full when releases became necessary such as after some period of below normal streamflows.

A reservoir on the Dry Frio would never be able to meet the demand of 400 cfs for 154 days. The maximum storage achieved at the Dry Frio site was on the order of 60,000 ac-ft, or less than one half the required amount of water. The Dry Frio Site does have enough storage when it is completely full to supply 200 cfs for the five-month drought; however, it is unlikely that the reservoir will be full when the water is required.

Based on the historical streamflow, precipitation pan, evaporation, and water levels in Well Nos. 68-37-203 and 68-27-204, a reservoir on the Frio River would have been able to supply a demand of 400 cfs for only 63 days of the total of 154 days in 1956 in which water levels in the Edwards

Aquifer were below 625 feet in elevation. This is approximately two months of the more than five months that water levels in the aquifer were low that year. At a recharge release rate of 300 cfs the Frio River site could supply water for 84 days; at a demand of 200 cfs the reservior could provide water for 123 days.

A reservoir on the Dry Frio, with a storage threshold of 200 cfs was able to yield a recharge flow of 400 cfs for only 28 days in 1956 or less than one month of the four months that releases were needed. A storage threshold of 200 cfs, however, is only one-half of the potential maximum recharge rate of the Dry Frio to the Edwards Aquifer and thus, reduces the amount of natural recharge to the aquifer. If the operating rules of the reservoir called for a storage threshold of 400 cfs, a reservoir on the Dry Frio would be able to provide a yield of 400 cfs for only fourteen days of the four months recharge was needed in 1956.

For the 1967 drought, a reservoir at either site would have been able to meet the required demand. Only two weeks of artificial recharge would have been called for, and the simulated amounts of water in storage at both reservoirs would have been sufficient.

For the 1984 drought, the reservoir on the Frio River would have been able to supply 400 cfs for all 52 days when water was needed; thus, it also would have been able to supply demands of 300 and 200 cfs. The Dry Frio site also could have yielded a release rate of 400 cfs for all 52 days of the 1984 drought but would have been empty after the last day of release.

Considering the three drought periods together, a total of 220 days of artificial recharge would have been desirable. A reservoir on the Frio River could have supplied 400 cfs for only about 130 days, or slightly more than one half the time it was actually needed. For a yield of 300 cfs, the site could have supplied the demand for 150 days, and for a release of 200 cfs approximately 189 days could have been available from the Frio River Site. A reservoir on the Dry Frio could have met the demand of 400 cfs less than 37 percent of the time it was required. This information is summarized in Table 4.0-1.

TABLE 4.0-1

SUMMARY OF RESERVOIR SIMULATION RESULTS
400 CFS DISCHARGE

Reservoir	Total No. Days 400 cfs Required	Total No. Days 400 cfs Supplied
Frio River	220	129
Frio River w/ wea. mod.	220	131
Dry Frio River 200 cfs threshold	220	94
Dry Frio River 200 cfs threshold w/wea. mod.	220	96
Dry Frio River 400 cfs threshold	220	80
Dry Frio River 400 cfs threshold w/wea. mod.	220	82

The impact of proposed weather modification efforts on the feasibility of constructing storage/release reservoirs on the Frio and the Dry Frio Rivers was also investigated. Inflows were increased five percent as an estimate of the amount of increase in streamflow that could be reasonably expected. The increase was added to all flows because of the uncertainty of what the actual effect of weather modification would be. The increase in streamflows resulted in an increase of approximately two days of storage at both sites for all cases considered. It is doubtful, however, that weather modification would have any noticeable effect on storage in the two potential reservoir sites. Weather modification will have the greatest impact on the lower flows of the stream including base flows. Ideally, a weather modification program would not increase flood flows. Yet, under the operating rules investigated, only flows in excess of 200 cfs on the Frio River or either 200 cfs or 400 cfs on the Dry Frio River would be retained in the reservoirs.

For the historical period of record, reservoirs on both the Frio and the Dry Frio Rivers were able to refill after each of the 1956 and 1967 drought periods. Data were not available beyond September 1984 to determine if the reservoirs would have refilled; but considering the magnitude of flooding in the Fall of 1984, it is safe to assume that the reservoirs would have been at least 50 percent full at the beginning of 1985. Figure 4.0-1 displays time-histories of the water levels in the potential reservoirs, without considering the effects of weather modification. Both reservoirs return to a fifty percent full condition in less than 18 months after the drought period 1950 - 1956. During the historical period of record, water levels in the reservoir on the Frio River averaged approximately 1,350 ft in elevation, or 75 percent of the maximum full condition at the site, neglecting requirements for flood storage. In contrast, the water levels in the Dry Frio averaged 1,419 ft in elevation, only 20 percent of the maximum full condition at the site. These percentages are based on retaining the maximum possible pool at each site. In that the simulated maximum storage achievable at the Dry Frio Site is only 60,000 acre-feet, a lower conservation pool (1,435 ft elevation) would be adequate. If the conservation pool were at that level, the Dry Frio would average 60 percent full. With a conservation pool at the Dry Frio site of 1,435 ft, the reservoir did not

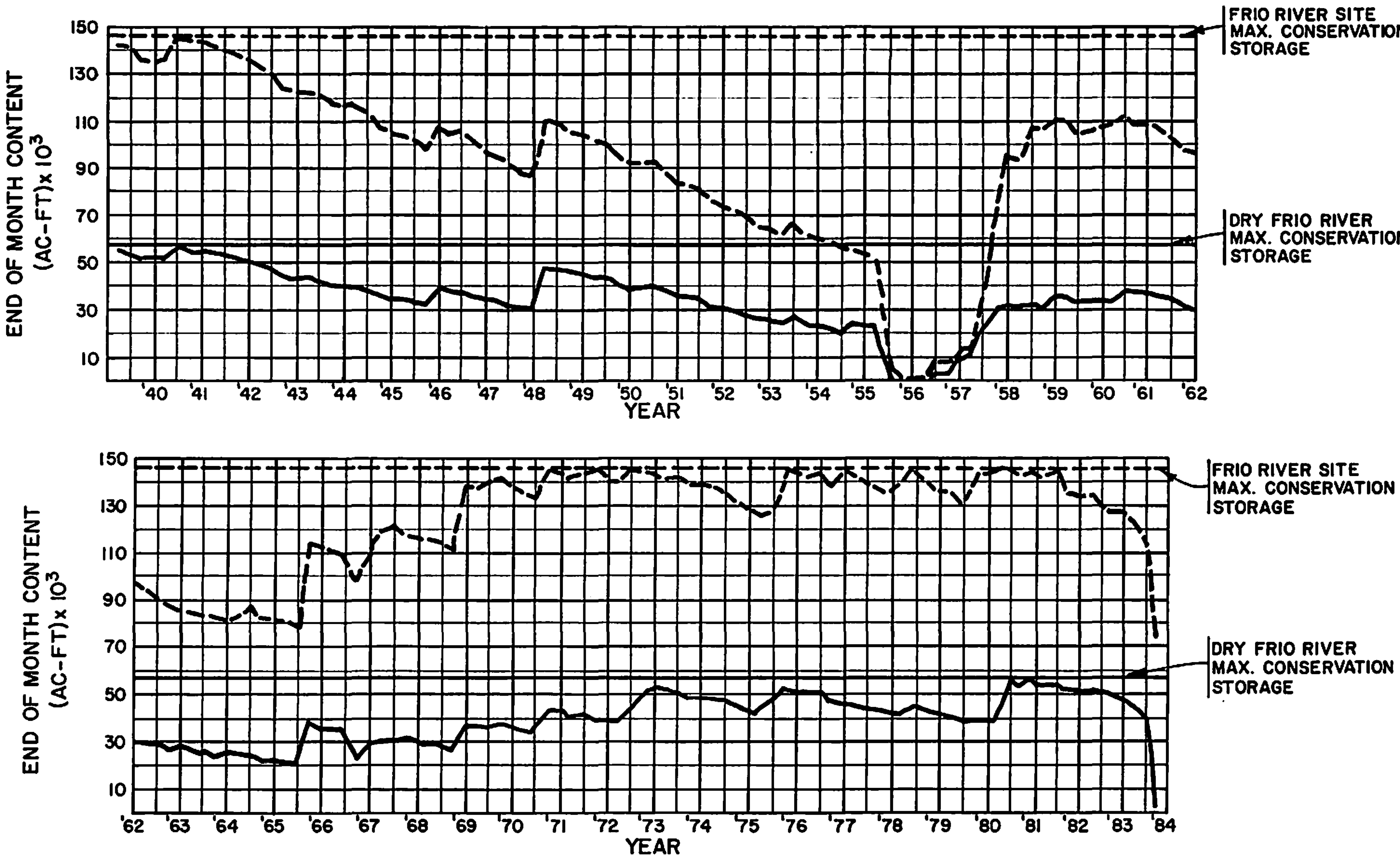


FIGURE 4.0-1

SIMULATED RESERVOIR STORAGE CONTENTS
FRIO & DRY FRIO SITES
(EVERY THREE MONTHS PLOTTED)

overflow the spillway (or "spill") during the simulation with the historical record. The reservoir at the Frio site spilled in nine years of the 45 years simulated.

The ratio of acres of drainage basin to acre-feet of storage in the Frio River is 1.78. At the lower conservation pool elevation (1,435 ft) at the Dry Frio River site, the ratio of acres of drainage basin to acre-feet of storage is 1.25. If the largest possible reservoir were constructed on the Dry Frio, the ratio of acres of drainage basin to acre-feet in storage would be only 0.41.

