Water for Texas

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Proceedings of the 24th Water for Texas Conference:

Sponsored by
Texas Water Development Board
Texas Water Resources Institute
Texas Water Conservation Association

Edited by Ric Jensen, TWRI

January 26th & 27th, 1995
Austin, TX

THE RELATIONSHIP BETWEEN LONG TERM CLIMATE CHANGE AND EDWARDS AQUIFER LEVELS, WITH AN EMPHASIS ON DROUGHTS AND SPRING FLOWS

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INTRODUCTION

The future management of the Balcones Fault Zone Edwards Aquifer in the San Antonio region is going to require that spring flow be preserved at Comal and San Marcos Springs. To better understand future scenarios it is important to have a historical perspective on water relationships in the region of the aquifer. Information regarding historical spring flow and well levels has been obtained from the Edwards Underground Water District (EUWD) and the United States Geological Survey (USGS). Information on climatic changes was obtained from the National Climatic Data Center (NCDC). Specifically a climate visualization interactive graphing tool (CLIMVIS) was used to select the appropriate indices and area to describe climatic changes in the watershed of the Edwards Aquifer. The region utilized was the Edwards Plateau of Texas. Additional supporting information was obtained from the Tree-Ring Laboratory at the University of Arkansas (Fayetteville).

LITERATURE REVIEW

There is a considerable interest by the public and the scientific community in what the impacts of possible climate change will be on Texas and its water supply in the future. Wilson (1994) described four scenarios where temperature varied from 0°C to +2.0°C and precipitation varied from -20% to +20%. He looked at water supply problems for municipalities, industries and agriculture, damage to coastal ecosystems and fisheries. He described policies to manage water resources for an uncertain climate. He indicates that climatic uncertainty has not been a factor in Texas water resource management, but deserves to be integrated into water planning. Longley et. al. (1994) evaluated the effects of climate change on Texas estuaries. They concluded there is not a simple one-to-one relationship between climate change parameters such as precipitation and the resulting freshwater inflow. The effect of temperature alone on inflow was much less than the effect of decreased precipitation. For a change in precipitation, the change in runoff will be greater in dry watersheds than in wet ones. Cleaveland and Stahle (1994) described long-term changes in Texas climate as indicated by tree ring studies. From a network of old Post Oak (*Quercus stellata*) tree ring chronologies were used to reconstruct June Palmer Drought Severity Indices (PDSI) for Texas from 1698 to 1980. They conclude that the El Nino/Southern Oscillation (ENSO) affects the climate of Texas. Strong warm (El Nino) events usually cause wetter than average winter and spring climate in Texas, while cold (La Nina) events cause drier conditions. Extreme events like the 1950's drought of record seem to occur about once every 100 years, and the interannual persistence of dry and wet conditions may provide some probability basis for forecasting. Stahle and Cleaveland (1988) reconstructed June PDSI from tree ring analysis for the period 1698 to 1980. They noted that other extreme droughts occurred from 1855-64 and 1772-81. They also observed that most prolonged droughts were either preceded and/or followed by extended wet periods, suggesting a weak oscillatory behavior in extended moisture anomalies in Texas. They observed that the summer climate of southern Texas is more variable and drought prone than northern Texas. Wanakule (1990) did a stochastic drought analysis of the Edwards Aquifer. He determined that there is a 78% probability that recharge will be less than 229 thousand acre-feet at least once in every ten year period. He noted the importance of understanding the random nature of drought and how the understanding would help design effective short term regulations and assist in planning the long term risk-based management alternatives. The information in his study would be useful for predicting the expected frequency of the aquifer being below various levels in index wells.

DISCUSSION

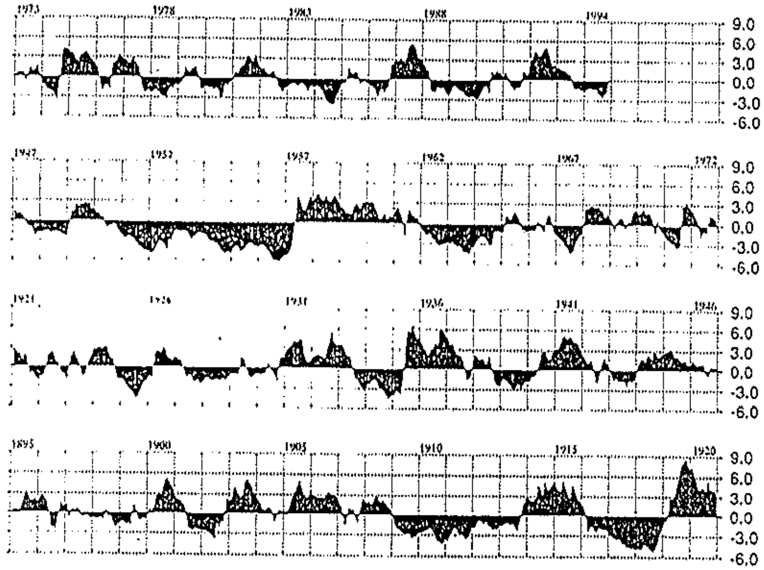
Information on four drought indices was obtained from the National Climatic Data Center (NCDC) utilizing the internet. The information describes a climate sequence for the Edwards Plateau of Texas for the period of 1895 to November 1994 NCDC (1994). The four indices shown are the: **Palmer Drought Severity Index (PDSI)** This is the monthly value (index) that is generated indicating the severity of a wet or dry spell. This index is based on the principles of a balance between moisture supply and demand. Man-made changes were not considered in this calculation. The index generally ranges from -6 to +6, with negative values denoting dry spells and positive values indicating wet spells. There are a few values in the magnitude of +7 or -7. PDSI values 0 to -.5 = normal; -0.5 to -1.0 = incipient drought; -1.0 to -2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought; and greater than - 4.0 = extreme drought. Similar adjectives are attached to positive values of wet spells. This is a meteorological drought index used to assess the severity of dry or wet spells of weather; **Palmer Hydrological Drought Index (PHDI)** This is the monthly value (index) generated monthly that indicates the severity of a wet or dry spell. This index is based on the principles of a balance between moisture supply and demand. Man-made changes such as increased irrigation, new reservoirs, and added industrial water use were not included in the computation of this index. The index generally ranges from - 6 to +6, with negative values denoting dry spells, and positive values indicating wet spells. There are a few values in the magnitude of +7 or -7. PHDI values 0 to -0.5 = normal; -0.5 to -1.0 = incipient drought; -1.0 to - 2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought; and greater than -4.0 = extreme drought. Similar adjectives are attached to positive values of wet spells. This is a hydrological drought index used to assess long-term moisture supply; **Palmer "Z" Index (ZNDX)** This is the generated monthly Z values, and they can be expressed as the "Moisture Anomaly Index." Each monthly Z value is a measure of the departure from normal of the moisture climate for that month. This index can respond to a month of above-normal precipitation, even during periods of drought. Table 1 contains expected values of the Z index and other drought parameters; and the **Modified Palmer Drought Severity Index (PMDI)** This is a modification of the Palmer Drought Severity Index. The modification was made by the National Weather Service Climate Analysis Center for operational meteorological purposes. The Palmer drought program calculates three intermediate parallel index values each month. Only one value is selected as the PDSI drought index for the month. This selection is made internally by the program on the basis of probabilities. If the probability that a drought is over is 100%, then one index is used. If the probability that a wet spell is over is 100%, then another index is used. If the probability is between 0% and 100%, the third index is assigned to the PDSI. The modification (PMDI) incorporates a weighted average of the wet and dry index terms, using the probability as the weighting factor. The PMDI and PDSI will have the same value during an established drought or wet spell (i.e., when the probability is 100%), but they will have different values during transition periods NCDC, 1994.

Table 1. Classes for Wet and Dry Periods NCDC (1994).

Approximate Cumulative Frequency %	**Range PHDI**	**Category**	**Range Z**
> 96	> 4.00	Extreme wetness	> 3.50
90-95	3.00, 3.99	Severe wetness	2.50, 3.49
73-89	1.50, 2.99	Mild to moderate wetness	1.00, 2.49
28-72	-1.49, 1.49	Near normal	-1.24, 0.99
11-27	-1.50, -2.99	Mild to moderate drought	-1.25, -1.99
5-10	-3.00, -3.99	Severe drought	-2.00, -2.74
< 4	<-4.00	Extreme drought	<-2.75

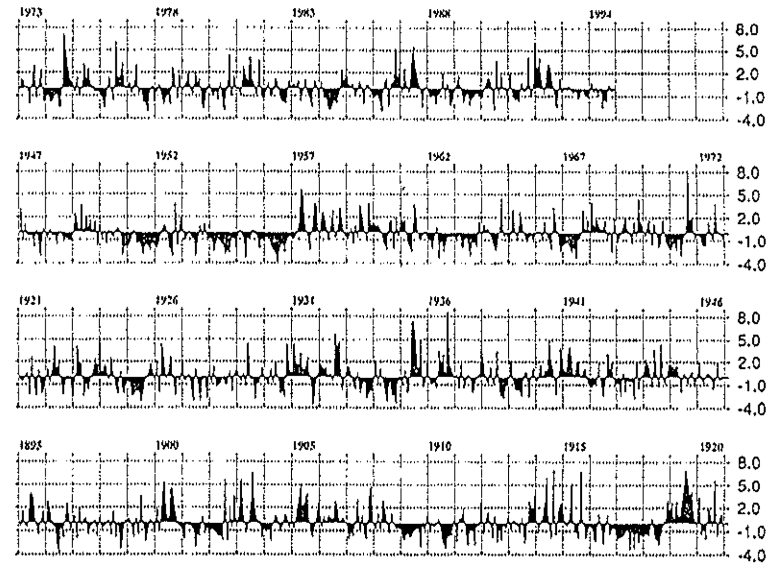
When the Palmer Drought indices are examined closely one can note that severe droughts have occurred in the watershed of the Edwards Aquifer in 1902, 1909-11, 1917-18, 1925, 1934, 1939, 1951- early 1957, 1962-64, 1967, 1971, 1974, 1978, 1980, 1984 and 1989 (Figure 1). The drought of record that occurred in the period of 1947- 56 was