Assessment of the actual effects of artificial recharge on water levels in the Edwards Aquifer requires modeling the behavior of the aquifer with the artificial recharge as a component. This was not done. There are two existing regional groundwater models for the Edwards Aquifer. The one constructed by TDWR uses annual time steps (computes aquifer behavior only on an average annual basis) and would be relatively insensitive to the inputs from an artificial recharge facility that likely could yield water for only two months of the year. The other model, developed by the U.S. Geological Survey is more sensitive; but currently, it is not yet fully calibrated (Bob Maclay, 1984, personal communication), and thus, is not available for use. Furthermore, it is intended as a research tool and would require modification to investigate the affects of artificial recharge on the aquifer.

5.0 CONCLUSIONS

5.1 SUMMARY OF RESULTS

The results of the hydrologic analyses of potential storage/release sites on the Frio and the Dry Frio rivers show that, under the proposed operating rules and considering the characteristics of the sites, neither site is capable of yielding enough water during a drought, especially a prolonged drought such as occurred in the mid 1950's, to halt declines in groundwater levels in the Edwards Aquifer through release and recharge of those waters. For the purposes of this investigation, a water level of 625 feet elevation in the observation wells at Fort Sam Houston was defined as critical and the lowest elevation to which the water levels in the Edwards Aquifer should be allowed to decline. It is estimated that current average rate of withdrawal from the Edwards Aquifer for municipal purposes in the six counties of the District during 1980 was approximately 400 cfs. Recharge of this amount of water would contribute significantly to reducing water level declines in the Edwards Aquifer during a drought.

Of the two sites investigated, however, the Frio River site is by far the more feasible for construction of an artificial recharge facility. Based on historical streamflows and at release rates of 200, 300 and 400 cfs, the Frio site had approximately 123, 84 and 63 days, respectively, of water in storage during the most critical drought of record (1956)--a drought, however, that led to water levels in selected observation wells in the Edwards Aquifer falling below critical levels (625 feet) for a total of 154 days. By extrapolating the data from the reservoir simulations, a release rate of only 150 cfs could have been sustained for all 154 days of the 1950's drought. The storage threshold for the Frio River, the maximum rate at which leakage from the river bed recharges the Edwards aquifer, is 200 cfs.

The site on the Dry Frio River could provide a yield of 400 cfs for a maximum of only 28 days, and only if the storage threshold for the reservoir was held to 200 cfs, which is less than maximum recharge rate of 400 cfs for the reach of the Dry Frio crossing the Balcones Fault zone. By extrapolating the data, the Dry Frio River site with a storage threshold of 200 cfs could have supplied a maximum of 70 cfs and with a storage threshold of 400 cfs a maximum of only 30 cfs during the 1950's drought. These release rates are considerably less than the rate of recharge necessary to halt decline in the Edwards Aquifer during a drought. From a hydrologic point of view, a facility on the Dry Frio can only be considered feasible if an alternative source of water is found in addition to the natural yield of the basin.

5.2 ADDITIONAL FACTORS AFFECTING THE HYDROLOGIC FEASIBILITY OF THE STORAGE/RELEASE RESERVOIRS

During the 45-year historic period for which simulations were performed for the proposed storage/release facilities, releases were needed only four times; two of those times being in one year. As demands on the groundwater resources in the District grow, intervals of less than normal rainfall and, thus, reduced recharge will become more significant. The available reserves will be reduced, causing small shortages to become more critical. In other words, in years for which conditions are less than a true drought, but in which rainfall is still less than normal, water levels in the aquifer may fall to critical elevations more frequently.

This is already beginning to occur, as can be seen in the water level records for Observation Wells 68-37-203 and 68-37-204 (Figure 3.5-1). During the last few years, fluctuations in the water levels have increased in magnitude and frequency as the demands on the aquifer have increased relative to the amount of recharge. Thus, the frequency that an artificial recharge facility might be needed is likely to increase in the future even though the facility will be incapable of yielding all the water needed on every occassion. Increasing the frequency that the water stored in the reservoir is needed affects the feasibility of the project both by increasing the value of the water and the importance of a low ratio of storage to average annual runoff and by decreasing the unit cost of the water.

The value of water and the feasibility of an artificial recharge project are also affected by the pattern and type of water use. Typically, municipal and industrial demands are less per unit value of output than agricultural demands. This means that municipal and industrial consumers can afford to pay more per unit of water than agricultural users. Although conservation efforts by municipal and industrial users can lead to savings of water and reductions in demands, ultimately municipal and industrial demands are less elastic than agricultural demands. If a farmer can draw no more irrigation water, it is a personal disaster and, perhaps, a regional economic disaster. If a municipality can draw no more water for its public supply, specifically drinking water, water for sanitary purposes and fighting fires, the scope and consequences of the disaster are far larger and more critical. Thus, the feasibility of constructing an artificial recharge facility must be judged not only in the light of increasing total demands but the types of demands and the future value of water.

In addition to drought mitigation, construction of a storage/release reservoir on the Frio River may have certain other benefits. These have not been investigated, but include potential flood control and recreational benefits. When empty, the reservoir would provide ample flood control, and even when full, the reservoirs could have some storage allocated for flood control. Recreational benefits also may accrue; however, the occurrence of recreational activities on the reservoir may ultimately hamper use of the water in the reservoir for its intended purpose.

5.3 FUTURE WORK

As indicated above, although neither site is capable of meeting all anticipated demands, from a hydrologic point of view, the Frio site appears to be more feasible than the Dry Frio site for construction of an artificial recharge facility. Several other major issues bear on the overall feasibility of the project, however, and need to be resolved before a committment is made to construct a storage/recharge facility on either the Frio River or the Dry Frio River, but especially on the Frio River. The first of these issues is the water rights issue. The City of Corpus Christi holds extensive water rights in the Nueces River basin, of which the Frio and Dry Frio rivers are a part. Although thus far, Corpus Christi has not been concerned with streamflows above the Edwards Aquifer recharge zone, because these flows were largely "lost" from the stream system and unavailable for storage in Choke Canyon Reservoir or Lake Corpus Christi, the 1984 drought has increased Corpus Christi's awareness of its water situation. A storage/release recharge project, as considered here, would capture much of the flow that would otherwise cross the recharge zone and would undoubtedly attract the attention of officials in Corpus Christi; only flood flows too large for capture would continue to cross the recharge zone.

The water rights issue is very significant and an investigation is necessary to ascertain whether water is available for appropriation, or could be made available, and whether streamflows that cross the recharge area actually reach the Choke Canyon Reservoir or are lost through seepage and evaporation. An important consideration in the water rights issue is that less than ten percent (405 sq mi) of the Choke Canyon drainage area lies above the Frio River site and less than three percent (117 sq mi) lies above the Dry Frio site. The runoff from these areas may not, in fact, contribute to the Choke Canyon Reservior. Furthermore, downstream water rights (except for Corpus Christi) may be seasonal such that the occurrence of peak flows that would fill a storage/release recharge reservoir would not be available to satisfy those rights.

The second major issue, or set of issues, involves the cost of land, socio-economic conflicts, and environmental costs. The area in which water would be impounded on the Frio River is very scenic. Garner State Park would lie within the uppermost parts of the storage pool. Flood flows might temporarily inundate part of the park. From the park downstream to the potential dam site near Concan, there are numerous camps, second homes, and principal residences; these would all be lost. Because of the scenic and recreational value of the Frio River above Concan and the existence of so many recreational facilities, land costs are likely to be high, even if condemnation proceedings are used to acquire the land. No detailed study has been made, but posted asking prices in the summer of 1984 were in the neighborhood of $10,000 per acre. Neglecting flood considerations, the normal pool of a storage/release facility on the Frio River would inundate 3,620 acres. If the advertised land costs are representative, acquisition of the site would cost more than $36,000,000. Construction costs for the facility would be above this figure, and the environmental costs, not all of which can be easily measured in dollars, would also be significant.

Land acquisition costs on the Dry Frio River are unknown, but anticipated to be less than on the Frio River. There has been considerably less development along the Dry Frio River, which will probably reduce the socio-economic conflicts. In addition, the environmental costs are considerably less than for the Frio River.

A third major issue to be considered is that the maximum recharge rate of the reach of the Frio River crossing the recharge zone of the Edwards Aquifer is only 200 cfs. If recharge amounts in excess of 200 cfs are required to halt the decline in groundwater levels, other recharge sites will be necessary. One possibility would be to divert flow from the Frio to the Dry Frio, which has greater recharge capability. The solution to this problem quite likely will affect the cost of constructing an artificial recharge facility and, thus, the cost of the water. Furthermore, there must be some assurance that the current maximum rates of recharge to the aquifer from either stream can be sustained.

Finally, the issue of potential leakage from the reservoir sites must be addressed. If leakage ultimately reaches the Edwards Aquifer, it is not "lost", but likely would not contribute to recharge of the aquifer when it is needed most. Furthermore, leakage would reduce the available supply in storage for release, perhaps rendering the project infeasible.