Palmer Hydrological Drought Index



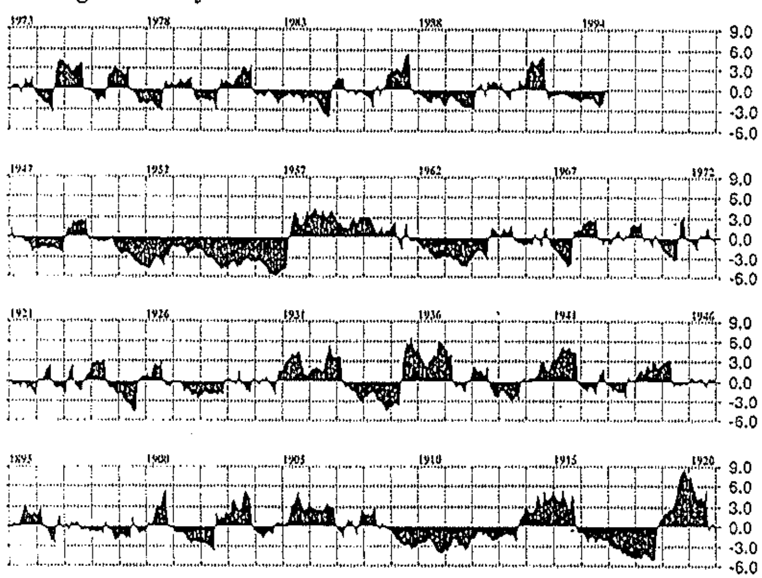
Texas - Division 06: 1895-1994 (Monthly Averages)

Palmer Z Index



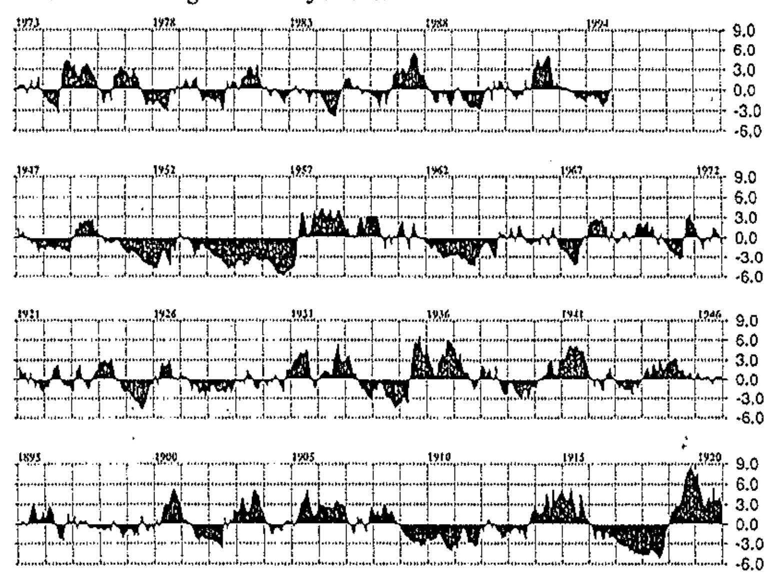
Texas - Division 06: 1895-1994 (Monthly Averages)

Palmer Drought Severity Index



Texas - Division 06: 1895-1994 (Monthly Averages)

Modified Palmer Drought Severity Index



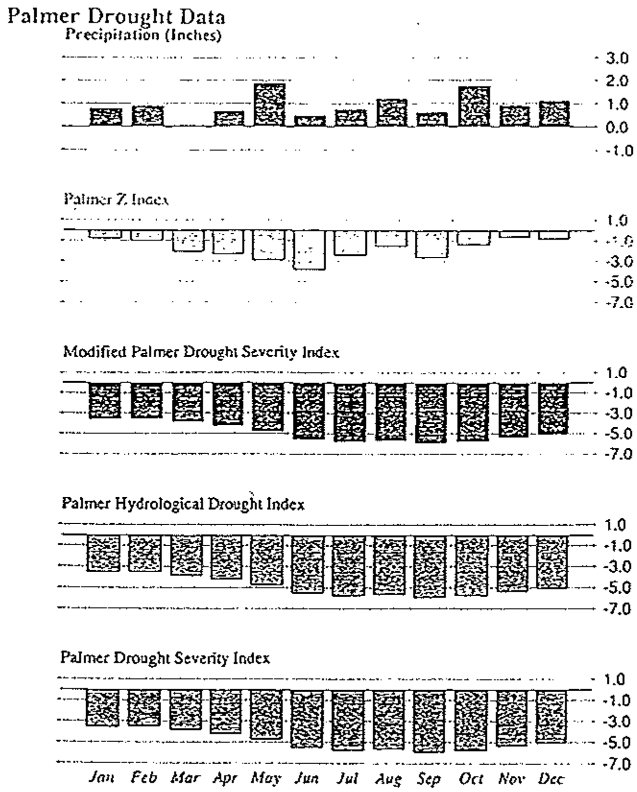
Texas - Division 06: 1895-1994 (Monthly Averages)

Figure 1. Drought indices for the Edwards Plateau = Texas (Division 06)1895-1994 (NCDC, 1994).

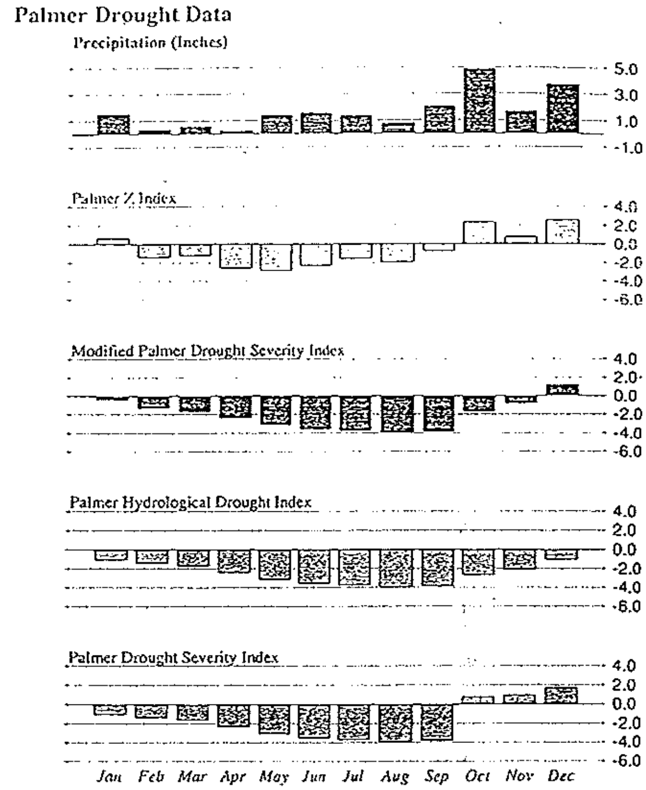
considered extreme due to the intensity and duration. The relatively lower intensity and shorter duration droughts that occurred in the region in 1984 and 1989 came very close to drying Comal Springs. These short duration droughts lowered the aquifer levels rapidly during late spring and early summer at rates exceeding one foot per day. A comparison of the worst year of the drought of record (1956) and the 1984 and 1989 droughts is made with this past year in Figure 2. One can get a long term perspective when they view the June PDSI for South Texas for the period 1698 - 1980 (Fig. 3). In the figure the recurrence of drought is apparent, with other severe droughts occurring in the 1700's and 1800's. As use of the aquifer increases on the average it takes less intense and shorter duration droughts to cause the aquifer level to fall to points that threaten continued spring flow.

There is a direct relationship between amounts of rainfall in the watershed of the Edwards Aquifer and the resulting spring flow. There is also a high correlation between the J-17 index well in San Antonio and Comal Spring flow Wanakule, 1988. The annual mean Comal spring flows from 1928 to 1994 are shown in Figure 4. An examination of this graph shows that even on an annualized basis the spring flow has been below the jeopardy level set by the US Fish and Wildlife Service. The US Fish and Wildlife Service has provided information to Judge Bunton of the Texas Western District Court that the "Take" level for Comal Springs is 200 cfs and the "Jeopardy" level is 150 cfs. If one changes the time series to monthly or daily, the latter being most important to the species, the true nature of the problem could be seen (Figure 4). Recharge to the aquifer is highly variable from year to year where discharge tends to be dampened, yet follows the trend of the average of recharge Figure 5. The amount of recharge is approximately the same as the amount of discharge over time. To get a perspective on how spring flow varies throughout a year one can examine the daily record of San Marcos Springs over the period of May 1956 through October 1994 as shown in Figure 6. The critical aspect of the graph is the daily minimum shown for the period. This amount is usually 50 to 75 cfs below the daily average at different times of the year. This figure also shows the highest year, 1992; the lowest year, 1956; the most recent severe drought year, 1989 and last year, 1994. The flows in 1994 varied from about 20 cfs below average in the winter to 70 cfs below average flows in mid summer. The average flow for San Marcos Springs over the period of record, beginning in 1934 is approximately 160 cfs. The historical high of 451 cfs occurred March 12-15, 1992 and the historical low occurred on August 15-16, 1956. These values compare with the Index well in Bexar County, J-17 that had a record high in 1992 of 700+ ft MSL and a record low of 612.5 ft MSL on August 17, 1956.

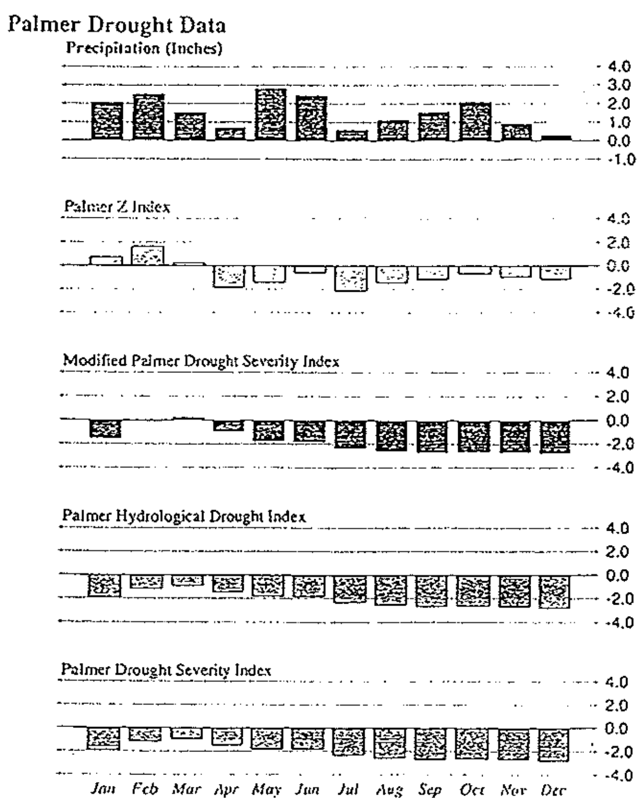
The information provided here should allow managers in future to have more insight into the nature of the aquifers dynamics. To have the long term perspective with a look into past events one should be convinced of the need to plan for "worst case scenarios" knowing that severe droughts occur periodically in this region and our water supply from the aquifer will not be able to satisfy additional demands. A serious effort must be made to establish effective management, including pumping controls, in this region. Additional water supplies must be developed for major users, by a combination of conservation, reuse, interbasin transfer and development of a ground water markets, by allocating supplies to various parts of the aquifer region based on