APPENDIX A

LITERATURE CITED

Appendix A

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APPENDIX B

STREAMFLOW RECORDS FOR THE FRIO AND DRY FRIO RIVERS

TABLE B-1

FRIO RIVER AT CONCAN, TEXAS (D.A. = 405 sq.mi.)
MONTHLY VOLUME (AC - FT)

Gage Station Number	Calendar Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Volume (acft/yr)
0819500	1940	2,550	2,870	2,770	4,450	6,890	5,460	6,590	2,950	2,210	1,830	2,480	4,060	45,110
	1941	3,630	4,240	5,350	15,070	20,690	8,880	6,050	9,480	11,600	13,420	9,570	6,910	114,890
	1942	5,220	4,120	3,940	5,670	7,330	3,910	3,420	3,450	9,950	9,040	6,510	4,950	67,510
	1943	4,170	3,150	3,280	3,550	3,010	3,420	2,480	1,370	1,570	1,850	1,730	2,470	32,050
	1944	3,140	3,010	5,550	4,660	6,460	7,360	3,730	4,510	5,620	4,650	3,360	4,010	56,060
	1945	8,340	6,620	6,360	7,050	5,880	3,260	2,110	1,240	972	3,760	2,820	3,230	51,642
	1946	2,820	2,690	2,500	2,260	3,060	2,160	1,730	877	1,660	17,150	6,320	4,240	47,467
	1947	6,510	5,580	5,140	5,140	6,110	9,750	6,590	3,420	2,310	1,930	2,220	2,690	57,390
	1948	2,490	2,470	2,440	2,010	1,750	1,900	1,730	842	834	1,170	1,200	1,420	20,256
	1949	1,780	27,720	10,960	8,190	7,080	5,120	3,170	3,140	3,280	3,730	3,190	3,310	80,670
	1950	3,430	3,220	3,440	2,860	2,990	2,570	1,790	1,430	1,360	1,460	1,160	1,530	27,240
	1951	1,290	1,400	2,030	2,250	7,520	2,600	888	433	2,300	728	984	1,230	23,653
	1952	1,260	1,150	1,410	1,900	2,620	1,610	727	248	91	95	415	1,230	12,756
	1953	1,760	1,320	1,280	980	474	71	77	181	851	1,290	1,220	1,210	10,714
	1954	1,080	885	781	650	10,710	3,530	2,700	1,130	522	358	439	567	23,352
	1955	807	994	1,070	692	2,560	856	2,270	894	1,980	1,110	908	946	15,087
	1956	823	730	726	507	399	64	166	1.2	0	0	0	0	3,416
	1957	185	458	1,710	10,600	5,590	8,380	1,980	720	1,340	6,650	6,140	5,130	48,883
	1958	5,740	8,560	12,980	6,580	5,720	31,240	12,830	8,490	45,570	24,790	23,290	12,110	197,900
	1959	8,170	5,660	5,180	5,030	5,370	23,040	14,630	7,660	5,850	15,530	7,930	6,510	110,560
	1960	6,450	5,970	5,890	5,060	4,300	2,880	5,640	13,050	7,220	7,920	10,440	12,070	86,890
	1961	10,450	13,010	11,050	7,680	5,600	13,030	11,040	9,000	5,820	6,400	5,450	4,870	103,400
	1962	4,330	3,470	3,240	3,460	3,190	5,200	1,750	879	785	3,950	3,110	3,120	36,404
	1963	2,800	2,510	2,820	2,750	2,800	1,450	814	384	466	758	2,190	2,550	22,292
	1964	2,620	3,550	3,820	3,950	3,210	1,690	820	557	6,910	6,410	3,850	3,600	40,987
	1965	3,240	3,920	3,640	3,760	9,670	12,260	4,480	2,260	1,630	3,030	3,310	3,980	55,180
	1966	3,800	3,120	3,130	4,040	4,700	2,980	5,870	38,590	18,250	9,700	5,850	4,620	104,650
	1967	4,020	3,300	3,270	2,930	2,090	1,060	8,700	2,690	5,230	16,920	17,960	9,960	78,130
	1968	13,670	12,860	12,300	10,730	16,450	8,970	10,190	5,580	4,710	4,380	3,900	4,490	108,230
	1969	3,840	3,380	3,490	4,370	4,030	2,350	1,340	1,340	2,300	39,830	9,770	11,380	87,420
	1970	7,620	5,610	8,430	6,370	11,320	8,020	4,640	3,220	13,230	9,580	6,360	5,390	89,790
	1971	4,450	3,460	3,670	3,090	2,620	1,690	1,640	64,570	12,010	29,440	17,560	11,570	155,770
	1972	8,120	6,120	5,440	4,180	16,690	8,480	5,490	16,930	11,610	9,270	6,770	5,730	104,830
	1973	5,150	4,780	5,970	5,910	4,580	16,780	51,860	14,560	7,530	38,060	14,510	9,910	179,600
	1974	7,950	5,750	5,790	4,750	14,040	5,080	3,240	7,840	6,610	6,870	7,600	6,170	81,690
	1975	6,340	8,870	7,440	6,010	10,200	8,890	7,620	5,860	4,550	5,010	5,090	4,560	80,440
	1976	4,120	3,520	3,500	5,200	12,920	5,940	49,080	16,610	9,560	7,960	8,780	9,110	136,300
	1977	9,250	9,890	9,400	28,520	18,070	9,980	6,510	4,620	3,720	22,530	11,080	6,890	162,100
	1978	6,310	5,020	4,010	3,340	2,880	3,390	1,730	9,980	4,450	3880	4,760	4,980	54,730
	1979	4,670	4,580	12,250	12,560	8,720	23,200	7,420	5,560	4,070	3,090	3,130	3,730	92,990
	1980	4,000	3,560	3,200	2,660	3,240	2,220	1,170	2,230	31,550	8,030	6,020	6,970	74,870
	1981	5,910	4,420	12,450	51,120	23,230	66,940	23,740	12,300	7,850	32,480	11,540	8,710	260,600
	1982	7,460	6,260	6,980	5,640	16,420	7,260	5,060	3,090	3,070	2,810	2,900	4,120	71,070
	1983	4,020	3,770	5,410	3,830	3,990	5,040	3,710	2,510	2,120	4,160	8,140	4,890	51,590
	1984	4,200	3,330	3,040	2,250	1,770	1,440	902	661	693				

TABLE B-2

DRY FRIO RIVER NR REAGAN WELLS, TEXAS (D.A. = 117 SQ. MI.)
MONTHLY VOLUME (AC - FT)

Gage Station Number	Calendar Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0819600	1940E	735	827	798	1,282	1,986	1,574	1,899	850	637	527	715	1,170	13,000
	1941E	1,046	1,222	1,542	4,343	5,963	2,559	1,744	2,732	3,343	3,868	2,758	1,991	33,111
	1942E	1,504	1,187	1,136	1,634	2,113	1,127	986	994	2,868	2,605	1,876	1,427	19,457
	1943E	1,202	908	945	1,023	867	986	715	395	452	533	499	712	9,237
	1944E	905	867	1,600	1,343	1,862	2,121	1,075	1,300	1,620	1,340	968	1,156	16,157
	1945E	2,404	1,908	1,833	2,032	1,695	940	608	357	280	1,084	813	931	14,885
	1946E	813	775	721	651	882	623	499	253	478	4,943	1,821	1,222	13,681
	1947E	1,876	1,608	1,481	1,481	1,761	2,810	1,899	986	666	556	640	775	16,539
	1948E	718	712	703	579	504	548	499	243	240	337	346	409	5,838
	1949E	513	7,989	3,159	2,360	2,040	1,476	914	905	945	1,075	919	954	23,249
	1950E	989	928	991	824	862	741	516	412	392	421	334	441	7,851
	1951E	372	403	585	648	2,167	749	256	125	663	210	284	354	6,816
	1952E	363	331	406	548	755	464	210	71	26	27	120	354	3,675
	1953	391	235	284	221	82	12	4.8	15.0	1,510	529	412	271	3,967
	1954	223	178	138	95	5,350	1,610	1,090	249	112	164	120	122	9,451
	1955	186	244	252	155	160	116	471	218	6,190	877	299	266	9,434
	1956	202	190	167	89	53	19	13	0	0	0	0	3.4	736
	1957	32	48	266	1,590	2,870	7,750	502	184	1,170	13,630	2,480	1,510	32,032
	1958	2,570	5,110	6,470	2,260	1,810	13,760	5,020	2,150	16,460	10,190	7,540	3,190	76,530
	1959	2,070	1,440	1,190	1,210	2,010	4,530	3,500	1,520	3,430	10,230	2,210	1,710	35,050
	1960	1,640	1,250	1,090	926	979	430	1,510	5,740	1,790	2,430	2,560	2,400	22,745
	1961	2,370	3,230	2,110	1,250	720	8,580	4,400	3,810	1,560	1,620	1,250	906	31,806
	1962	781	657	649	607	691	337	181	91	86	64	62	437	4,643
	1963	349	510	428	685	977	297	104	24	12	41	236	440	4,103
	1964	491	1,330	1,540	1,150	528	184	39	14	1,110	1,520	863	543	9,312
	1965	421	1,870	768	799	4,840	2,020	497	166	237	685	576	1,410	14,289
	1966	1,390	801	699	568	701	233	475	22,470	5,250	1,940	1,060	817	36,404
	1967	702	611	595	451	266	138	1,500	487	3,200	10,570	7,980	2,970	29,470
	1968	3,540	3,200	3,430	4,950	4,490	2,510	5,900	1,910	1,340	1,040	789	1,070	34,169
	1969	821	698	713	1,110	846	544	231	264	417	15,870	3,170	3,310	27,994
	1970	1,790	1,540	2,290	1,440	1,370	1,210	614	362	6,620	3,160	1,470	1,130	22,996
	1971	867	768	767	653	505	537	1,080	17,790	3,610	10,210	4,770	2,460	44,017
	1972	1,620	1,320	1,130	758	1,070	2,670	683	1,790	1,790	1,440	901	756	15,928
	1973	819	1,070	1,330	1,490	1,160	12,490	16,290	4,660	2,450	14,130	4,610	2,520	63,019
	1974	1,850	1,220	1,280	950	3,100	938	680	4,150	1,940	2,330	2,480	1,710	22,628
	1975	1,900	3,360	1,860	1,350	2,490	2,380	2,800	1,240	801	830	799	669	20,479
	1976	323	468	479	1,800	8,190	1,560	17,010	4,700	5,380	3,630	3,780	3,990	51,590
	1977	3,190	3,440	2,460	2,910	3,610	2,160	877	550	381	993	3,020	1,160	24,760
	1978	936	859	743	572	436	907	234	1,990	537	353	922	821	9,310
	1979	754	899	4,150	4,960	2,230	10,120	2,580	1,030	412	326	453	501	28,420
	1980	560	443	456	365	835	217	108	351	1,970	592	825	1,180	7,900
	1981	873	825	3,350	15,320	5,790	16,140	4,050	1,440	510	6,830	1,540	1,200	58,310
	1982	996	839	988	678	5,170	2,400	1,370	442	557	357	555	845	15,197
	1983	681	633	956	707	2,360	1,250	481	317	375	1,200	2,350	1,410	27,917
	1984	1,210	962	878	650	511	416	261	191	200				

E following the date indicates the data is extended and not measured.