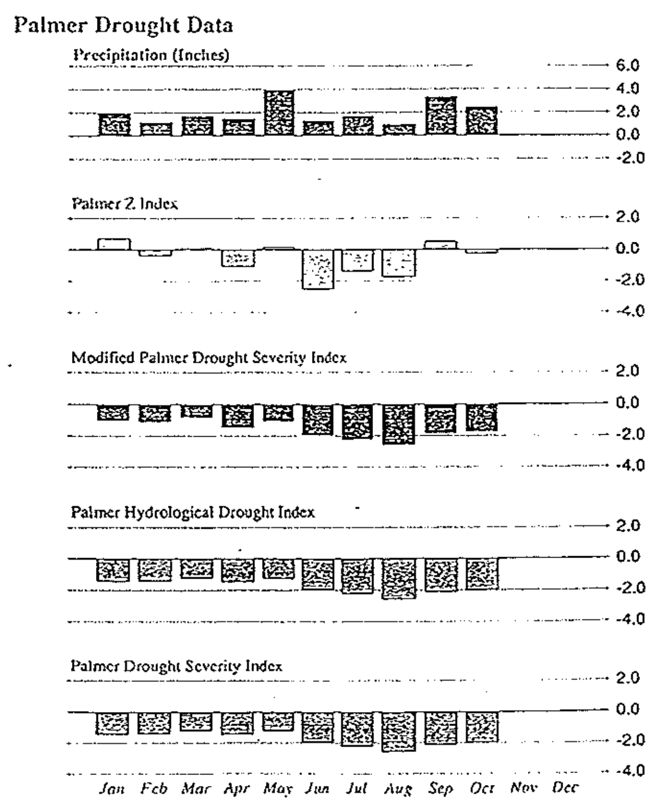
Texas-Division 06: 1956 (Monthly Averages)



Texas-Division 06: 1984 (Monthly Averages)



Texas-Division 06: 1989 (Monthly Averages)



Texas-Division 06: 1994 (Monthly Averages)

Figure 2. A comparison of three drought years with this past year(NCDC, 1994).