APPENDIX C

NET EVAPORATION RECORDS
FOR THE FRIO AND DRY FRIO RIVERS

TABLE C-1

MONTHLY NET RESERVOIR EVAPORATION RATES (FT)
(SOURCE: TDWR R-64)

Quadangle No.	Calendar Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
H-8	1940	0.17	0.10	0.23	0.13	0.04	0.13	0.63	0.65	0.71	0.31	0.11	-0.05	3.16
	1941	-0.01	-0.23	-0.17	-0.09	0.14	0.17	0.49	0.62	0.17	0.21	0.26	0.14	1.70
	1942	0.20	0.09	0.32	-0.08	0.18	0.55	0.37	0.53	0.16	0.14	0.33	0.18	2.97
	1943	0.17	0.28	0.33	0.41	0.36	0.28	0.57	0.93	0.13	0.30	0.22	0.06	4.04
	1944	0.01	0.02	0.15	0.44	-0.07	0.38	0.87	0.24	0.50	0.45	0.13	0.05	3.17
	1945	-0.08	0.05	0.02	0.16	0.47	0.47	0.82	0.85	0.43	0.27	0.33	0.19	3.98
	1946	0.06	0.15	0.35	0.16	0.02	0.42	0.76	0.60	0.13	0.14	0.25	0.13	3.17
	1947	-0.06	0.27	0.28	0.32	0.37	0.23	0.88	0.49	0.90	0.62	0.24	0.20	4.74
	1948	0.23	0.02	0.35	0.29	0.45	0.37	0.59	0.87	0.34	0.28	0.38	0.22	4.39
	1949	0.01	-0.17	0.12	-0.14	0.33	0.26	0.61	0.46	0.42	0.07	0.37	-0.02	2.32
	1950	0.07	0.07	0.43	0.26	0.21	0.33	0.70	0.62	0.48	0.58	0.40	0.32	4.47
	1951	0.16	0.02	0.02	0.22	-0.30	0.48	0.83	0.86	0.76	0.82	0.41	0.33	4.61
	1952	0.21	0.13	0.13	0.13	0.07	0.46	0.81	0.97	0.33	0.58	0.12	0.22	4.16
	1953	0.26	0.16	0.20	0.52	0.58	0.84	0.99	0.59	0.28	0.00	0.29	0.15	4.86
	1954	0.19	0.42	0.49	0.33	-0.43	0.56	0.78	0.95	0.86	0.34	0.31	0.35	6.01
	1955	0.12	0.14	0.31	0.53	0.22	0.64	0.67	0.68	0.55	0.70	0.30	0.24	5.10
	1956	0.13	0.17	0.40	0.41	0.62	0.92	0.91	0.97	0.78	0.51	0.40	0.27	6.49
	1957	0.22	0.13	0.22	-0.43	-0.35	0.35	0.93	1.07	0.33	0.01	-0.07	0.11	2.52
	1958	-0.19	-0.08	0.09	0.21	0.24	0.15	0.68	0.73	-0.12	-0.21	0.19	0.12	1.81
	1959	0.11	0.01	0.32	0.09	0.20	0.27	0.57	0.64	0.47	-0.12	0.14	0.11	2.81
	1960	0.03	0.14	0.10	0.32	0.37	0.71	0.38	0.37	0.58	-0.05	0.12	-0.17	2.90
	1961	0.01	-0.10	0.23	0.31	0.52	0.11	0.22	0.47	0.58	0.09	0.16	0.07	2.67
	1962	0.16	0.28	0.32	0.16	0.52	0.45	0.89	0.76	0.47	0.49	0.18	0.05	4.73
	1963	0.14	0.03	0.33	0.22	0.22	0.49	0.73	0.78	0.37	0.35	0.14	0.08	3.88
	1964	0.04	0.09	0.17	0.24	0.24	0.44	0.72	0.64	0.07	0.28	0.17	0.08	3.18
	1965	0.19	-0.20	0.14	0.18	0.02	0.46	0.78	0.74	0.61	0.19	0.14	-0.13	3.12
	1966	0.15	0.03	0.20	0.18	0.07	0.42	0.63	0.48	0.29	0.04	0.30	0.18	2.97
	1967	0.09	0.11	0.15	0.18	0.26	0.55	0.77	0.37	0.19	0.34	0.04	0.18	3.23
	1968	0.00	0.03	0.03	0.05	0.00	0.29	0.57	0.48	0.21	0.18	0.19	0.05	2.08
	1969	0.04	-0.04	0.12	0.06	0.00	0.47	0.67	0.38	0.08	0.08	0.16	0.09	2.11
	1970	0.04	0.05	0.13	0.06	0.04	0.39	0.57	0.45	0.17	0.05	0.27	0.18	2.40
	1971	0.27	0.24	0.44	0.31	0.47	0.33	0.63	0.14	0.27	0.06	0.24	0.06	3.46
	1972	0.13	0.22	0.34	0.36	0.17	0.41	0.53	0.40	0.33	0.37	0.20	0.20	3.66
	1973	0.08	-0.03	0.26	0.10	0.43	0.21	0.30	0.53	0.19	0.16	0.27	0.29	2.79
	1974	0.09	0.31	0.22	0.38	0.28	0.62	0.75	0.13	0.31	0.24	0.10	0.04	3.47
	1975	0.18	0.07	0.32	0.16	0.10	0.37	0.44	0.61	0.39	0.29	0.40	0.18	3.51
	1976	0.23	0.30	0.24	0.03	0.15	0.45	0.17	0.56	0.22	0.13	0.10	0.07	2.65
	1977	0.01	0.16	0.27	0.12	0.14	0.44	0.76	0.75	0.59	0.36	0.14	0.24	3.98
	1978	0.13	0.09	0.35	0.32	0.35	0.40	0.76	0.32	0.22	0.34	0.06	0.12	3.46
	1979	0.02	0.06	0.08	0.08	0.28	0.21	0.48	0.46	0.62	0.64	0.18	0.08	3.19
	1980	0.11	0.16	0.26	0.42	0.21	0.68	0.86	0.46	0.31	0.34	0.04	0.11	3.96
	1981	0.07	0.10	0.09	-0.03	0.21	0.12	0.59	0.59	0.39	0.12	0.31	0.21	2.77
	1982	0.19	-0.08	0.24	0.30	-0.09	0.42	0.52	0.79	0.72	0.54	0.08	0.11	3.76
	1983	0.02	0.05	0.03	0.50	0.29	0.12	0.27	0.33	0.43	0.30	0.19	0.14	2.66
	1984	0.02	0.29	0.42	0.60	0.58	0.63	0.86	0.66	-0.18				

APPENDIX D

STREAMFLOW RECORDS FOR THE FRIO AND DRY FRIO RIVERS ADJUSTED FOR STORAGE THRESHOLD

TABLE D-1

INFLOW INTO FRIO RIVER SITE IN EXCESS OF 200 CFS
MONTHLY VOLUME (AC-FT)

	Calendar Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0819500	1940	0	0	0	0	645	317	879	0	0	0	0	0	1,841
	1941	0	0	0	8,309	8,551	0	0	2,438	1,749	2,057	10	0	23,114
	1942	0	0	0	123	218	0	0	300	1,277	480	0	0	2,398
	1943	0	0	0	0	0	0	0	0	0	0	0	0	0
	1944	0	0	0	0	922	579	0	1,930	71	0	0	0	3,502
	1945	1,353	0	50	0	20	0	0	0	0	0	0	0	1,423
	1946	0	0	0	0	0	0	0	0	0	10,481	32	0	10,513
	1947	0	0	0	0	0	3,604	0	0	0	0	0	0	3,604
	1948	0	0	0	0	0	0	0	0	0	0	0	0	0
	1949	0	23m825	1,200	946	0	0	0	0	0	0	0	0	25,971
	1950	0	0	0	0	0	0	0	0	0	0	0	0	0
	1951	0	0	0	0	3,126	0	0	0	1,448	0	0	0	4,574
	1952	0	0	0	0	48	0	0	0	0	0	0	0	48
	1953	0	0	0	0	0	0	0	0	0	0	0	0	0
	1954	0	0	0	0	7,722	516	0	0	0	0	0	0	8,238
	1955	0	0	0	0	494	0	545	0	615	0	0	0	1,654
	1956	0	0	0	0	0	0	0	0	0	0	0	0	0
	1957	0	0	77	6,764	992	1,712	0	0	248	575	0	0	10,338
	1958	0	762	1,757	0	0	24,313	2,041	903	34,979	12,488	11,393	803	89,439
	1959	0	0	0	0	0	16,871	2,531	0	145	4,534	0	0	24,081
	1960	0	0	0	0	0	0	432	3,580	0	821	157	714	5,704
	1961	0	2,325	71	0	0	5,038	783	202	0	506	0	0	8,925
	1962	0	0	0	0	0	877	0	0	0	1,148	0	0	2,025
	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
	1964	0	0	0	0	0	0	0	0	2,985	0	0	0	2,985
	1965	0	0	0	0	2,334	5,034	0	0	0	0	0	0	7,368
	1966	0	0	0	190	0	0	2,023	30,192	6,613	99	0	0	39,117
	1967	0	0	0	0	0	0	5,639	0	764	8,448	6,805	69	21,725
	1968	4,264	1,361	367	278	4,195	93	1,143	0	0	0	0	0	11,701
	1969	0	0	0	0	0	0	0	0	0	28,739	305	415	29,459
	1970	0	0	0	0	2,608	46	0	0	7,373	73	0	0	10,100
	1971	0	0	0	0	0	0	0	55,466	877	17,294	5,659	327	79,623
	1972	0	0	0	0	6,083	196	0	6,520	666	0	0	0	13,465
	1973	0	0	0	0	0	6,752	40,030	3,146	0	27,112	2,646	0	79,686
	1974	0	0	0	0	4,760	0	0	1,287	0	1,563	272	0	7,882
	1975	0	0	0	0	738	0	0	0	0	0	0	0	738
	1976	0	0	0	0	4,181	0	37,178	4,447	75	0	0	0	45,881
	1977	0	0	0	18,811	2,912	133	0	0	0	16,354	1,652	0	39,862
	1978	0	0	0	0	0	0	0	2,682	0	0	0	0	2,682
	1979	0	0	4,435	1,684	6	11,651	0	0	0	0	0	0	17,776
	1980	0	0	0	0	0	0	0	6	24,670	182	0	0	24,852
	1981	0	0	2,414	39,340	10,937	55,331	11,447	732	0	21,419	432	0	142,052
	1982	0	0	0	0	7,130	0	0	0	0	0	0	0	7,130
	1983	0	0	0	0	0	0	0	0	0	0	1,152	0	1,152
	1984	0	0	0	0	0	0	0	0	0				

TABLE D-2

INFLOW INTO DRY FRIO RIVER SITE IN EXCESS OF 200 CFS
MONTHLY VOLUME (AC-FT)

	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Calendar Annual
08196000	1940	0	0	0	0	0	0	0	0	0	0	0	0	0
	1941	0	0	0	4,592	305	0	0	630	0	610	0	0	6,137
	1942	0	0	0	0	0	0	0	0	0	0	0	0	0
	1943	0	0	0	0	0	0	0	0	0	0	0	0	0
	1944	0	0	0	0	0	0	0	370	0	0	0	0	370
	1945	11	0	0	0	0	0	0	0	0	0	0	0	11
	1946	0	0	0	0	0	0	0	0	0	7,627	0	0	7,627
	1947	0	0	0	0	0	670	0	0	0	0	0	0	670
	1948	0	0	0	0	0	0	0	0	0	0	0	0	0
	1949	0	18,392	0	0	0	0	0	0	0	0	0	0	18,392
	1950	0	0	0	0	0	0	0	0	0	0	0	0	0
	1951	0	0	0	0	1,483	0	0	0	471	0	0	0	1,954
	1952	0	0	0	0	0	0	0	0	0	0	0	0	0
	1953	0	0	0	0	0	0	0	0	0	0	0	0	0
	1954	0	0	0	0	3,287	0	0	0	0	0	0	0	3,287
	1955	0	0	0	0	0	0	0	0	4,828	0	0	0	4,828
	1956	0	0	0	0	0	0	0	0	0	0	0	0	0
	1957	0	0	0	0	381	3,136	0	0	85	9,070	0	0	12,672
	1958	0	1,081	419	0	0	8,471	107	0	10,413	1,260	260	0	22,011
	1959	0	0	0	0	0	1,271	0	0	750	4,189	0	0	6,210
	1960	0	0	0	0	0	0	10	1,039	0	77	0	0	1,126
	1961	0	0	0	0	0	5,121	641	301	0	0	0	0	6,063
	1962	0	0	0	0	0	0	0	0	0	0	0	0	0
	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
	1964	0	0	0	0	0	0	0	0	0	0	0	0	0
	1965	0	0	0	0	1,107	0	0	0	0	0	0	0	1,107
	1966	0	0	0	0	0	0	0	17,615	0	0	0	0	17,615
	1967	0	0	0	0	0	0	373	0	58	6,732	1,708	0	8,871
	1968	0	0	0	674	0	0	1,789	0	0	0	0	0	2,463
	1969	0	0	0	0	0	0	0	0	0	9,047	0	0	9,047
	1970	0	0	0	0	0	0	0	0	3,108	0	0	0	3,108
	1971	0	0	0	0	0	0	0	9,848	0	1,033	0	0	10,881
	1972	0	0	0	0	0	508	0	0	0	0	0	0	508
	1973	0	0	0	0	0	6,184	6,883	0	0	5,155	0	0	18,222
	1974	0	0	0	0	188	0	0	569	0	0	0	0	757
	1975	0	0	0	0	0	0	0	0	0	0	0	0	0
	1976	0	0	0	0	3,784	0	7,513	0	762	0	0	0	12,059
	1977	0	0	0	0	0	0	0	0	0	0	254	0	254
	1978	0	0	0	0	0	0	0	266	0	0	0	0	266
	1979	0	0	793	498	0	3,134	0	0	0	0	0	0	4,425
	1980	0	0	0	0	0	0	0	0	785	0	0	0	785
	1981	0	0	543	9,187	18	9,358	0	0	0	3,489	0	0	22,595
	1982	0	0	0	0	1,198	0	0	0	0	0	0	0	1,198
	1983	0	0	0	0	343	0	0	0	0	0	0	0	343
	1984	0	0	0	0	0	0	0	0	0				

TABLE D-3

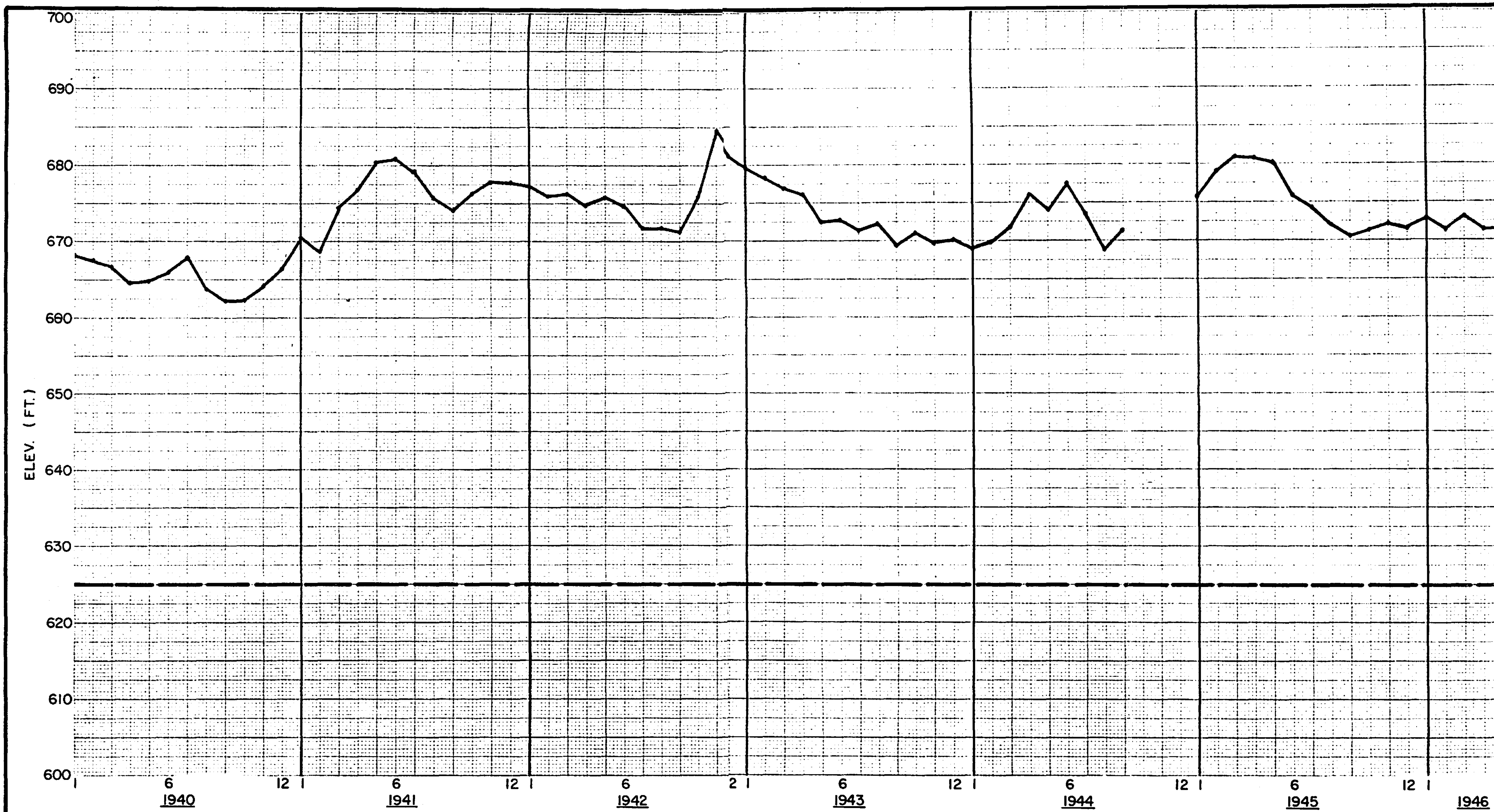
INFLOW INTO DRY FRIO RIVER SITE IN EXCESS OF 400 CFS
MONTHLY VOLUME (AC-FT)