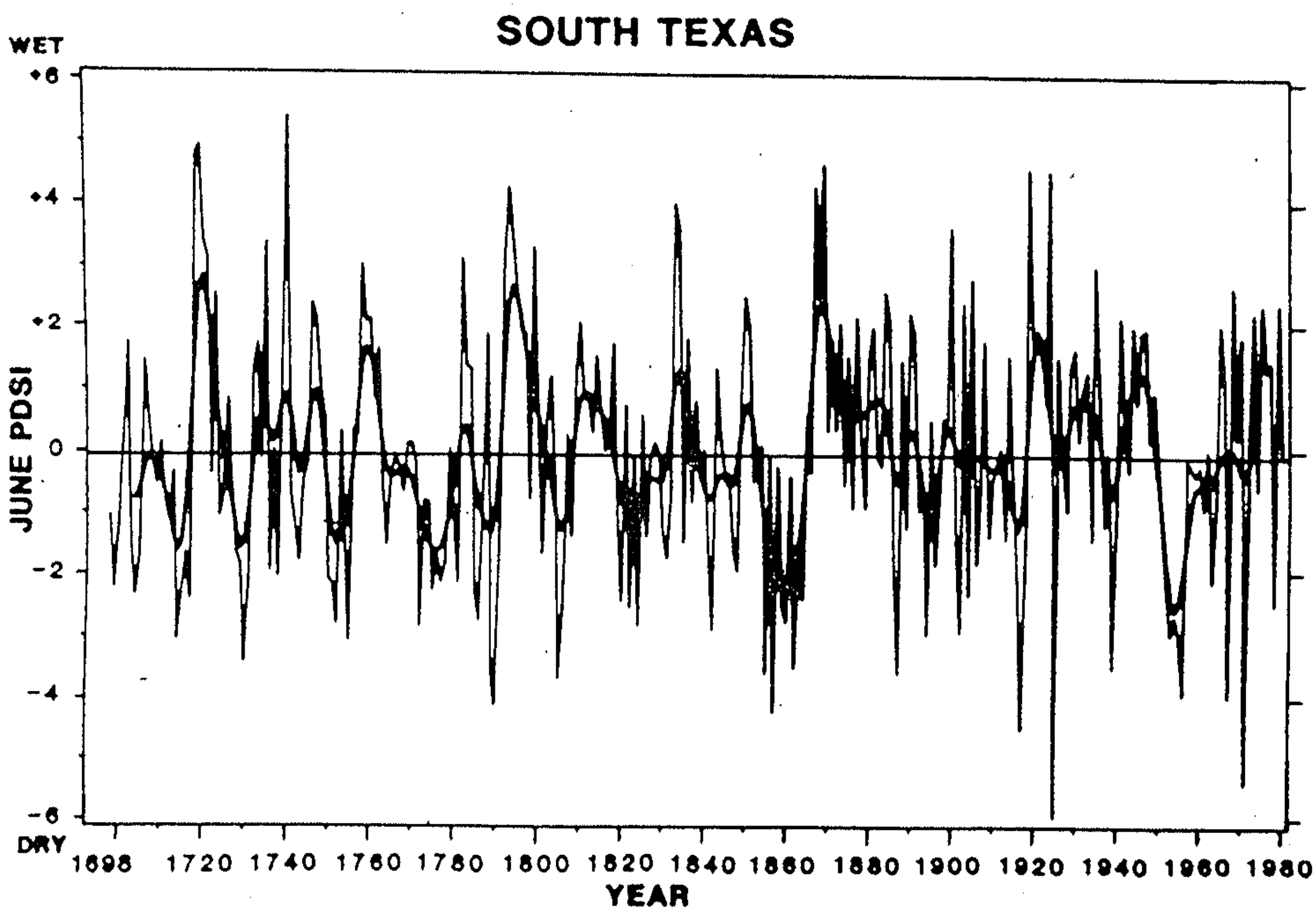
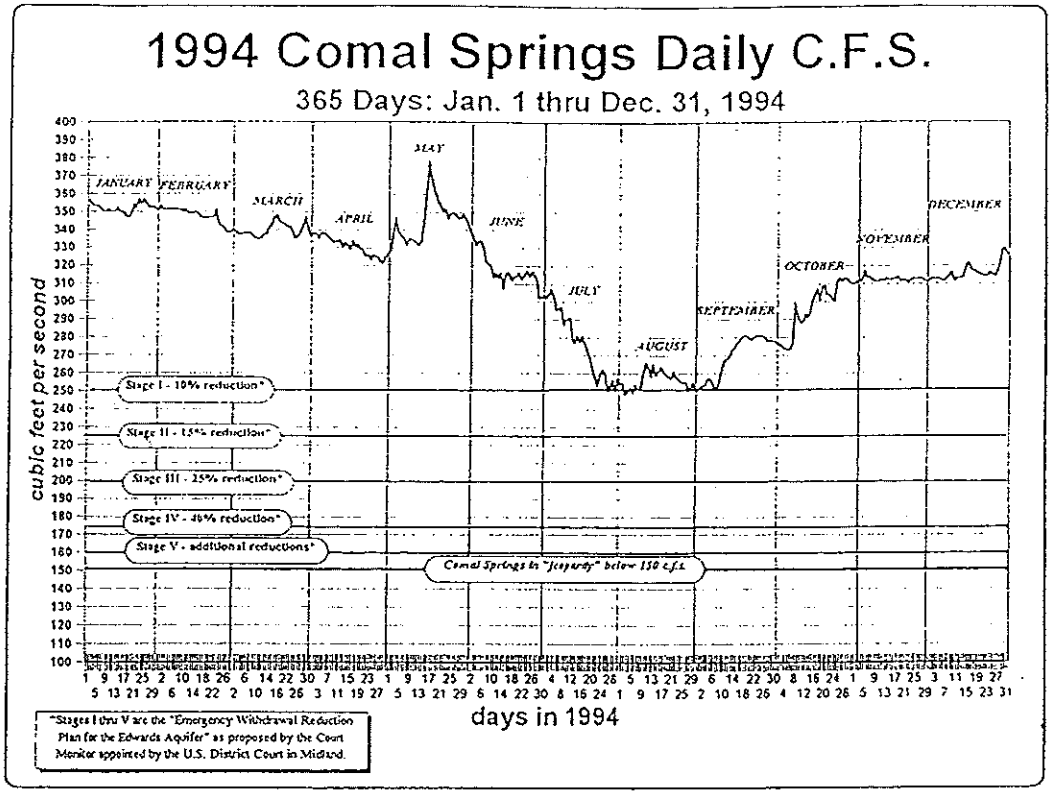


Figure 3. Reconstructed June PDSI for south Texas plotted annually from 1698 to 1980 (Stahle and Cleaveland, 1988) modified.