	Calendar Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
08196000	1940	0	0	0	0	0	0	0	0	0	0	0	0	0
	1941	0	0	0	3,862	0	0	0	265	0	245	0	0	4,372
	1942	0	0	0	0	0	0	0	300	0	0	0	0	300
	1943	0	0	0	0	0	0	0	0	0	0	0	0	0
	1944	0	0	0	0	0	0	0	5	0	0	0	0	5
	1945	0	0	0	0	0	0	0	0	0	0	0	0	0
	1946	0	0	0	0	0	0	0	0	0	6,897	0	0	6,897
	1947	0	0	0	0	0	305	0	0	0	0	0	0	305
	1948	0	0	0	0	0	0	0	0	0	0	0	0	0
	1949	0	17,159	0	0	0	0	0	0	0	0	0	0	17,159
	1950	0	0	0	0	0	0	0	0	0	0	0	0	0
	1951	0	0	0	0	1,118	0	0	0	106	0	0	0	1,224
	1952	0	0	0	0	0	0	0	0	0	0	0	0	0
	1953	0	0	0	0	0	0	0	0	0	0	0	0	0
	1954	0	0	0	0	2,469	0	0	0	0	0	0	0	2,469
	1955	0	0	0	0	0	0	0	0	4,264	0	0	0	4,264
	1956	0	0	0	0	0	0	0	0	0	0	0	0	0
	1957	0	0	0	0	0	2,178	0	0	0	8,212	0	0	10,390
	1958	0	167	0	0	0	6,922	0	0	7,607	194	0	0	14,890
	1959	0	0	0	0	0	273	0	0	60	3,283	0	0	3,616
	1960	0	0	0	0	0	0	0	181	0	0	0	0	181
	1961	0	0	0	0	0	4,245	0	0	0	0	0	0	4,245
	1962	0	0	0	0	0	0	0	0	0	0	0	0	0
	1963	0	0	0	0	0	0	0	0	0	0	0	0	0
	1964	0	0	0	0	0	0	0	0	0	0	0	0	0
	1965	0	0	0	0	266	0	0	0	0	0	0	0	266
	1966	0	0	0	0	0	0	0	16,522	0	0	0	0	16,522
	1967	0	0	0	0	0	0	0	0	0	6,069	803	0	6,872
	1968	0	0	0	0	0	0	996	0	0	0	0	0	996
	1969	0	0	0	0	0	0	0	0	0	7,263	0	0	7,263
	1970	0	0	0	0	0	0	0	0	2,142	0	0	0	2,142
	1971	0	0	0	0	0	0	0	6,438	0	4	0	0	6,442
	1972	0	0	0	0	0	111	0	0	0	0	0	0	111
	1973	0	0	0	0	0	4,909	4,165	0	0	2,983	0	0	12,057
	1974	0	0	0	0	0	0	0	161	0	0	0	0	161
	1975	0	0	0	0	0	0	0	0	0	0	0	0	0
	1976	0	0	0	0	3,035	0	2,878	0	307	0	0	0	6,220
	1977	0	0	0	0	0	0	0	0	0	0	0	0	0
	1978	0	0	0	0	0	0	0	0	0	0	0	0	0
	1979	0	0	198	56	0	2,162	0	0	0	0	0	0	2,416
	1980	0	0	0	0	0	0	0	0	274	0	0	0	274
	1981	0	0	147	6,426	0	7 ,440	0	0	0	2,836	0	0	16,849
	1982	0	0	0	0	228	0	0	0	0	0	0	0	228
	1983	0	0	0	0	0	0	0	0	0	0	0	0	0
	1984	0	0	0	0	0	0	0	0	0				

APPENDIX E

WATER LEVEL FLUCTUATIONS

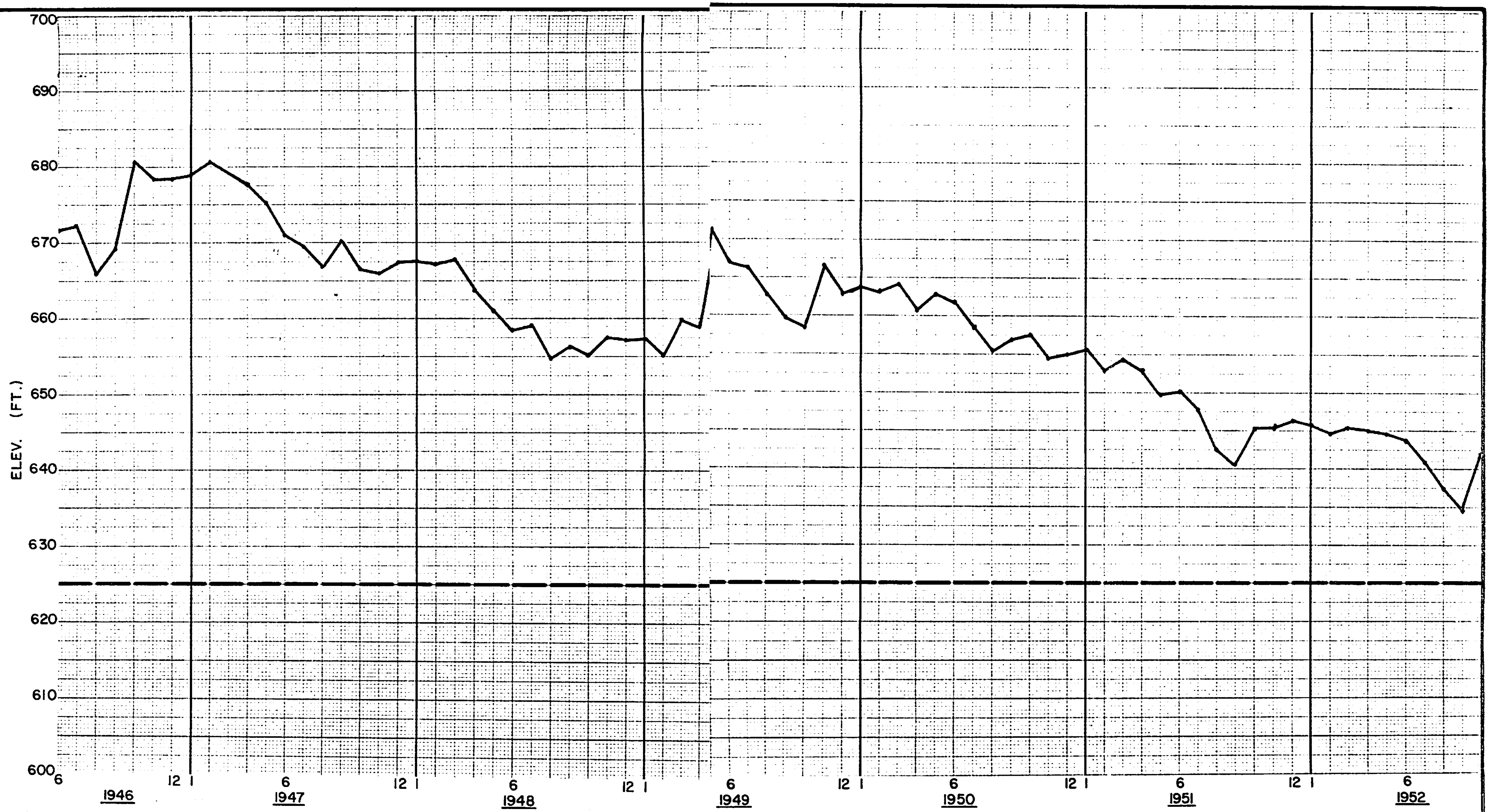
WELL NO. 68-37-204; 11/32 - 6/63
WELL NO. 68-37-203; 2/62 - PRESENT



FIIURE E-1

WATER LEVEL ELEVATIONS· EDWARDS AQUIFER IN BEXAR CO.

CAMP DRESSER & MCKEE INC.



FI(URE E-2

WATER LEVEL ELEVATIONS--EDWARDS AQUIFER IN BEXAR CO.

CAMP DRES(ER & MCKEE INC.

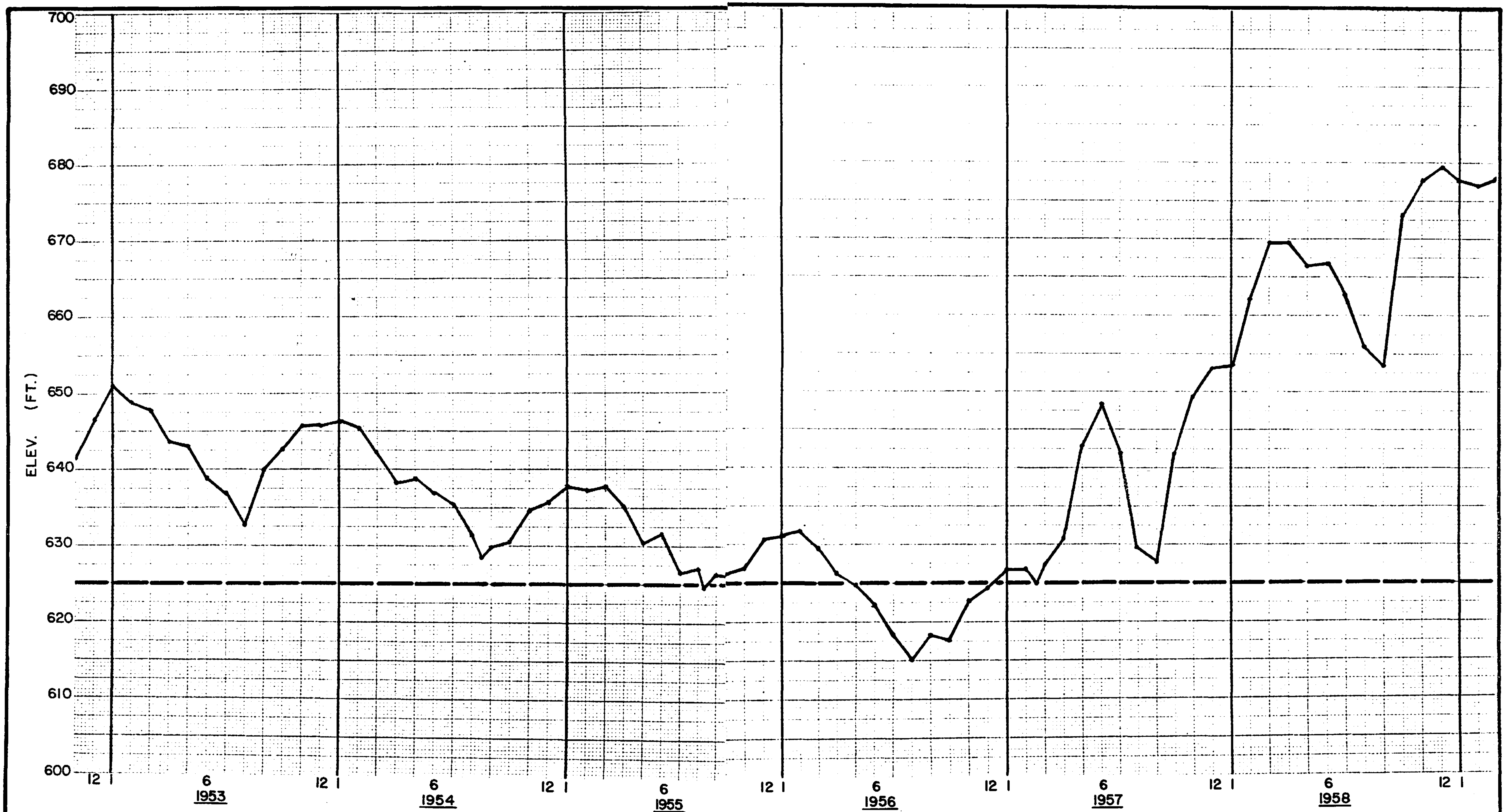


FIGURE E-3

WATER LEVEL ELEVATIONS-EDWARDS AQUIFER IN BEXAR CO.

CAMP DRESSER & McKEE INC.

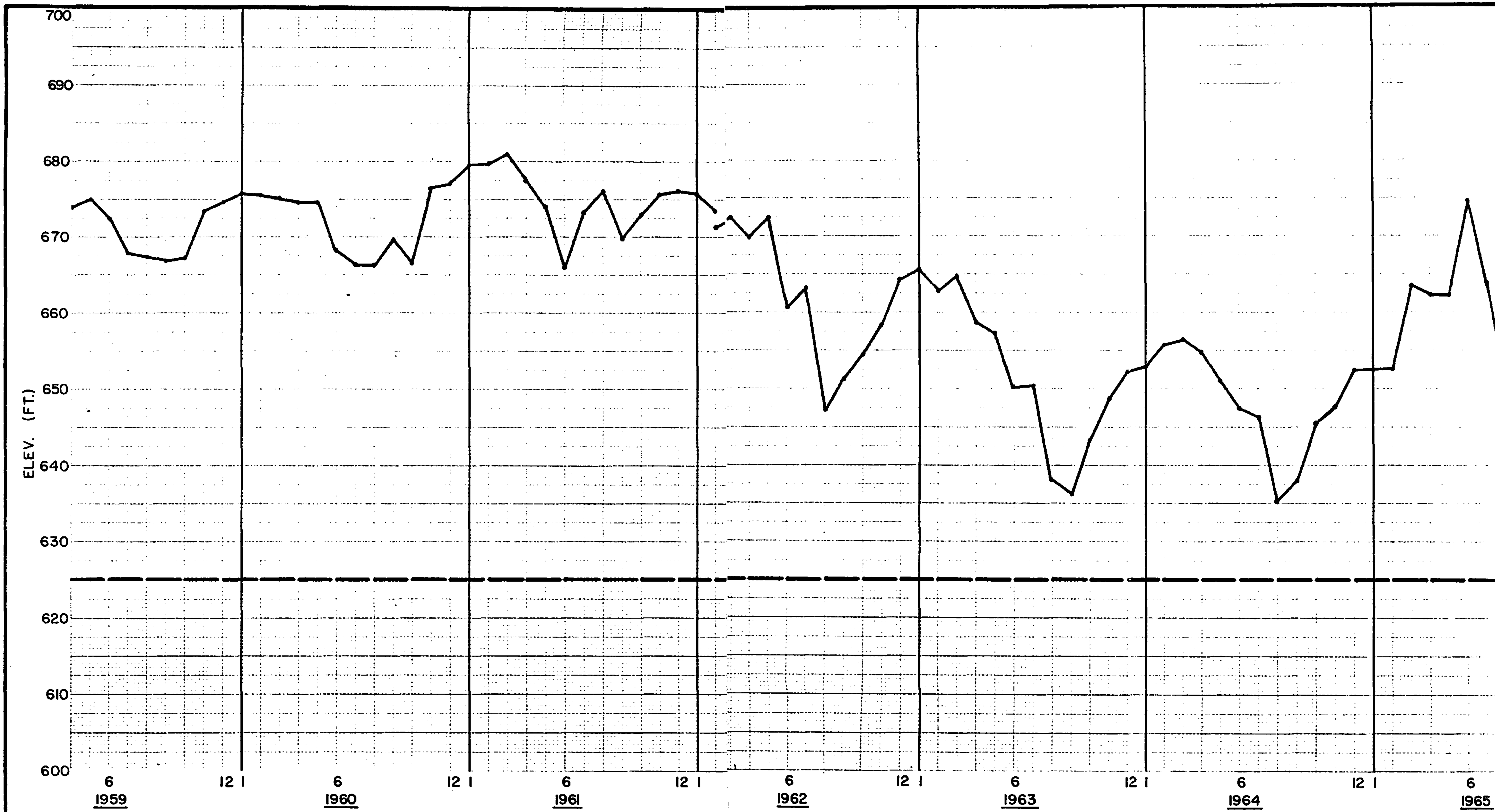


FIGURE E-4

WATER LEVEL ELEVATIONS-EDWARDS AQUIFER IN BEXAR CO.

CAMP DRESSER & MCKEE INC.