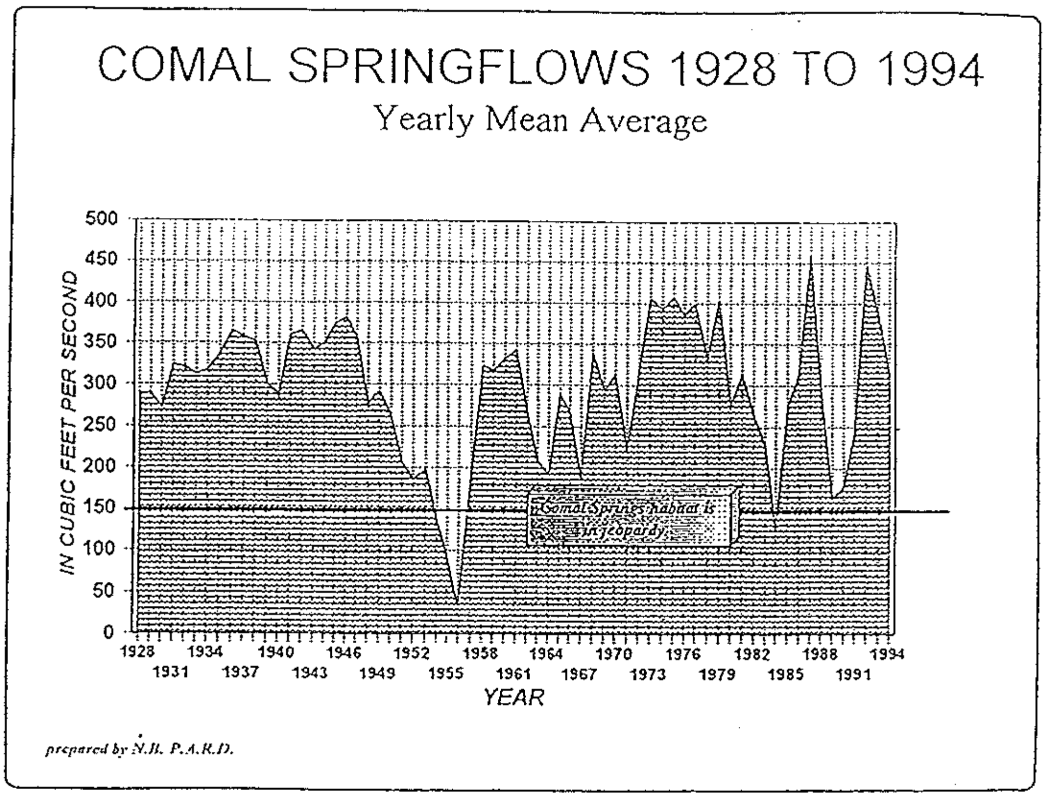


Figure 4. Comal spring flows (David Whatley, New Braunfels Parks and Recreation Department, 1995)

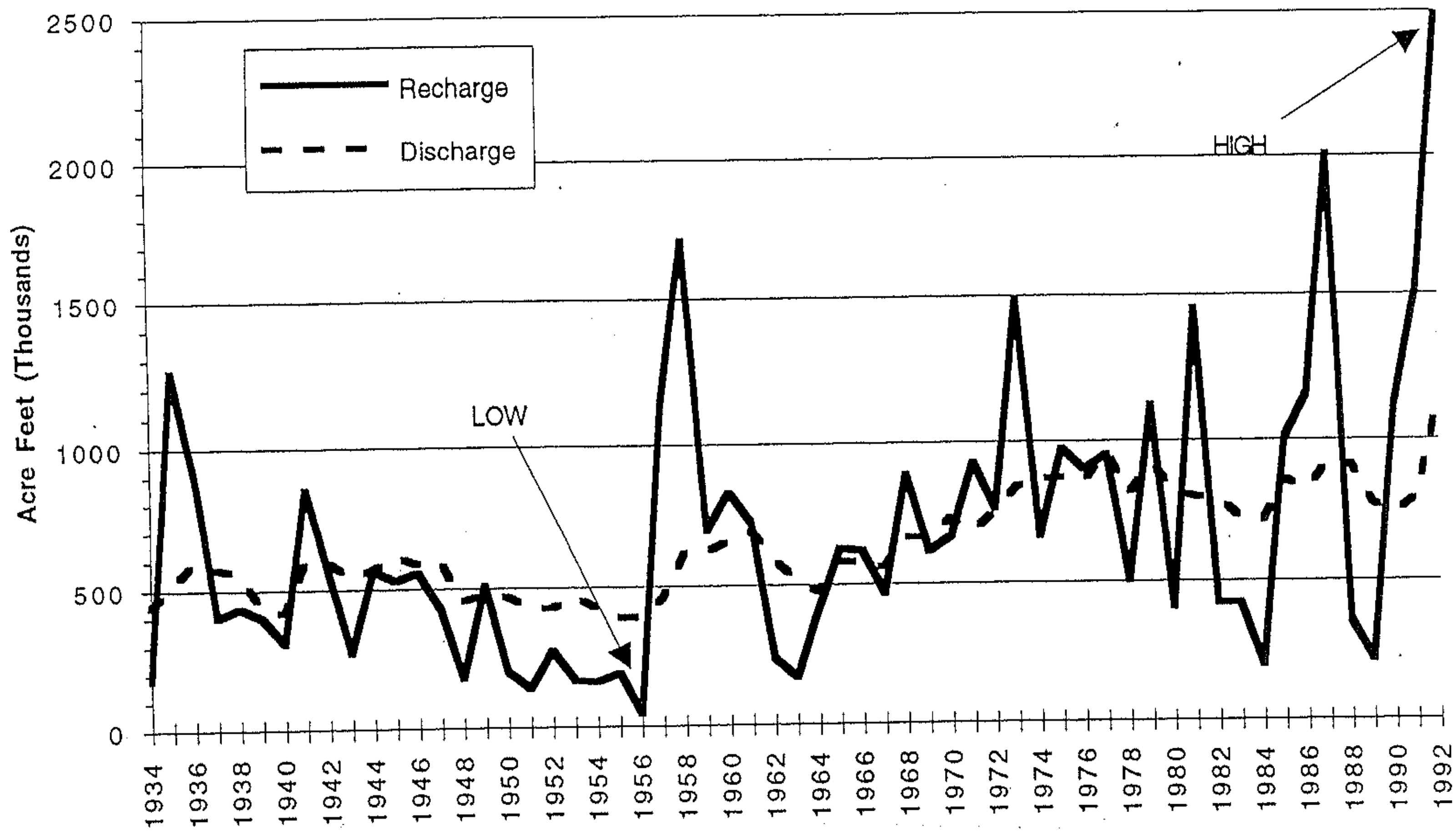


Figure 5. Recharge and discharge for the Balcones Fault Zone Edwards Aquifer in the San Antonio region.

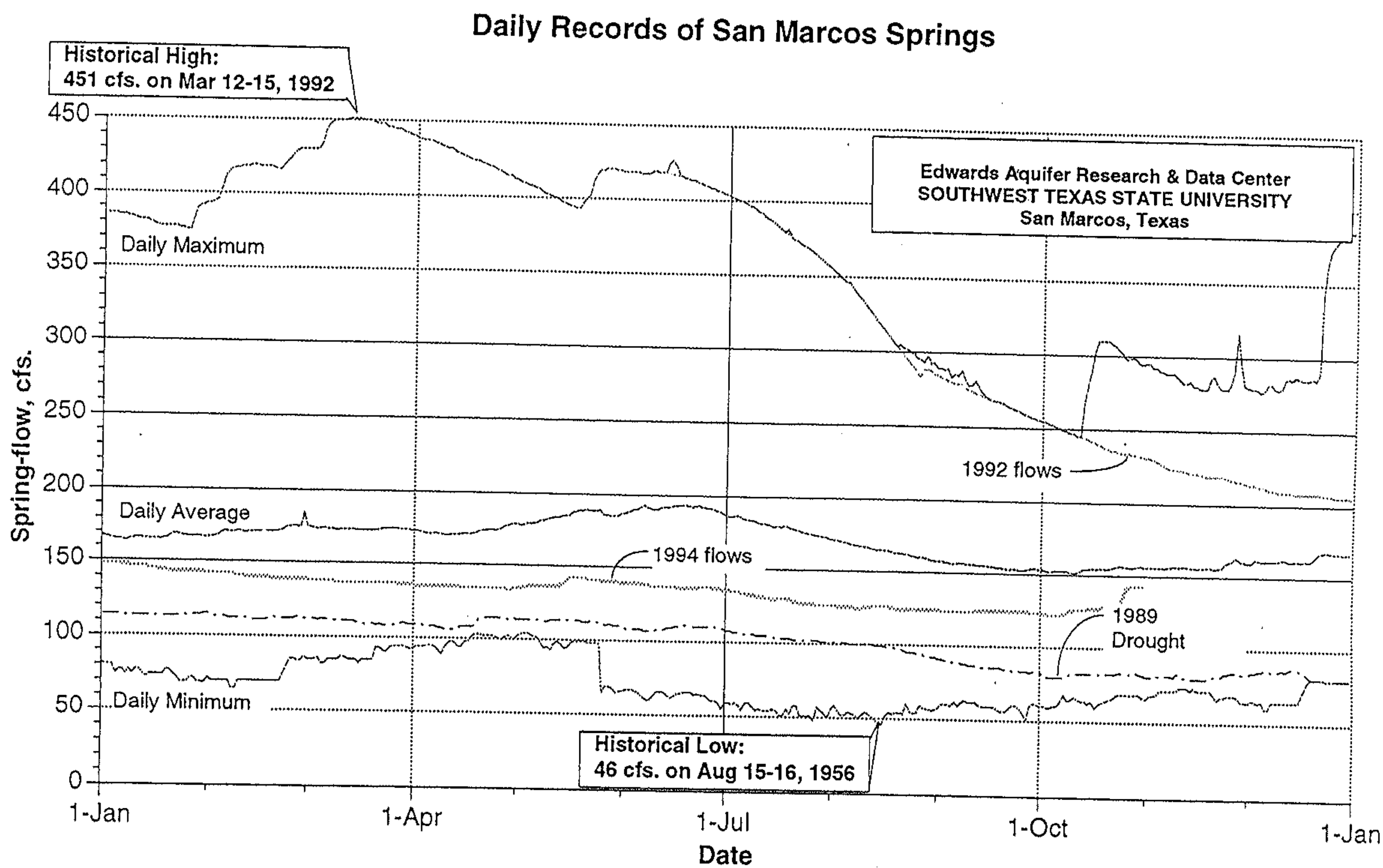


Figure 6. Statistics are compiled from USGS gaging station 08170000 from May 1956 to November 1994.

historic use. In addition to allocation, a mechanism for decreasing use to preserve spring flows must be developed that is effective in predicting spring flows under varying conditions. The best model that is available at this time was developed by Wanakule and Anaya, 1993. It was calibrated using existing data and was shown to be very efficient and provides good accuracy in predicting spring flows and aquifer levels. It has additional advantages since it accounts for recharge capacity, water levels and is less complex that existing models. It currently runs on a microcomputer and will generate new simulations in less than four minutes. It is also currently being adapted to run on an Excel spreadsheet.

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