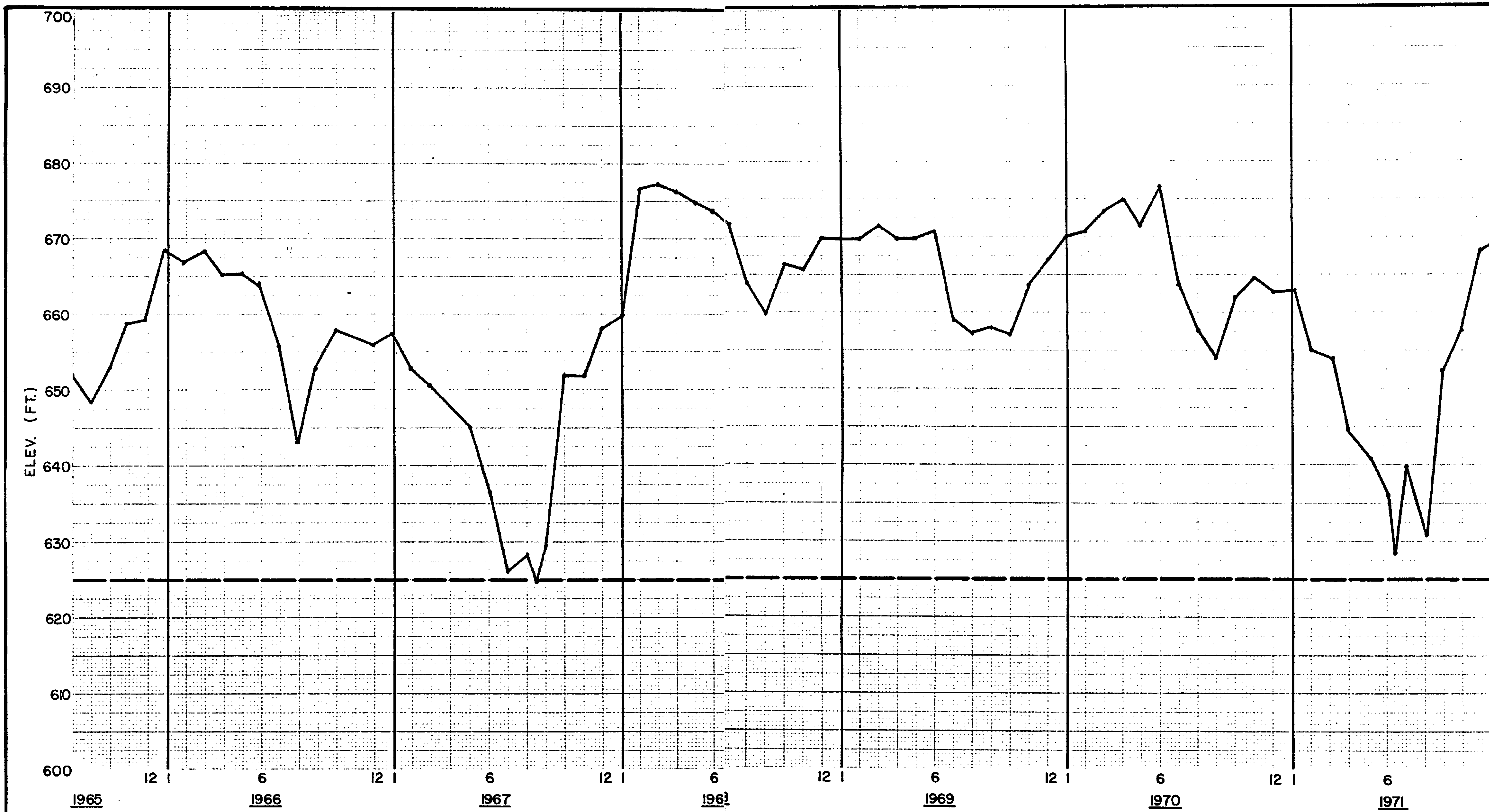


FIGURE E-5

WATER LEVEL ELEVATIONS-EDWARDS AQUIFER IN BEXAR CO.

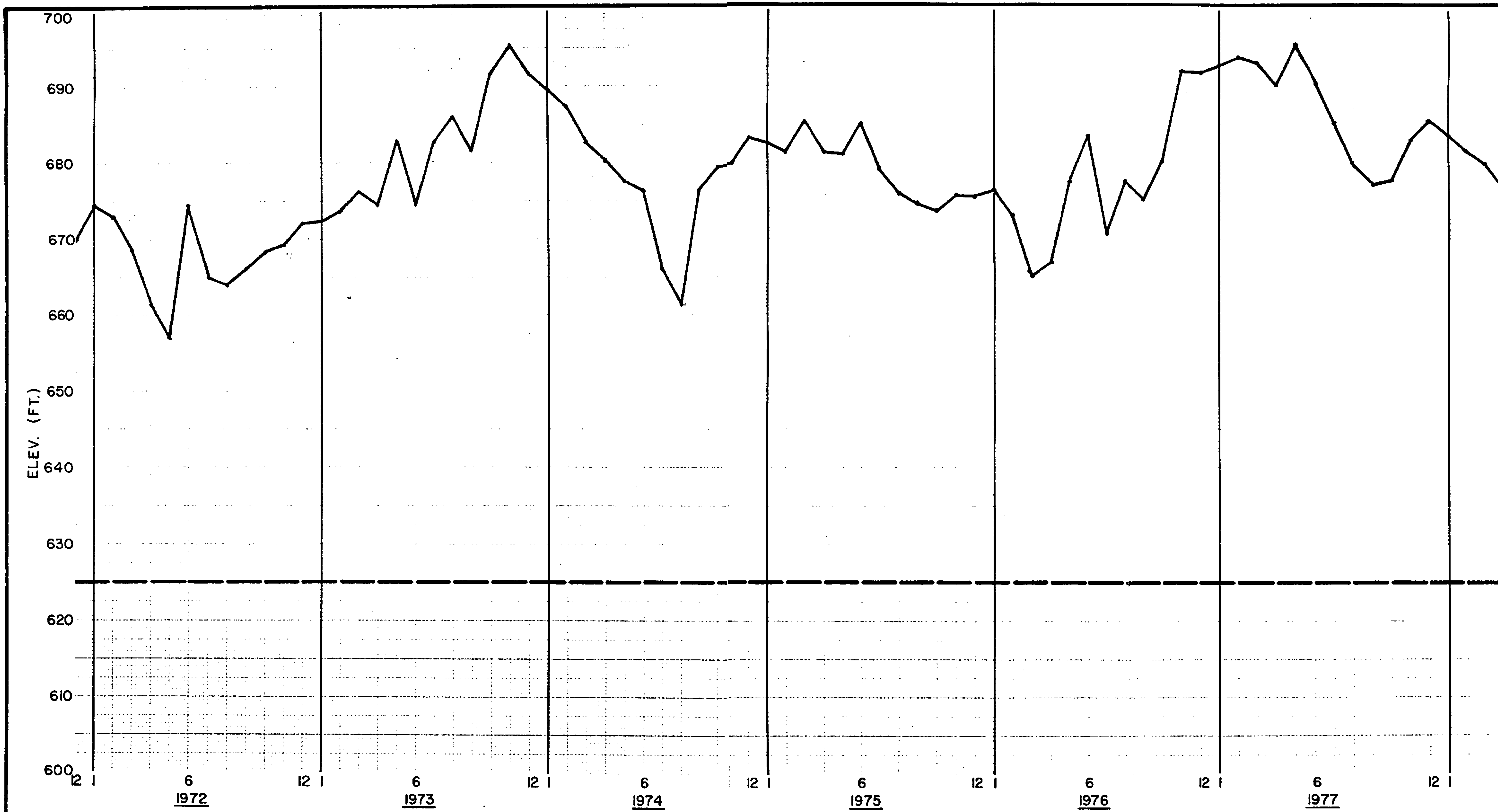
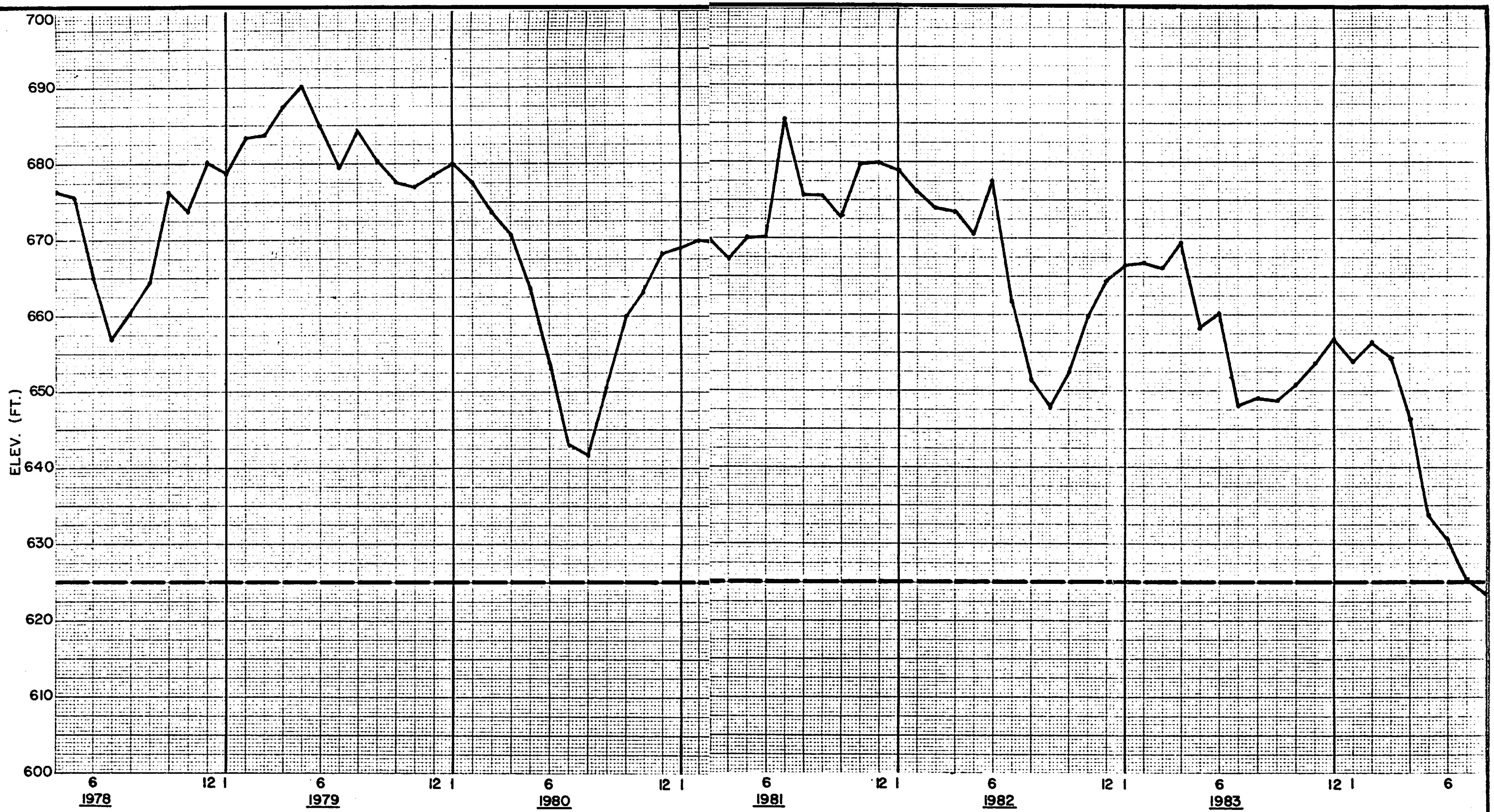


FIGURE E-6

WATER LEVEL ELEVATIONS-EDWARDS AQUIFER IN BEXAR CO.

CAMP DRESSER & MCKEE INC.



FIURE E-7

WATER LEVEL ELEVATIONS-EDWARDS AQUIFER IN BEXAR CO.

CAMP DRESSER & MCKEE INC.